PERFORMANCE ANALYSIS IN SPORT

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PERFORMANCE ANALYSIS IN SPORT

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Editorial: Performance Analysis in Sport

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Editorial on the Research Topic

Performance Analysis in Sport

Performance analysis is a sub-discipline of Sport Science research (Borms, 2008) that has attained great interest for many stakeholders (i.e., coaches, technical staff, performance analysts, managers, media, fans, and players) at different levels of performance (i.e., youth, semi-professional, or professional players). The development and implementation of new technologies to measure individual or team's performances (e.g., tracking systems such as local positioning systems, LPS; video tracking, or observational video analysis systems) with multiple practical applications have intensified the focus of performance analysis in sport (Hughes and Franks, 2007). Traditional approaches have included static analysis focused on retrospective performances; however, dynamic and complex analyses (i.e., non-linear Multi-Dimensional Scaling, classification and regression tree, logistic regression, etc.) have become increasingly utilized by researchers for a deeper understanding of sport performance during training and competition (O'Donoghue, 2009). In particular, a holistic and multidisciplinary perspective such as the Grand Unified Theory analyses (GUT, see Glazier, 2017) has been suggested to be fundamental for sports performance. This approach, provides a framework to examine the inter- and intra-athlete's behavior dimensions under the environmental and task-related (ecological) factors that affect the performance. Specifically, isolated approaches have been suggested to be avoided with the integration of the biomechanical, physiological, psychological, technical, tactical, positional, motor development and/or strength and conditioning perspectives recommended when evaluating match-related contexts and training tasks (Glazier, 2017). Additionally, Woods et al. (2020) highlighted the importance of ecological dynamics to guide the control, preparation and assessment of athletes and teams. Subsequently, the use of interdisciplinary research designs would provide clear and well-described rationales, powerful data collection and analyses, resulting in robust findings. Innovative sports performance analyses that incorporate new technologies to understand individual's behaviors within real-based and ecological contexts would provide a greater understanding of how players and teams act and react for greater performance development and application (Bertollo et al., 2020). In fact, as Robertson (2020) argued, the development of professionalism and data gathering in sport had lead to a new scenario for coaching staff, athletes, and performance analysts where adaptative tools are essentially required to understand the needs of sports performance (e.g., human-machine interaction, perspective, innovation, versatility, visualization, evaluation, feedback, generalization, and future planning).

This special issue was initiated to gain a greater insight of current sport performance theory considering analytics and a wide range of sport disciplines (e.g., individual, dual, team sports) and variables studied (e.g., physical, positional, technical, tactical, psychological, or pedagogical). Of note was that this special issue drew immense attention resulting in the publication of 65 articles (and one corrigendum) improving the research knowledge of the following topics: performance

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profiling (18 articles), performance measurement (13 articles), reliability and validity of coding systems (eight articles), non-linear performances (seven articles), performances of females (four articles), tactical analysis (four articles), gender analysis (three articles), technical analysis (three articles), psychological aspects of performance (three articles), referees' performance (two articles), coaching issues (two articles), contextual variables (two articles), and new technologies in sport (two articles).

A focus on performance-related variables within sport has been the key issue studied for performance analysis. In particular, the use of fundamental indicators to model performance and establish performance profiling has provided the basis with high applicability for coaching staff to manage performance during training and competition. This approach was widely acknowledged in this Research Topic with 18 studies published. The analysis of soccer was presented in five studies from different perspectives and included the importance of technical indicators in the Big five teams of the UEFA Champions League (Yi, Groom et al.), running performances differentiated by Confederations (Tuo et al.), player's age and performance trends within the UEFA Champions League (Kalén et al.), and player migration and nationality (Lago-Peñas et al.). The analysis of other team sports showed the importance of multifactorial benchmarking and longitudinal performance in Australian football (McIntosh et al.), the long-term analysis of basketball players' performances (Lorenzo et al.), the multifactorial performance (physical, technical, and anthropometrical) of youth basketball players (Matulaitis et al.), the key determinants to succeed in wheelchair basketball [Francis et al.(a)], the positional, in-match running demands in rugby union (Donkin et al.), and the importance of ball type and innings in cricket batter's performance (Connor, Sinclair et al.). Individual sports were also investigated from different approaches including the relative age effect of track and field athletes (Brustio et al.), the world record profiles of long distance runners (Knechtle et al.), the spatiotemporal performance of 60 m hurdle athletes (González-Frutos et al.), the race strategies for long distance open-water swimmers (Veiga et al.), the longitudinal performance of elite rhythmic gymnasts (Sierra-Palmeiro et al.) and the pathway to succeed in elite swimming (Yustres et al.). Lastly, dual sports were studied with Torres-Luque, Fernández-García, Blanca-Torres et al. examining badminton (statistical analysis of men's/women's players), and Murray et al. examining squash (performance profiles of the top two players when considering the opponent's performance).

Measurement of performance analysis in sport was another main feature presented within this Research Topic with 13 articles covering different approaches and variables. Specific articles focused on postural skills and body related measures associated with sport expertise (Paillard), anthropometric measures (Eriksrud et al.; Gomez-Campos et al.), ranges of movement related to pain (Cejudo et al.), post-activation potentiation in soccer (Petisco et al.), and the effect of thermal conditions on performance (Gasparetto and Nesseler). Additionally, articles focused on physical fitness measures and performances in junior tennis players (Colomar et al.) and academy soccer players (Raya-González et al.) while physiological measures were considered when assessing elite male wheelchair basketball players' performance (Marszałek, Kosmol et al.). Finally, two studies investigated a research framework for the importance of several measures in Australian football (Bonney et al.) and the beginning of a senior career in team sports (Lupo et al.).

While the measurement of performance has been focused upon in this Research Topic, the reliability and validity of match-observation, as well as the observation systems used in performance analysis, were also extremely important with eight articles incorporated. In particular, the design and validation of observational instruments of technical and tactical actions were examined by Ortega-Toro et al. in soccer and Torres-Luque, Fernández-García, Cabello-Manrique et al. in tennis. A similar approach was undertaken by Francis et al. (b) who quantified actions in elite wheelchair basketball, and by Gong et al. who studied the validity of the CHAMPDAS match analysis system in elite soccer. Additionally, four studies considered reliability/validity procedures via various techniques; Belli et al. studied the reproducibility and validity of the stroke effectiveness in table tennis based on game temporal structure; Ibáñez et al. employed a learning and performance assessment instrument in basketball; Colino et al. validated an indoor tracking system that assessed activity distance and time for court-based sports; and Premelč et al. analyzed the reliability of judging artistic sport (danceSport).

A novel feature of this Research Topic was the coverage (seven studies) of the complexity and non-linear nature of sports that required different approaches to control for performance variability under unpredictable contexts. First, Ribeiro et al. focused their attention on bidirectional self-organizing tendencies in team sports with a specific approach based upon the game model and the principles of play. With this framework in mind, four studies analyzed soccer including: the interpersonal coordination perspective (i.e. importance of team dyads and task design) by Santos et al. with comments by Gesbert and Hauw in their commentary letter; the effect of interpersonal dynamics within 2 vs. 1 playing contexts (importance of field location and player roles) by Laakso et al.; and the effect of temporary numerical imbalances in youth players by Canton et al.. In addition, non-linear approaches were examined in beach volleyball 'winning streaks' that considered the impact of failure in the temporal series (Link and Wenninger), and in padel which analyzed the effect of return of serve on the athlete movement patterns and rally outcome (Ramón-Llin et al.).

One of the most relevant and important issues in our collection of performance analysis, due to its high applicability, was tactical analysis with the following four studies: (i) Spencer et al. studied the quality of player's passing decisions in Australian football using commitment modeling that accounted for spatial influence and bounds/density of players; (ii) Méndez et al. analyzed the attacking patterns of elite futsal teams from Spain, Italy, and Russia that also considered the importance of efficiency, offensive organization, match type, scoring first and match outcome; (iii) Kim et al. investigated the attacking process in soccer from a goal scoring approach with the establishment of a taxonomy of how teams developed their attack when creating scoring opportunities; and (iv) Scharfen and Memmert analyzed the importance of cognitive function and specific-related motor skills during different tasks by elite youth soccer players.

A distinctive gender focus in performance analysis was also of importance within this Research Topic. Firstly, Pedersen et al. focused on the gender differences of soccer players based upon physiological and anthropometrical factors. Specifically, they presented a detailed approach to analyse and tailor-design training and competition based on gender differences. Secondly, Mclean et al. presented a work domain analysis that allowed the modeling of performance in women's netball. This research established the importance of complex relationships between key performance indicators, such as passing and possession measures, cognitive performance, and physical demands. Finally, two studies focused on the technical and tactical actions of elite soccer female players during the FIFA World Cup (Sainz de Baranda et al.) and the physical and external loads experienced by amateur women's basketball players (Reina et al.).

The importance of the technical analysis was also reflected in three studies with each focused on a different sport (i.e., cross-country, soccer, and cricket). Tjønnås et al. identified the basic motion patterns of cross-country skiing athletes and the need to control for physical, track, and environmental factors that influence these patterns. Additionally, Yi, Liu et al. studied the technical performance indicators of soccer players over nine seasons of the UEFA Champions league. Their results via Poisson regression and autocorrelation models showed trivial changes for shooting variables and defensive actions, but higher variability of passing and attacking-related variables. Lastly, Connor, Mann et al. studied the performance advantages of junior cricket batters based upon batting stance, lateral dominance, and type of technique. Their results highlighted the left-handed advantage and the need to control for these factors during team selection practices.

Two studies focused on the importance of contextual-related variables and their impact on players and teams' performance. Firstly, Pino-Ortega et al. analyzed the importance of the situational factors that effected external loads of Under-18 basketball players according to their playing position (i.e., team quality, match period, and consecutive matches). Secondly, Marszalek, Gryko et al. studied the heart rate profile of elite wheelchair basketball players who were classified according to their functional classification and playing time. Their results identified different performance trends according to the contextual factors of tournament level, game type, and game quarter.

The psychological approach in performance analysis was covered by three studies reflecting the importance of multifactorial analyses as key factors in sports performance. These articles focused on: analysis of self-control during pressure situations of penalty kicks in soccer (Navia et al.); the importance of competitive psychological disposition and self-perception of performance in youth female soccer players (Olmedilla et al.); and the psychological demands and well-being needs of Elite South African rugby players (Kruyt and Grobbelaar).

While a focus of the articles in this special issue was on players, the referee and coach were also examined. For referees, Kolbinger and Stöckl analyzed two common rule violations that were rarely penalized (i.e., misbehavior during penalty kicks and the goalkeeper holding the ball for more than 6 s) with their results from the German Bundesliga indicating that when players committed offenses, the referee's accuracy was only 20.8% for these situations. Likewise, Kraak et al. studied the rate of sanctioning illegal and dangerous ruck cleanouts in the 2018 Super Rugby competition with some dangerous illegal rucks not sanctioned by the referees (i.e., shoulder charge, neck roll, and contact above the shoulder). For coaches, Tozetto et al. analyzed the importance of coach turnover on team's performance in the Brazilian professional soccer league (2012-2017). Their results highlighted the impact of replacing the coach in terms of short-term performances and the minimal influence of the coach's prior experience. The second study by Bateman and Jones highlighted the importance of coach and performance analyst relationships in professional soccer. Their study used the COMPASS (conflict, openness, motivation, preventative strategies, assurance, support, and social networks) framework and identified the importance of all aspects to maintain a positive coach-analyst relationship. These articles highlighted the practical applications of this special issue for stakeholders (i.e., players, coaches, referees, and analysts).

Finally, the use of new technologies was also addressed in this Research Topic with a data driven visual prototype reported by Benito Santos et al.. This software technology employed geospatial data and visualization techniques and allowed stakeholders to understand the collective behaviors of soccer teams during competitions and training.

In light of the positive engagement and great number of high-quality articles published, this special issue has made an important contribution to exemplify and stimulate the evolving research sub-discipline of performance analysis in sport. We look forward to the current articles supporting future research approaches that consider the complex nature, emerging techniques and "big data" associated with sport.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

Bertollo, M., Doppelmayr, M., and Robazza, C. (2020). "Using brain technologies in practice," in *Handbook of Sport Psychology,* eds G. Tenenbaum and R. C. Eklund (Hoboken, NJ: Wiley), 666–693.

Borms, J. (2008). *Directory of Sport Science: A Journey Through Time: The Changing Face of ICSSPE*. Champaign, IL: Human Kinetics.

Glazier, P. S. (2017). Towards a grand unified theory of sports performance. *Hum. Mov. Sci.* 56, 139–156. doi: 10.1016/j.humov.2015.08.001

Hughes, M., and Franks, I. (2007). *The Essentials of Performance Analysis: An Introduction*. London: Routledge.

O'Donoghue, P. (2009). *Research Methods for Sports Performance Analysis*. London: Routledge.

Robertson, P. S. (2020). Man & machine: adaptive tools for the contemporary performance analyst. *J. Sports Sci.* 38, 2118–2126. doi: 10.1080/02640414.2020.1774143

Woods, C. T., McKeown, I., O'Sullivan, M., Robertson, S., and Davids, K. (2020). Theory to practice: Performance preparation models in contemporary high-level sport guided by an ecological dynamics framework. *Sports Med. Open* 6, 1–11. doi: 10.1186/s40798-020-00268-5

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World Single Age Records in Running From 5 km to Marathon

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This study investigated the relationship between race times and age, in 1-year intervals, by using the world single age records, from 5 km to marathon running (i. e., 5 km, 4 miles, 8, 10, 12, 15 km, 10 miles, 20 km, half-marathon, 25 km, 30 km, and marathon). For each race, a regression model was fitted. Effects of sex, alone and in interaction with age, and the effect of country of origin on performance were examined in a multi-variable model. The relationship between age and race time was modeled through a 4th order-polynomial function. Women achieved their best half-marathon and marathon race time, respectively, 1 year and 3 years earlier in life than men. On the contrary, in the other races, the best women performances were achieved later in life than men (i.e., 4 miles and 30 km: 2 years later, 8 km: 3 years later, 15–20–25 km: 1 year later, 10 miles: 4 years) or at the same age (i.e., 5, 10, 12 km). Moreover, age of peak performance did not change monotonically with the distance of race. For all races, except 12 km, sex differences had an absolute maximum at old ages and a relative maximum near the age of peak performance. From 8 km onward, estimated sex differences were increasing with increasing race distance. Regarding country, runners from Canada were slower than runners from the United States of America in 5 km by 00:10:05 h:min:s ($p < 0.001$) and in half-marathon by 00:18:43 h:min:s ($p < 0.01$). On the contrary, in marathon, they were 00:18:43 h:min faster ($p < 0.05$). Moreover, in 10 miles, runners from Great Britain were 00:02:53 h:min:s faster ($p < 0.05$) than runners from the United States of America. In summary, differences seem to exist in the age of peak performance between women and men and for nearly all distances sex differences showed an absolute maximum at old ages and relative maximum near the age of peak performance. Thus, these findings highlight the need for sex-specific training programs, especially near the age of peak performance and for elder runners.

Keywords: female, male, aging, youth, performance

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INTRODUCTION

It is well known that for each sports discipline a specific age of peak athletic performance exists (Allen and Hopkins, 2015). Generally, this age of peak performance increases with increasing duration of an endurance performance (Allen and Hopkins, 2015). This is especially obvious in ultra-marathon running, where the age of peak athletic performance increases with increasing race duration when ultra-marathons from 6 h to 10 days were investigated (Knechtle et al., 2014). Accordingly, when two of the most popular ultra-marathon distances, the 50 km (Nikolaidis and Knechtle, 2018a) and the 100 km (Nikolaidis and Knechtle, 2018b), were analyzed, the age of peak running performance was older in the longer running distance.

For running, the age of peak athletic performance has mainly been investigated for half-marathon (Knechtle and Nikolaidis, 2018; Nikolaidis et al., 2018), marathon (Lara et al., 2014; Knechtle et al., 2017; Nikolaidis and Knechtle, 2018b,c; Nikolaidis et al., 2018), and ultra-marathon (Knechtle and Nikolaidis, 2017) running. However, the age of peak athletic performance in shorter endurance running distances has not been studied previously to the best of our knowledge.

It is also important for athletes and coaches to be aware of potential differences in the age of peak athletic performance between the sexes. Regarding a systematic review investigating the age of peak athletic performance for different events (i.e., explosive power/sprint, endurance, mixed/skill), it was showed that there was little difference in estimates of peak age for these event types between men and women (Allen and Hopkins, 2015). Nevertheless, very recent studies showed differences in the age of peak athletic performance between women and men. For example, in half-marathon (Knechtle and Nikolaidis, 2018; Nikolaidis and Knechtle, 2018a; Nikolaidis et al., 2018) and in marathon running (Nikolaidis and Knechtle, 2018b; Nikolaidis et al., 2018), women achieved their best race times earlier in life than men in studies where all runners by age group were considered. These findings were in contrast to earlier findings where the age of peak marathon performance was assumed to appear earlier in life in men compared to women in a research where top 10 runners by age group were considered (Lara et al., 2014). When world class track-and-field athletes were investigated, the mean age of peak performance was older for marathon and male throwers whereas women reached an older age of peak performance than men in the hurdles, middle and long-distance running events. Furthermore, male throwers had a higher peak age than female throwers (Haugen et al., 2018).

A confounding variable that might influence the age of peak performance is nationality. The prevalence of particular nationalities in the endurance running has been documented recently (Nikolaidis et al., 2017a,b). For instance, half of participants in all running events of the World Championships from 1975 to 2015 were from USA, Germany, Australia, and Great Britain (Nikolaidis et al., 2017b), whereas most runners in the 10 km event, half-marathon and marathon were Kenyans according to the data of the International Association of Athletics Federations 1999–2015 (Nikolaidis et al., 2017a). In addition, differences in age of runners among nationalities were observed (Nikolaidis et al., 2017a). Thus, it would be reasonable to assume that nationality should be considered when analyzing the relationship between age and performance.

To gain more insight in the age of peak running performance for shorter running distances and the role of nationality, this study aimed at analyzing the world single age records in road races from 5 km to marathon for the distances of 5 km, 4 miles, 8 km, 10 km, 12 km, 15 km, 10 miles, 20 km, half-marathon, 25, 30 km, and marathon by using data of the of the "Association of Road Racing Statisticians" (ARRS). Based upon the findings that the age of peak athletic performance gets older while the race distance becomes longer in ultra-marathon running, the research hypothesis was to expect a younger age of peak performance in the shorter compared to the longer distances of road running races.

MATERIALS AND METHODS

Ethical Approval

The institutional review board of St Gallen, Switzerland, approved this study. Since the study involved analysis of publicly available data, the requirement for informed consent was waived.

Data Sampling and Data Analysis

The data set for this study was obtained from the website of the ARRS (https://arrs.run/SARec.htm) from 5 km to marathon for both women and men. The distances 5 km, 4 miles, 8, 10, 12, 15 km, 10 miles, 20 km, half-marathon, 25 km, 30 km, and marathon were considered. It should be highlighted that all distances referred to road running races. This section lists the fastest performances for each single age and for each of the standard distances, as known to ADR. Performances are subject to the same standards as listing for national records plus the additional requirement that the runner's date of birth (as well as the race date) must be known. These are required to be able to document the runner's exact age at the time of the performance. Single age records that meet the ARRS qualifying standards may be expected to be fairly reliable. At older (and younger) ages, the best marks known to ARRS are listed. We used the full data set without data cleaning.

Statistical Analyses

All data have been presented as means and standard deviations. Time was recorded in the format "h:m:s." For each race, *t*-tests were performed to compare the average performance between genders by age-groups and by country. Age-groups were [3,20), [20,30), [30,40), [40,50), [50,60), [60,75), [75,100). The most prevalent countries, in terms of participation, were USA, Canada (CAN), Kenya-Ethiopia (KEN-ETH) and, in 30 km and marathon also Japan (JPN). The other countries were grouped together. Age was considered as a continuous variable, in 1 year intervals, when defined as a predictor variable for race-time. A non-linear regression mixed model, with a fourth order (i.e., quartic) polynomial function, was performed to find the age of peak performance, which was the age at which the time record-fitted value had a minimum. The mixed model was used to correct for repeated measurements within runners (clusters) through the random effects of intercepts. Gender, country and age-gender interaction term, were also considered as predictors, fixed effects. In other words, for each race, from 5 km to marathon, the statistical model was specified as follows:

Race Time (Y) $\sim$ (Fixed effects (X) $=$ Sex $+$ ($P_{Age}+P_{Age}^2+P_{Age}^3+P_{Age}^4$) $+$ Sex $\times$ ($P_{Age}+P_{Age}^2+P_{Age}^3+P_{Age}^4$) $+$ Country] $+$ (Random effects of intercept=Runners]

where $\times$ denoted the interaction function and ($P_{Age}+P_{Age}^2+P_{Age}^3+P_{Age}^4$) a polynomial function on age of grade 4.

As a measure of goodness of fit of each model, the r-squared approximation (R^2) and a simplified version of the

TABLE 1 | Mean performance of world records (5 km to marathon) by sex, age-groups, and country.

		5 km, $N = 183$				4 mi, $N = 151$				8 km, $N = 167$				10 km, $N = 171$			
	Sex	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***
AGE																	
[3,20)	Men	17	00:18:49	00:06:45	0.702	13	00:25:36	00:09:28	0.959	14	00:29:56	00:08:03	0.890	13	00:34:33	00:06:43	0.385
[3,20)	Women	17	00:19:46	00:07:38		11	00:25:45	00:04:44		14	00:29:37	00:03:41		14	00:36:41	00:05:45	
[20,30)	Men	10	00:13:14	00:00:04	< 0.001	10	00:17:36	00:00:06	< 0.001	10	00:22:09	00:00:07	< 0.001	11	00:27:15	00:00:14	< 0.001
[20,30)	Women	10	00:14:55	00:00:07		11	00:20:09	00:00:31		10	00:25:02	00:00:20		10	00:30:27	00:00:21	
[30,40)	Men	10	00:13:32	00:00:09	< 0.001	10	00:18:09	00:00:27	< 0.001	11	00:22:33	00:00:18	< 0.001	10	00:27:38	00:00:21	< 0.001
[30,40)	Women	10	00:15:14	00:00:18		10	00:20:07	00:00:14		11	00:25:22	00:00:39		10	00:31:09	00:00:24	
[40,50)	Men	10	00:14:22	00:00:30	< 0.001	10	00:19:25	00:00:49	< 0.001	10	00:23:55	00:00:41	< 0.001	10	00:29:31	00:01:07	< 0.001
[40,50)	Women	10	00:16:11	00:00:17		10	00:22:20	00:01:01		10	00:26:36	00:00:42		11	00:33:15	00:00:41	
[50,60)	Men	10	00:15:44	00:00:38	< 0.001	10	00:21:43	00:00:37	< 0.001	10	00:26:01	00:00:54	< 0.001	10	00:32:11	00:00:52	< 0.001
[50,60)	Women	10	00:17:52	00:00:49		10	00:25:05	00:01:42		10	00:29:49	00:01:30		11	00:36:10	00:01:24	
[60,75)	Men	15	00:17:38	00:01:06	< 0.001	14	00:24:09	00:01:29	< 0.001	15	00:29:50	00:02:22	< 0.001	15	00:36:12	00:02:00	< 0.001
[60,75)	Women	15	00:21:00	00:01:50		12	00:31:40	00:03:16		16	00:35:28	00:02:50		15	00:42:48	00:03:20	
[75,100)	Men	21	00:29:37	00:08:37	0.039	14	00:43:26	00:14:36	0.681	16	00:49:16	00:22:21	0.948	18	00:55:50	00:15:33	0.405
[75,100)	Women	18	00:42:57	00:24:21		6	00:41:15	00:08:27		10	00:48:52	00:07:52		13	01:00:29	00:14:46	
COUNTRY																	
USA	Men	36	00:23:30	00:10:24	0.443	41	00:29:45	00:13:33	0.392	30	00:38:01	00:19:58	0.108	12	00:38:57	00:08:44	0.431
USA	Women	46	00:25:51	00:16:52		48	00:27:42	00:07:23		31	00:31:45	00:05:49		13	00:43:41	00:19:09	
CAN	Men	13	00:19:25	00:02:18	0.151	5	00:22:51	00:01:44		13	00:33:11	00:06:52	0.009	11	00:40:50	00:04:17	0.142
CAN	Women	4	00:48:53	00:30:44		1	00:23:37			10	00:45:24	00:11:10		2	01:07:38	00:09:19	
ETH-KEN	Men	18	00:13:18	00:00:14	< 0.001	17	00:18:00	00:00:32	< 0.001	17	00:22:21	00:00:27	< 0.001	25	00:27:36	00:00:31	< 0.001
ETH-KEN	Women	14	00:15:05	00:00:24		10	00:20:13	00:00:22		10	00:25:28	00:00:31		11	00:30:43	00:00:34	
GBR	Men	21	00:17:18	00:03:37	0.062	12	00:24:44	00:07:59	0.287	16	00:27:17	00:05:06	0.011	16	00:38:03	00:15:10	0.742
GBR	Women	12	00:19:43	00:03:18		3	00:29:24	00:05:24		13	00:32:39	00:05:23		19	00:39:25	00:06:49	
JPN	Men																
JPN	Women																
Other	Men	5	00:14:43	00:01:01	0.021	6	00:18:34	00:01:25	0.018	10	00:23:34	00:01:18	< 0.001	23	00:42:24	00:16:58	0.422
Other	Women	14	00:16:42	00:02:22		8	00:20:31	00:00:55		17	00:26:17	00:01:30		39	00:39:16	00:09:20	

(Continued)

TABLE 1 | Continued

		12 km, $N = 133$				15 km, $N = 163$				10 mi, $N = 155$				20 km, $N = 113$			
	Sex	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***
AGE																	
[3,20)	Men	8	00:43:04	00:11:18	0.641	13	01:02:57	00:22:13	0.862	13	01:01:38	00:17:54	0.850	7	01:07:25	00:17:10	0.117
[3,20)	Women	6	00:45:42	00:09:21		12	01:01:41	00:12:35		11	01:02:51	00:13:02		8	01:21:59	00:16:07	
[20,30)	Men	11	00:34:05	00:00:11	< 0.001	10	00:41:47	00:00:21	< 0.001	11	00:45:17	00:00:18	< 0.001	10	00:56:36	00:00:35	< 0.001
[20,30)	Women	10	00:38:36	00:00:33		10	00:47:40	00:00:46		10	00:51:59	00:00:29		10	01:04:50	00:00:54	
[30,40)	Men	10	00:34:24	00:00:26	< 0.001	10	00:42:42	00:00:41	< 0.001	9	00:46:10	00:00:48	< 0.001	10	00:58:12	00:00:57	< 0.001
[30,40)	Women	9	00:39:04	00:00:47		10	00:48:10	00:01:02		10	00:52:22	00:01:09		10	01:05:46	00:01:33	
[40,50)	Men	10	00:37:30	00:01:27	< 0.001	10	00:45:44	00:01:09	< 0.001	11	00:49:15	00:01:56	< 0.001	10	01:05:13	00:04:07	0.002
[40,50)	Women	11	00:42:25	00:02:14		10	00:50:45	00:00:57		10	00:55:23	00:01:12		10	01:11:08	00:03:12	
[50,60)	Men	10	00:41:20	00:01:03	< 0.001	10	00:51:04	00:02:00	< 0.001	9	00:53:45	00:02:20	< 0.001	10	01:11:28	00:04:34	0.001
[50,60)	Women	10	00:47:15	00:02:56		10	00:58:33	00:02:31		10	01:02:08	00:02:29		8	01:22:25	00:06:01	
[60,75)	Men	14	00:48:12	00:06:14	0.005	15	00:56:59	00:01:51	< 0.001	16	01:01:08	00:04:52	< 0.001	11	01:24:29	00:09:31	0.053
[60,75)	Women	13	00:57:08	00:08:33		15	01:10:36	00:08:07		14	01:12:13	00:05:04		6	01:40:03	00:14:56	
[75,100)	Men	9	01:15:56	00:15:19	0.096	15	01:36:28	00:42:00	0.105	13	01:24:07	00:16:26	0.028	2	01:32:03	00:02:40	
[75,100)	Women	2	01:06:10	00:01:39		13	01:59:05	00:28:35		8	01:40:48	00:14:44		1	01:58:51		
COUNTRY																	
USA	Men	39	00:51:45	00:16:38	0.469	23	01:24:09	00:40:17	0.690	26	01:15:30	00:17:25	0.512	17	01:18:48	00:10:20	0.183
USA	Women	33	00:49:22	00:10:48		37	01:20:07	00:33:09		27	01:12:11	00:19:06		23	01:24:57	00:18:04	
CAN	Men					13	01:02:10	00:06:06	0.063								
CAN	Women					2	00:58:35	00:00:42									
ETH-KEN	Men	18	00:34:14	00:00:21	< 0.001	21	00:42:17	00:00:52	< 0.001	21	00:45:46	00:01:18	< 0.001	16	00:57:42	00:02:34	< 0.001
ETH-KEN	Women	12	00:39:11	00:00:55		16	00:48:04	00:00:58		11	00:52:27	00:01:01		11	01:05:28	00:01:39	
GBR	Men									19	00:54:07	00:05:42	0.003				
GBR	Women									17	01:05:03	00:12:14					
JPN	Men																
JPN	Women																
Other	Men	15	00:38:23	00:03:49	< 0.001	26	00:50:03	00:07:05	0.002	16	00:53:43	00:07:40	0.082	27	01:08:03	00:12:38	0.157
Other	Women	16	00:45:25	00:04:47		25	01:01:55	00:16:28		18	01:00:52	00:14:38		19	01:12:30	00:08:22	

(Continued)

TABLE 1 | Continued

		Half marathon, $N = 170$				25 km, $N = 139$				30 km, $N = 119$				Marathon, $N = 170$			
	Sex	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***	***N***	**Mean**	**Sd**	***p***
AGE																	
[3,20)	Men	15	01:26:54	00:32:50	0.922	5	01:36:03	00:37:41	0.805	4	02:12:12	01:03:27	0.736	13	03:19:45	01:38:07	0.416
[3,20)	Women	15	01:27:56	00:23:50		8	01:40:42	00:16:40		3	02:27:41	00:51:08		14	02:55:30	00:37:18	
[20,30)	Men	10	00:58:46	00:00:15	< 0.001	10	01:12:28	00:00:59	< 0.001	11	01:29:16	00:01:04	< 0.001	10	02:04:17	00:00:32	< 0.001
[20,30)	Women	10	01:05:53	00:00:45		10	01:23:51	00:01:59		11	01:42:54	00:02:38		10	02:19:42	00:02:16	
[30,40)	Men	9	00:59:38	00:00:38	< 0.001	10	01:15:29	00:01:28	< 0.001	10	01:30:06	00:02:15	< 0.001	10	02:04:31	00:01:22	< 0.001
[30,40)	Women	10	01:07:05	00:01:18		10	01:25:26	00:01:52		10	01:44:34	00:02:32		10	02:19:54	00:02:12	
[40,50)	Men	11	01:04:16	00:02:05	< 0.001	10	01:20:27	00:02:52	< 0.001	10	01:39:54	00:08:05	< 0.001	10	02:13:19	00:04:21	< 0.001
[40,50)	Women	10	01:12:08	00:02:07		10	01:31:10	00:04:33		10	01:55:15	00:04:28		10	02:29:22	00:03:27	
[50,60)	Men	10	01:10:37	00:02:14	< 0.001	10	01:29:11	00:03:35	< 0.001	9	01:49:41	00:02:35	< 0.001	10	02:27:17	00:05:28	< 0.001
[50,60)	Women	10	01:20:42	00:03:35		10	01:45:49	00:06:59		8	02:05:26	00:06:34		10	02:49:44	00:09:26	
[60,75)	Men	15	01:19:44	00:06:01	< 0.001	15	01:44:32	00:09:40	< 0.001	13	02:11:43	00:19:33	0.007	15	02:49:11	00:08:27	< 0.001
[60,75)	Women	15	01:35:06	00:07:16		15	02:12:39	00:14:19		11	02:38:56	00:23:40		15	03:24:49	00:15:00	
[75,100)	Men	17	02:02:09	00:32:27	0.240	12	02:27:40	00:27:13	0.138	7	03:12:03	00:31:43	0.177	16	04:19:40	01:10:47	0.010
[75,100)	Women	13	02:20:38	00:47:10		4	02:41:45	00:08:36		2	03:55:42	00:25:13		17	05:48:17	01:48:55	
COUNTRY																	
USA	Men	19	01:46:01	00:37:14	0.315	38	01:54:22	00:31:09	0.574	21	02:31:09	00:45:22	0.761	20	03:57:08	01:38:05	0.546
USA	Women	14	01:35:22	00:22:16		40	01:58:01	00:25:24		17	02:35:23	00:39:51		18	04:19:24	02:03:45	
CAN	Men	10	01:32:52	00:10:38	0.021									12	03:11:16	00:21:04	0.042
CAN	Women	9	02:26:20	00:56:01										5	06:09:41	02:15:30	
ETH-KEN	Men	22	01:00:02	00:01:42	< 0.001	14	01:13:41	00:02:21	< 0.001	10	01:29:33	00:02:52	< 0.001	28	02:06:21	00:03:54	< 0.001
ETH-KEN	Women	21	01:06:54	00:01:51		11	01:23:32	00:01:40		4	01:40:22	00:02:19		10	02:19:46	00:01:32	
GBR	Men	14	01:17:12	00:21:39	0.069												
GBR	Women	6	01:43:24	00:27:03													
JPN	Men									12	01:30:08	00:01:06	< 0.001	3	02:36:22	00:01:55	0.014
JPN	Women									17	01:46:36	00:04:20		10	03:22:05	00:47:21	
Other	Men	22	01:20:24	00:30:42	0.665	20	01:20:55	00:06:32	< 0.001	21	01:49:41	00:11:27	0.031	21	02:48:30	00:52:22	0.654
Other	Women	33	01:23:28	00:14:17		16	01:31:34	00:05:53		17	02:05:56	00:27:01		43	02:54:26	00:42:31	

P-values of t-test of mean performances between sexes were shown.

TABLE 2 | Non-linear regression analysis (mixed model) of world records (5 km to marathon).

	5 km	4 mi	8 km	10 km	12 km	15 km	10 mi	20 km	Half-marathon	25 km	30 km	Marathon
	Estimate (CI)	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*	*Estimate (CI)*
FIXED PARTS												
(Intercept)	0.013 (0.011–0.014)***	0.017 (0.016–0.017)***	0.020 (0.020–0.021)***	0.026 (0.024–0.027) ***	0.030 (0.029–0.031)***	0.043 (0.040–0.046)***	0.041 (0.040–0.043)***	0.047 (0.045–0.049)***	0.056 (0.052–0.060) ***	0.065 (0.064–0.066)***	0.081 (0.078–0.085)***	0.122 (0.116–0.128)***
Sex:W	0.004 (0.002–0.005)***	0.003 (0.002–0.003)***	0.003 (0.002–0.004)***	0.004 (0.003–0.005) ***	0.004 (0.003–0.006)***	0.005 (0.002–0.008)***	0.006 (0.005–0.008)***	0.008 (0.006–0.010)***	0.007 (0.004–0.010)***	0.012 (0.011–0.013)***	0.014 (0.011–0.017)***	0.019 (0.014–0.024)***
AGE												
P_{Age}	0.038 (0.024–0.051)***	0.039 (0.032–0.047)***	0.049 (0.043–0.055)***	0.065 (0.057–0.073)***	0.064 (0.056–0.073)***	0.124 (0.095–0.153)***	0.064 (0.053–0.074)***	0.053 (0.041–0.065)***	0.094 (0.071–0.117)***	0.131 (0.119–0.143)***	0.166 (0.139–0.193)***	0.272 (0.223–0.321)***
P^2_{Age}	0.055 (0.043–0.068)***	0.056 (0.050–0.062)***	0.069 (0.063–0.074)***	0.058 (0.052–0.065)***	0.064 (0.057–0.071)***	0.126 (0.104–0.147)***	0.078 (0.070–0.086)***	0.049 (0.038–0.060)***	0.159 (0.138–0.179) ***	0.126 (0.117–0.136)***	0.162 (0.140–0.184)***	0.490 (0.446–0.534)***
P^3_{Age}	0.005 (−0.007–0.016)	0.002 (−0.004–0.009)	0.020 (0.015–0.025)***	0.001 (−0.005–0.008)	0.005 (−0.003–0.012)	−0.008 (−0.032–0.015)	−0.016 (−0.024–−0.007)***	−0.032 (−0.043–−0.021)***	−0.036 (−0.054–−0.019) ***	−0.011 (−0.021–−0.002)*	−0.024 (−0.047–−0.002)*	−0.114 (−0.159–−0.069)***
P^4_{Age}	0.031 (0.020–0.042)***	0.028 (0.023–0.034)***	0.040 (0.035–0.045)***	0.034 (0.027–0.040)***	0.020 (0.013–0.027)***	0.066 (0.042–0.089)***	0.045 (0.037–0.053)***	0.014 (0.004–0.023)**	0.087 (0.069–0.106)***	0.073 (0.065–0.082)***	0.100 (0.081–0.120)***	0.239 (0.201–0.277)***
COUNTRY (REF. USA)												
CAN	0.007 (0.003–0.010)***	−0.000 (−0.003–0.002)	0.000 (−0.001–0.001)	−0.002 (−0.005–0.000)		−0.006 (−0.016–0.004)			0.013 (0.004–0.022)**			−0.013 (−0.026–−0.000)*
ETH–KEN	0.001 (−0.001–0.003)	−0.000 (−0.001–0.001)	−0.000 (−0.001–0.001)	−0.000 (−0.002–0.001)	−0.001 (−0.003–0.001)	−0.000 (−0.005–0.005)	−0.001 (−0.004–0.001)	−0.001 (−0.004–0.002)	0.001 (−0.005–0.006)	0.000 (−0.002–0.003)	−0.003 (−0.009–0.003)	0.008 (−0.001–0.017)
GBR	0.000 (−0.002–0.003)	0.001 (−0.000–0.002)	−0.001 (−0.002–0.000)	−0.000 (−0.002–0.001)			−0.002 (−0.004–−0.000) *		0.001 (−0.006–0.008)			
JPN											−0.002 (−0.007–0.004)	0.001 (−0.010–0.012)
Other	0.000 (−0.002–0.003)	−0.000 (−0.002–0.001)	−0.001 (−0.002–0.000)	−0.001 (−0.002–0.000)	−0.001 (−0.002–0.001)	−0.003 (−0.007–0.000)	−0.001 (−0.003–0.001)	−0.001 (−0.003–0.001)	−0.000 (−0.005–0.004)	−0.001 (−0.003–0.001)	−0.003 (−0.007–0.001)	−0.001 (−0.007–0.006)
SEX × AGE												
W× P_{Age}	0.040 (0.022–0.058)***	0.017 (0.005–0.028)**	0.020 (0.011–0.028)***	0.033 (0.023–0.044)***	0.017 (−0.001–0.034)	0.041 (0.003–0.078) *	0.040 (0.026–0.055)***	0.022 (0.004–0.039) *	0.066 (0.030–0.102)***	0.078 (0.063–0.094)***	0.066 (0.033–0.099)***	0.291 (0.231–0.350)***
W× P^2_{Age}	0.032 (0.014–0.049)***	0.001 (−0.012–0.013)	−0.007 (−0.015–0.002)	0.029 (0.019–0.039)***	0.013 (−0.008–0.035)	0.036 (0.005–0.068)*	0.027 (0.013–0.041) ***	0.031 (0.013–0.049)**	0.029 (−0.001–0.059)	0.016 (−0.002–0.033)	0.052 (0.018–0.086)**	0.031 (−0.026–0.087)
W× P^3_{Age}	0.018 (0.002–0.034) *	0.004 (−0.008–0.016)	−0.008 (−0.016–0.001)	0.020 (0.011–0.030)***	0.002 (−0.019–0.023)	0.032 (0.002–0.062)*	0.015 (0.002–0.027)*	0.006 (−0.013–0.024)	0.034 (0.009–0.059)**	0.008 (−0.009–0.026)	0.023 (−0.010–0.056)	0.221 (0.166–0.277)***
W× P^4_{Age}	0.002 (−0.012–0.017)	−0.014 (−0.025–−0.004)**	−0.024 (−0.033–0.016)***	−0.004 (−0.013–0.005)	0.004 (−0.014–0.023)	−0.013 (−0.047–0.022)	−0.024 (−0.037–−0.011)***	−0.002 (−0.019–0.015)	−0.005 (−0.030–0.020)	−0.040 (−0.056–−0.023)***	−0.023 (−0.055–0.009)	−0.011 (−0.068–0.045)
RANDOM PARTS												
$N_{runners}$	105	98	121	105	112	114	99	91	109	98	89	109
ICC	0.918	0.869	0.786	0.846	0.859	0.821	0.903	0.807	0.961	0.135	0.593	0.557
N	183	151	167	171	133	163	155	113	170	139	119	170
R^2/Ω^2_0	0.993/0.993	0.995/0.995	0.996/0.996	0.996/0.996	0.997/0.997	0.989/0.989	0.997/0.997	0.991/0.991	0.998/0.998	0.981/0.981	0.985/0.984	0.988/0.988

*Estimates and confidence intervals (CI) of fixed effects were shown as numeric values. To convert them in h:min:s, one should multiply estimates by 1,440 (minutes per day). The integers obtained are minutes and the fraction should be multiplied by 60 to obtain the seconds. Effects of sex were reported with men being the reference gender group and effects on countries were reported with USA being the reference group. P-values ranges were remarked using * (see note). For the random effects, the number of clusters ($N_{runners}$), ICC (intra-cluster correlation), the number of observations (N), the r-squared approximation (R^2) together with a simplified version of the Omega-squared value (Ω^2_0) were reported.*

*$p<0.05$ **$p<0.01$ ***$p<0.001$.

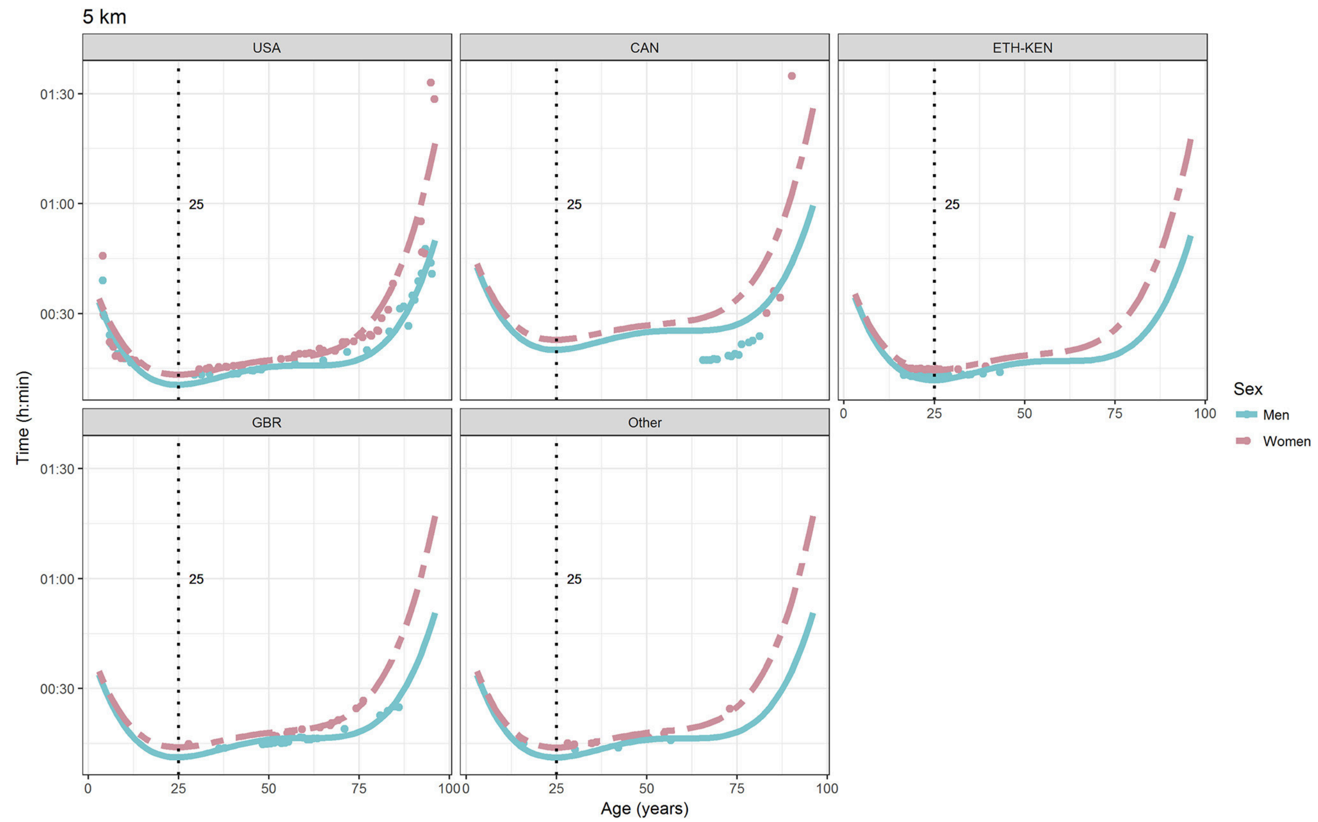

FIGURE 1 | World record in 5 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical line with the numeric label was the age at peak performance.

Omega-squared value (Ω_0^2) were computed. R^2 is the correlation between the fitted and observed values and Ω_0^2 is defined as 1−(residual variance/response variance). Moreover, the Intraclass Correlation Coefficient (ICC), which is a measure of how strongly units in the same cluster resemble each other, has been reported for each model.

In addition, sex differences in performance were examined and were defined, in percentages, as 100 × (women's race time-men's race time)/men's race time. For all tests and regressions, statistical significance was defined at $p < 0.05$. All statistical analyses were carried out using statistical package R, R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/. Packages ggplot2, lme4, and lmerTest were used, respectively, for data visualization and for the mixed model.

RESULTS

Summary Statistics

In **Table 1**, for each race from 5 km to marathon, the numbers of observations and the average performances by sex, age-groups, and countries have been reported. For each race, there was no significant difference between sex performances in the first age group [3, 20). For ages from 20 (included) to 60 excluded, differences between sex performances were significant ($p < 0.001$ for quite all cases) in all races. For ages [60, 75), differences were significant for all races excluded 20 km. In the last age group [75, 100), differences were significant between sex performances only in 5 km ($p = 0.039$), 10 mi ($p = 0.028$), and marathon ($p = 0.010$).

Regarding country, in all races differences were significant ($p < 0.001$) between sex performances for Kenya and Ethiopia. For Canada, significant differences were found only in 8 km ($p = 0.009$), half-marathon ($p = 0.021$), and marathon ($p = 0.042$). In Great Britain there were significant differences in 8 km ($p = 0.011$) and 10 mi ($p = 0.003$), in Japan in 30 km ($p < 0.001$) and marathon ($p = 0.014$). For other country groups, significant differences, between sex performances, were found in most of all races.

Statistical Model

In **Table 2**, for each race from 5 km to marathon, the estimates and confidence intervals of fixed effects have been reported. In all races, women were significantly slower than men ($p < 0.001$). The estimated sex differences ranged from a minimum of 0.003 (00:04:19 h:min:s), reached in 4 mi and 8 km, to a maximum of 0.019 (00:27:22 h:min:s) reached in marathon. Therefore, from 8 km onward, estimated sex differences were increasing.

Regarding country, there were no significant differences between nationalities except in these cases: (1) runners from

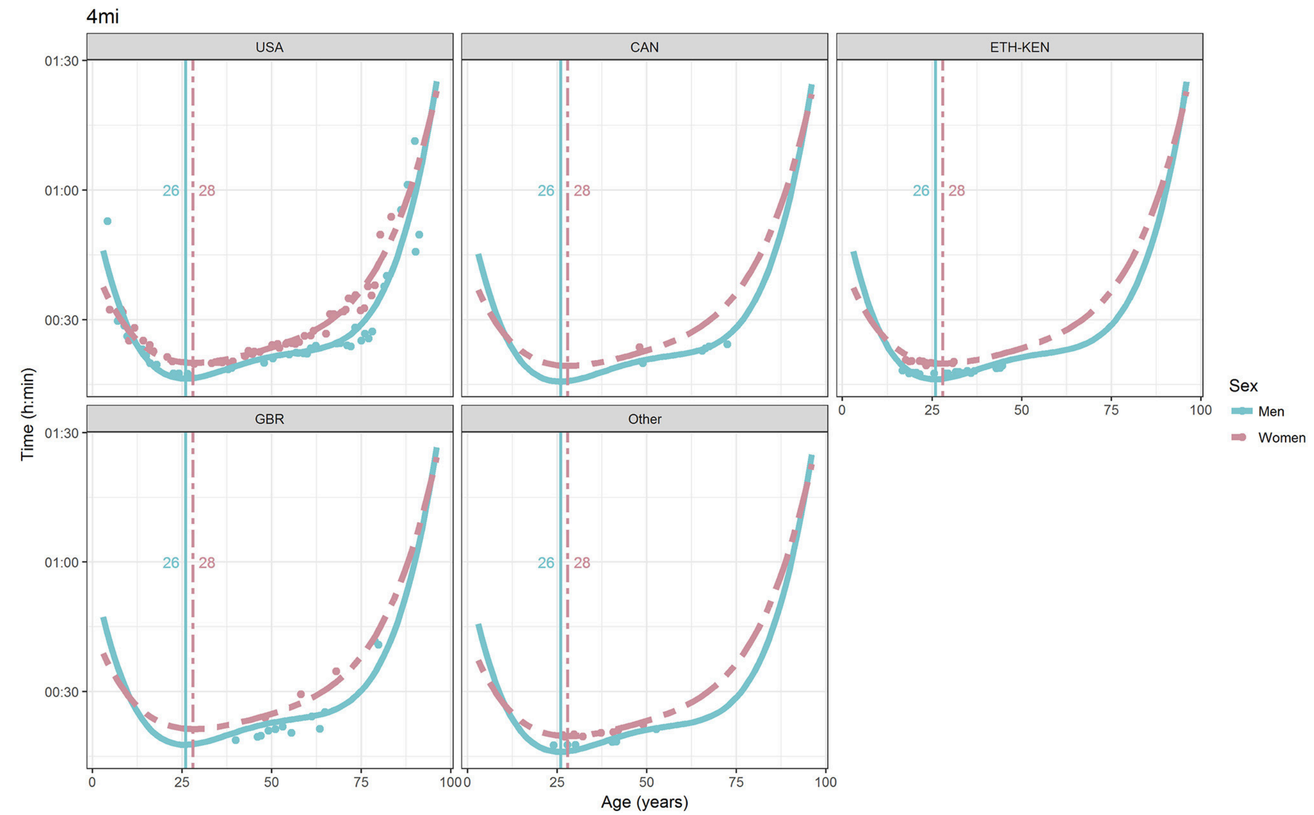

FIGURE 2 | World record in 4 miles by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

Canada were significantly slower than runners from the United States of America in 5 km (estimated difference 0.007, 00:10:05 h:min:s, $p < 0.001$) and half-marathon (estimated difference 0.013, 00:18:43 h:min:s, $p < 0.01$) but significantly faster in marathon (estimated difference −0.013, 00:18:43 h:min:s, $p < 0.05$); (2) runners from Great Britain were significantly faster than runners from the United States of America in 10 miles (estimated difference −0.002, 00:02:53 h:min:s, $p < 0.05$).

From **Table 2**, the values of R^2 were high for all races. This meant a good fit, for each model. Intra-class correlations (ICC) were also high, except in 25 km where ICC was poor. In 30 km and marathon ICC were fair.

For each race, all the effects in **Table 2**, together with the age of peak performances, were shown graphically in **Figures 1–12**. It could be observed that performances improved, reaching a minimum fastest time, and then they worsened with age. For each race, men performances, in the first part of the curve, were not always better than women performances, in particular in 25 km and in marathon, but men race times improved faster compared with women. These effects have been explained by the coefficients Sex × Age reported in **Table 2**.

As shown in **Figures 9**, **12**, the age of peak performance in half-marathon and marathon for men was, respectively, 27 and 28 years. Instead, women achieved their best half-marathon and marathon race time earlier in life than men. The difference was, respectively, of 1 and 3 years. On the contrary, in the other races, the best women performances were achieved later in life than men or at the same. The differences were: 2 years later in 4 miles and 30 km (**Figures 2**, **11**), 3 years later in 8 km (**Figure 3**), 1 year later in 15–20–25 km (**Figures 6**, **8**, **10**), and 4 years later in 10 miles (**Figure 7**). In 5, 10, and 12 km (**Figures 1**, **4**, **5**) the age of peak performance was equal for both sexes: 25 years for the first two races and 29 years for the latter. Therefore, there was, apparently, no relationship in the age of peak performances with increasing race distance.

In **Figure 13,** the sex differences by ages and by race, from 5 km to marathon were shown. The fitted values lines were calculated from the model in **Table 2** with country factor at the reference group level (USA). Except in 12 km, where sex differences appeared quite constant on age, even if a little higher in the older ages, in all other races sex difference had two maximum: they increased in the younger ages, until an age near the age of peak performance, then, after decreasing, they increased again reaching an absolute maximum in the older ages.

The relationship between sex differences with age and by distance in km was shown in **Figure 14**. Points were the observed differences, for all countries and races, and lines were the smoothed trends at the three classes of distance, [5, 10], (10, 20], and >20 km. It could be observed that the trend of sex differences

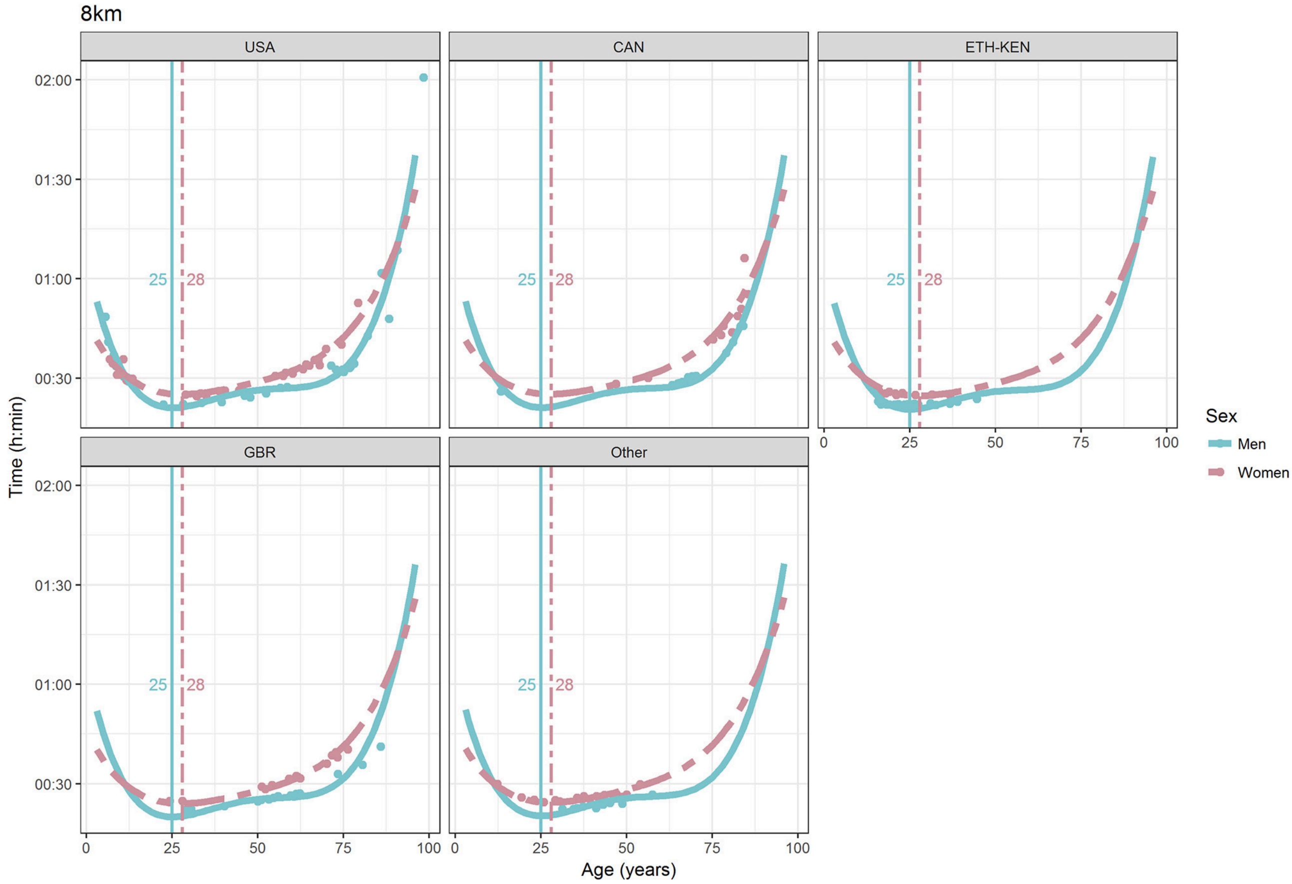

FIGURE 3 | World record in 8 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

in shortest distances, from 5 to 10 km included is more similar to the trend of sex differences in longest distances, >20 km, except for the older ages, where the sex differences were more increasing in shortest distances. In younger ages, the sex differences were highest in distances from 10 to 20 km and lowest in longest distances. In older ages, on the contrary, the sex differences were lowest in distances from 10 to 20 km and highest in shortest distances.

DISCUSSION

The aim of this study was to analyze the world single age records from 5 km to marathon with the hypothesis to find a lower age of peak running performance in the shorter compared to the longer running distances. The most important findings were (i) differences in the age of peak performance between women and men (e.g., women achieved their best half-marathon and marathon race time earlier in life than men), and (ii) for nearly all distances sex differences showed an absolute maximum at old ages and relative maximum near the age of peak performance. The disagreement between our research hypothesis and the main finding concerning the lack of variation of the age of peak performance by distance might be due to the different methodological approaches adopted in the present study compared with previous research which was conducted either in ultra-endurance running (Knechtle et al., 2014; Nikolaidis and Knechtle, 2018a,b) or other exercise modes (Baker and Tang, 2010; Berthelot et al., 2012; Elmenshawy et al., 2015). This study was conducted on world records, i.e., the best runners were selected, in contrast with previous research that used all runners to model the age of peak performance. When all runners were included in this model, the variation of participation by age might influence this model. For instance, a larger participation in a specific age would be likely associated with slower performance and *vice versa*.

Differences in Performance Between Countries

In this study, it was found that (i) runners from Canada were slower than runners from the United States of America, in 5 km and half-marathon, but faster in marathon; and (ii) runners from Great Britain were significantly faster than runners from the United States of America in 10 miles. Nonetheless, the reason for these cases should be due to the different age distribution within countries. In fact, in case (i) above, for Canada, there were

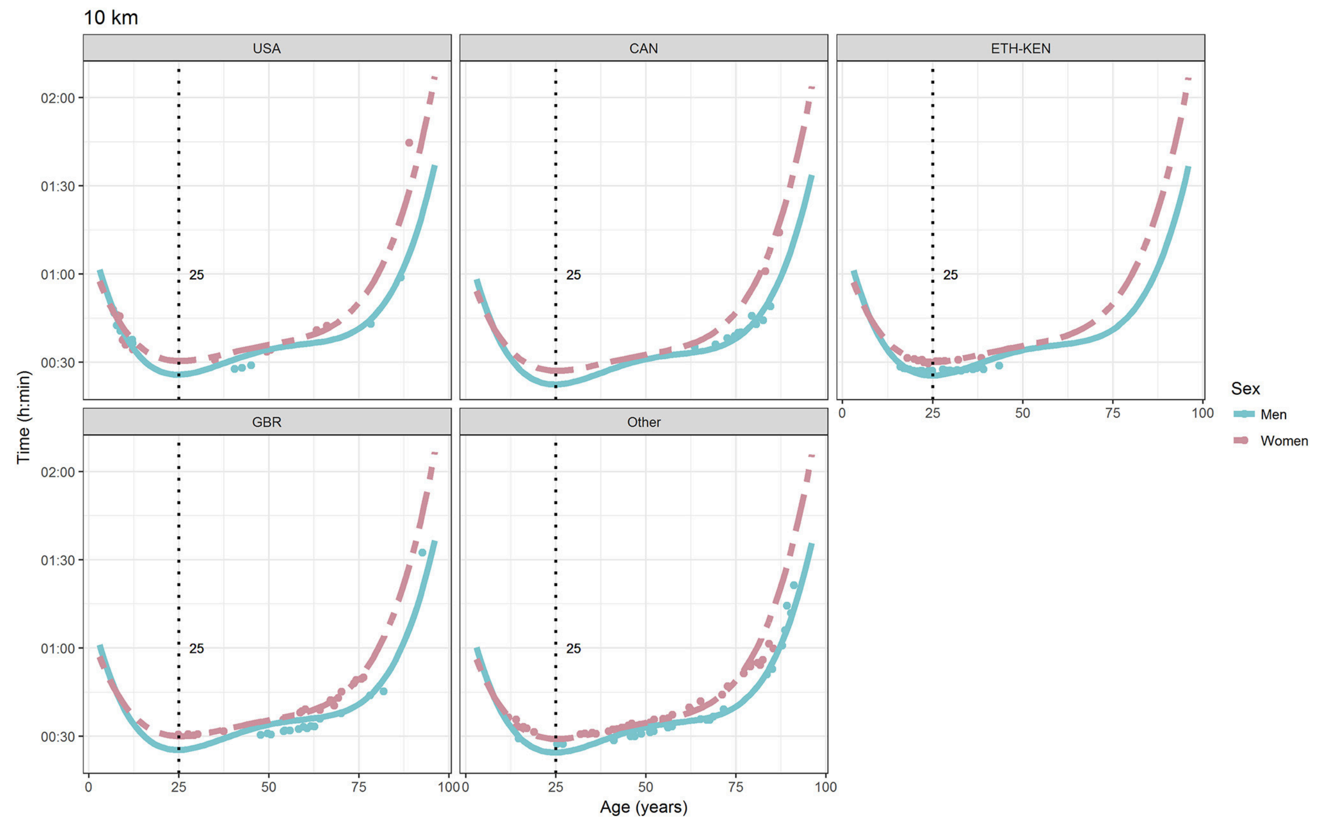

FIGURE 4 | World record in 10 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical line with numeric label was the age at peak performance.

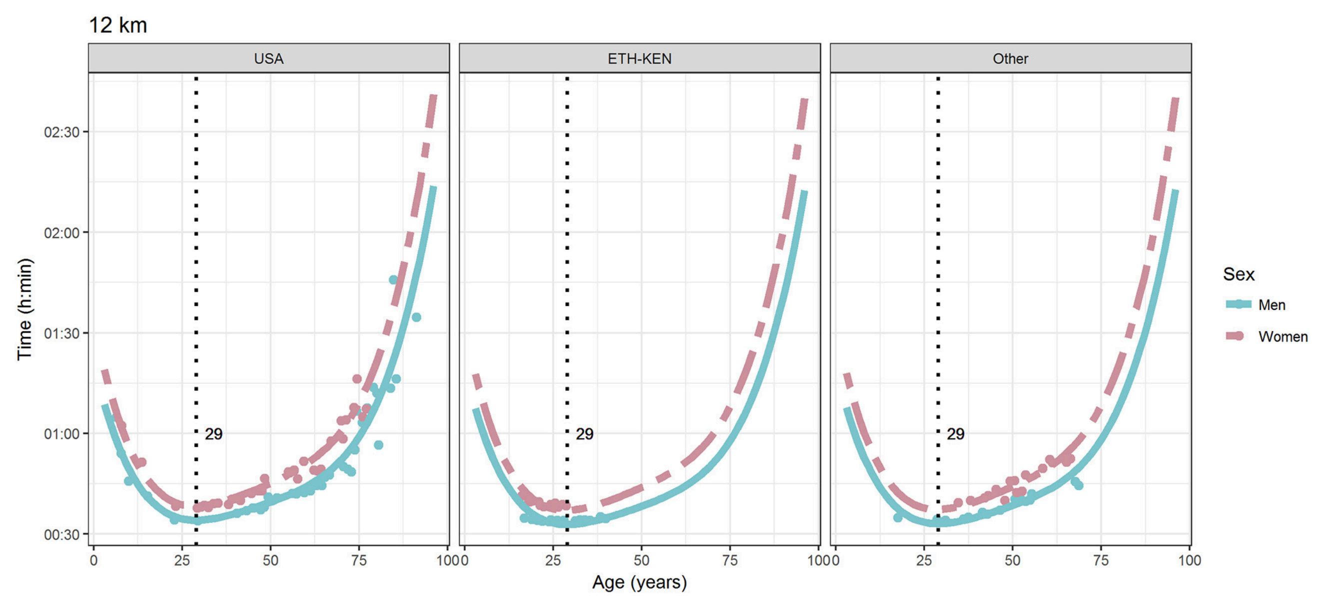

FIGURE 5 | World record in 12 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical line with numeric label was the age at peak performance.

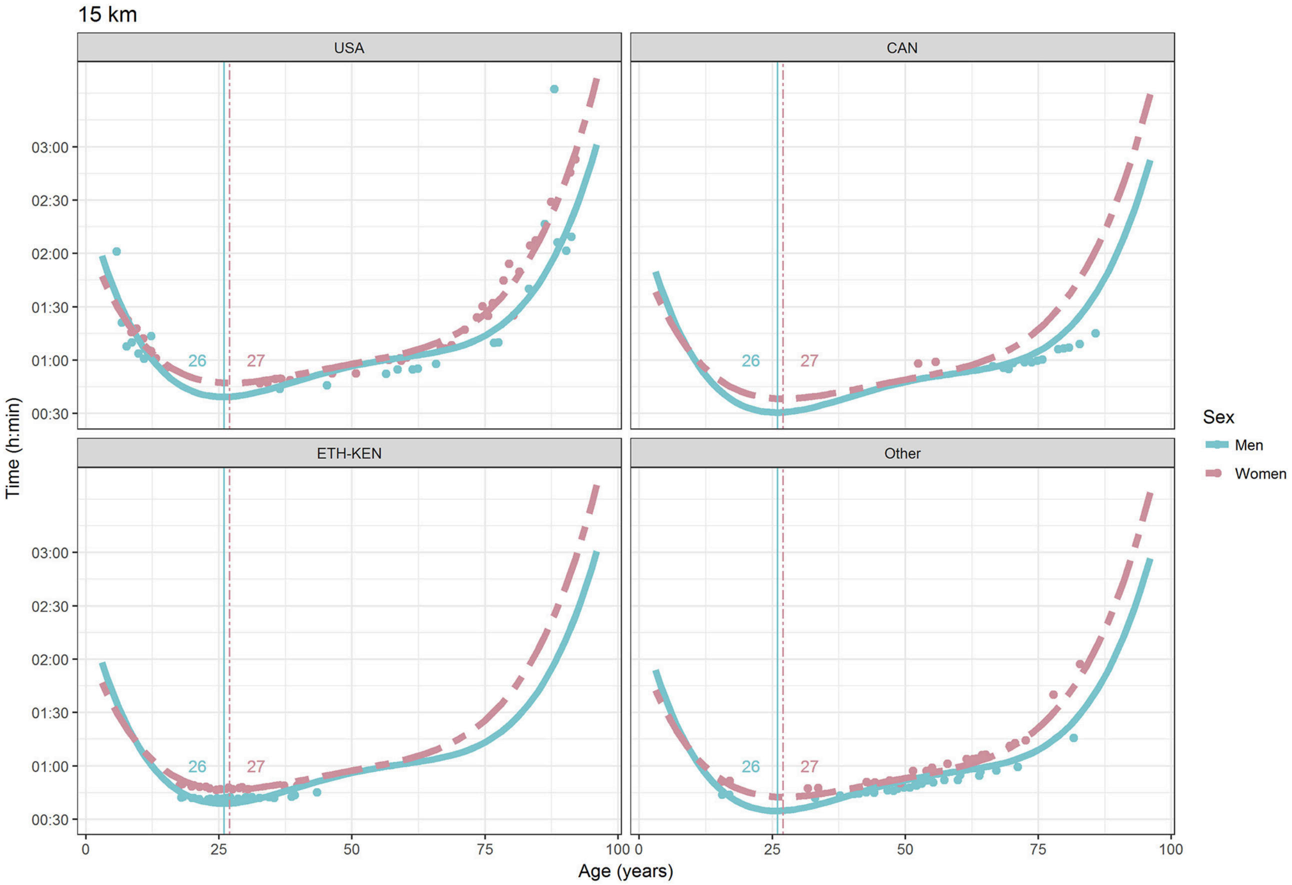

FIGURE 6 | World record in 15 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

only observations at the age of 65 years and older. In marathon, instead, there were, for USA, few observations in the central age classes and more or less the same number of observations in the older ages. In 10 miles, in USA, compared to GBR, the number of observations in the older ages was greater.

Differences in the Age of Peak Performance Between Women and Men

A first important finding was that women achieved their best half-marathon and marathon race time earlier in life than men. Half-marathon and marathon are very popular race distances and the actual findings confirm findings from earlier studies where women achieved their best race times earlier in life than men in both half-marathon (Knechtle and Nikolaidis, 2018; Nikolaidis et al., 2018) and marathon (Nikolaidis et al., 2018) running. The age of peak performance was in agreement with the range (25–34 years old) proposed by Zavorsky et al. (2017). Furthermore, the age of peak performance in the present study was younger than what was reported in marathon (~34 years old) in a study that analyzed all finishers (Lehto, 2016).

Overall, the age of peak performance seems to depend from the duration and/or distance of the performance with a clear trend to increase with increasing duration and/or distance (Allen and Hopkins, 2015). Regarding the age of peak running performance, longer distances than the marathon distance (e.g., 50 and 100-km ultra-marathon) have been investigated where women seemed to achieve their best race time in 50-km ultra-marathon later in life compared to men (Nikolaidis and Knechtle, 2018a). In contrast, the age of peak performance was younger in women than in men in 100-km ultra-marathon running (Nikolaidis and Knechtle, 2018b).

Obviously, the age of peak running performance seems not to follow a specific pattern regarding the actual findings (e.g., the best women performances were achieved later in life than men (i.e., 4 miles, 15 km, 10 miles, 20, 25, 30 km) or at the same age (i.e., 5, 10, 12 km), where the age of peak performance did not change monotonically with the distance of race). This aspect seems to be confirmed with the two ultra-marathon distances of 50 and 100 km.

To interpret the differences of age of peak performance in endurance running between women and men, the correlates of sex difference in performance should be considered. Since these correlates vary by age, it would be reasonable to assume that this variation would partly explain the corresponding variation

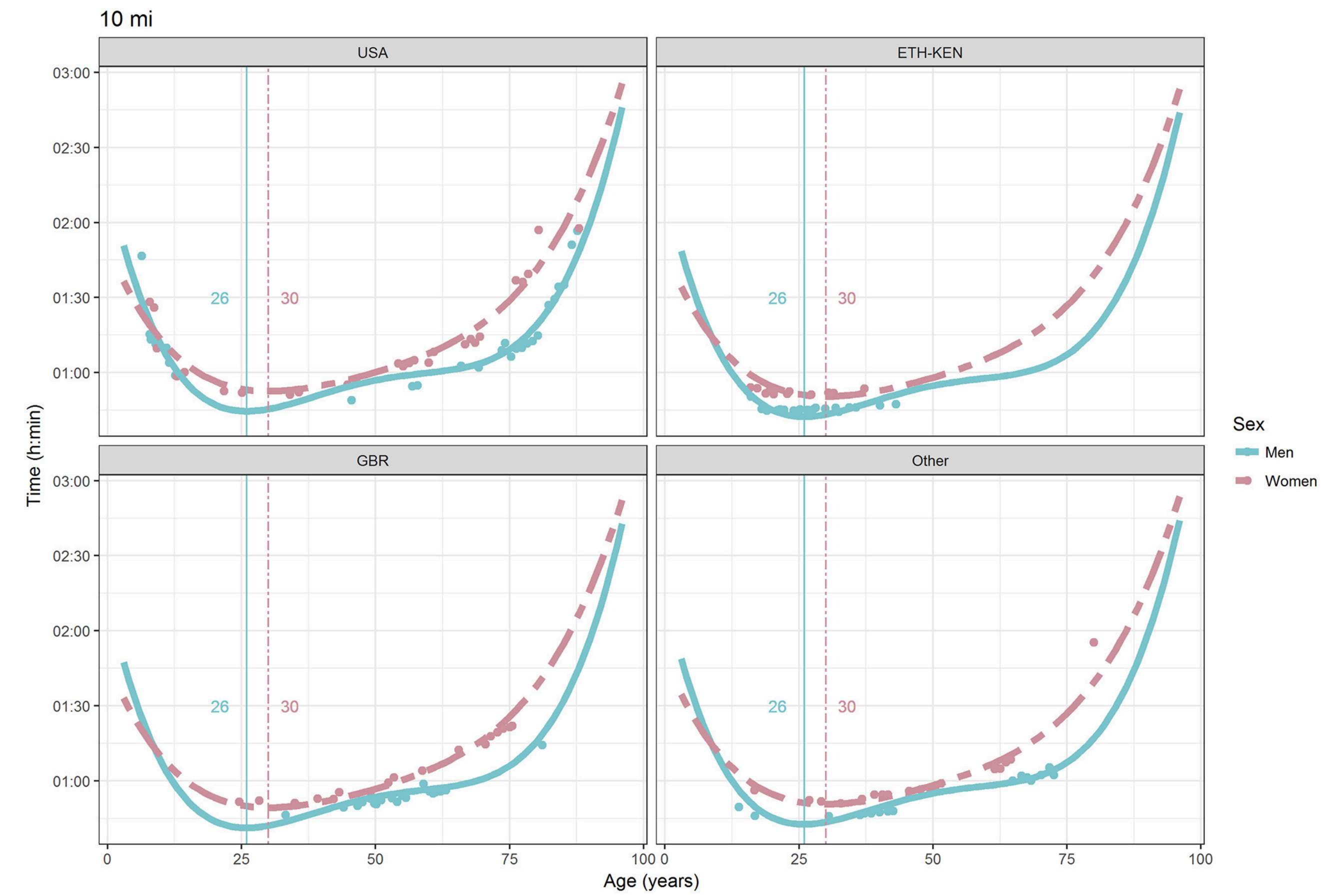

FIGURE 7 | World record in 10 miles by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

of peak performance by age. With regards to physiological correlates, it has been supported that the main physiological factor explaining the 10–12% slower race times in women than in men at the elite level is maximal oxygen uptake (Joyner, 2017). Other physiological correlated include longer limb levers, greater muscle mass and lower fat mass in men than in women (Millard-Stafford et al., 2018). On the other hand, it has been proposed that the greater sex difference in race speed in marathon with age might be due to the lower number of women finishers than men, as the lower participation levels of women and less depth among women would amplify the physiological sex differences (Hunter and Stevens, 2013). Moreover, these physiological and participation factors vary by age. For instance, the maximal oxygen uptake declines with age due to a reduction of muscle oxygen delivery (lower cardiac output) and of skeletal muscle oxidative capacity (mitochondrial dysfunction; Betik and Hepple, 2008). The decline of maximal oxygen uptake might be attenuated by endurance training (Rogers et al., 1990; Katzel et al., 2001). In addition, the participation rates in endurance running and the men-to-women ratio might also vary by age (Leyk et al., 2007; Lehto, 2016).

Sex Difference in Performance

A second important finding was that sex differences showed an absolute maximum at old ages and relative maximum near the age of peak performance for nearly all distances. In other words, men are relatively faster at higher ages compared to women. This confirms earlier findings from marathon runners. When running times of the first 10 placed men and women in the 5-years age brackets between 20 and 79 years and the number of men and women who finished the "New York City Marathon" were analyzed for a 31-year period (1980–2010), the sex difference increased with advanced age and decreased across the 31 years, but more for the older age groups. The authors assumed that the greater sex difference in running speed that occurs with age was primarily explained by the lower number of women finishers than men (Hunter and Stevens, 2013). However, in the present study, only the performance of one woman to one man, in the specific 1-year age intervals, was compared.

The observation that the sex difference in performance increases with increasing age is most likely due to a specific discipline as the sex difference increases with age more for running than for swimming (Senefeld et al., 2016). For instance, this finding is in agreement with studies on endurance running

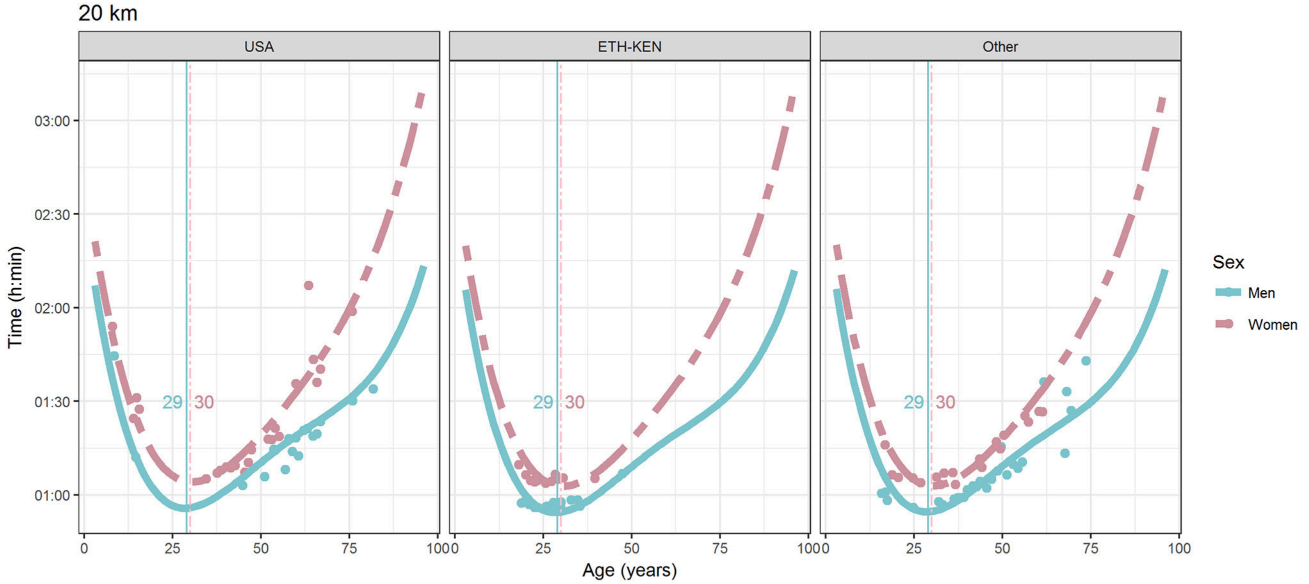

FIGURE 8 | World record in 20 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

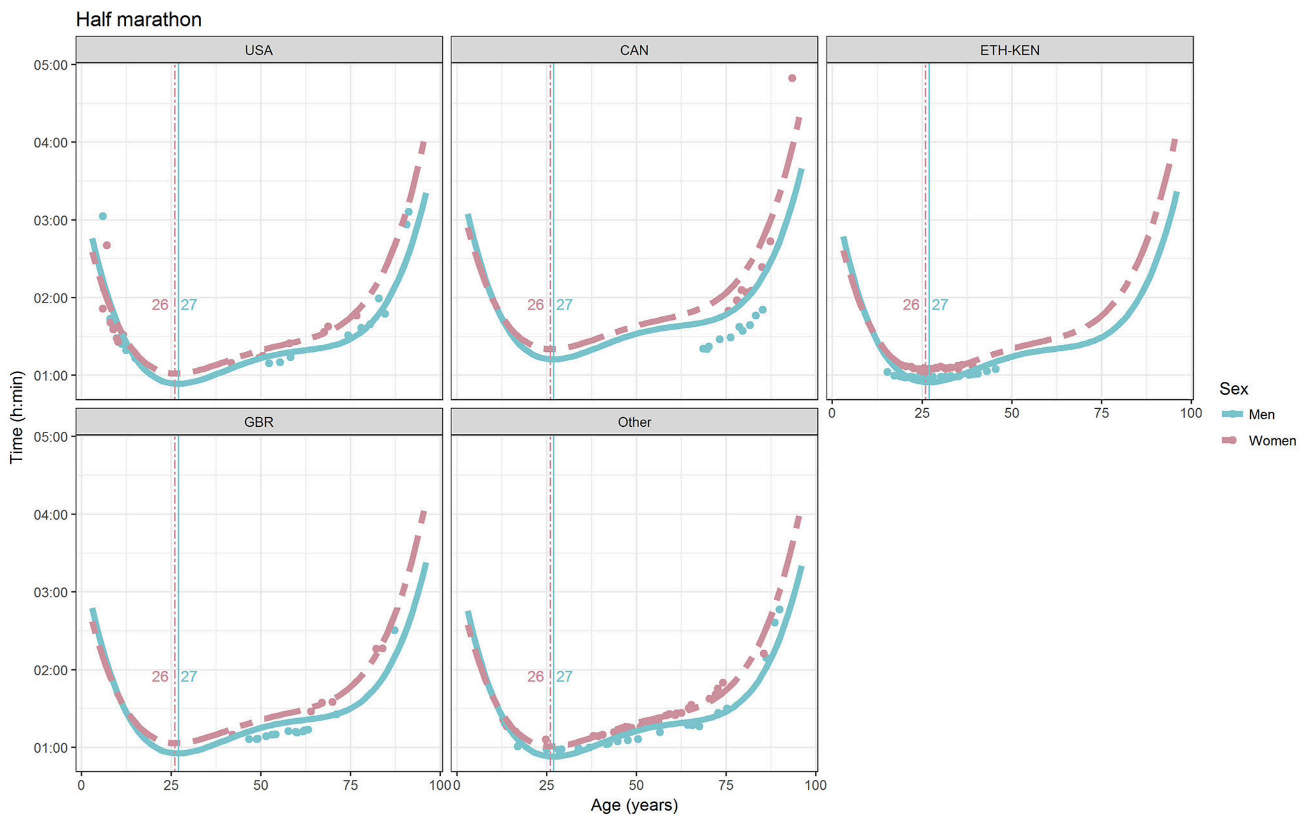

FIGURE 9 | World record in half-marathon by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

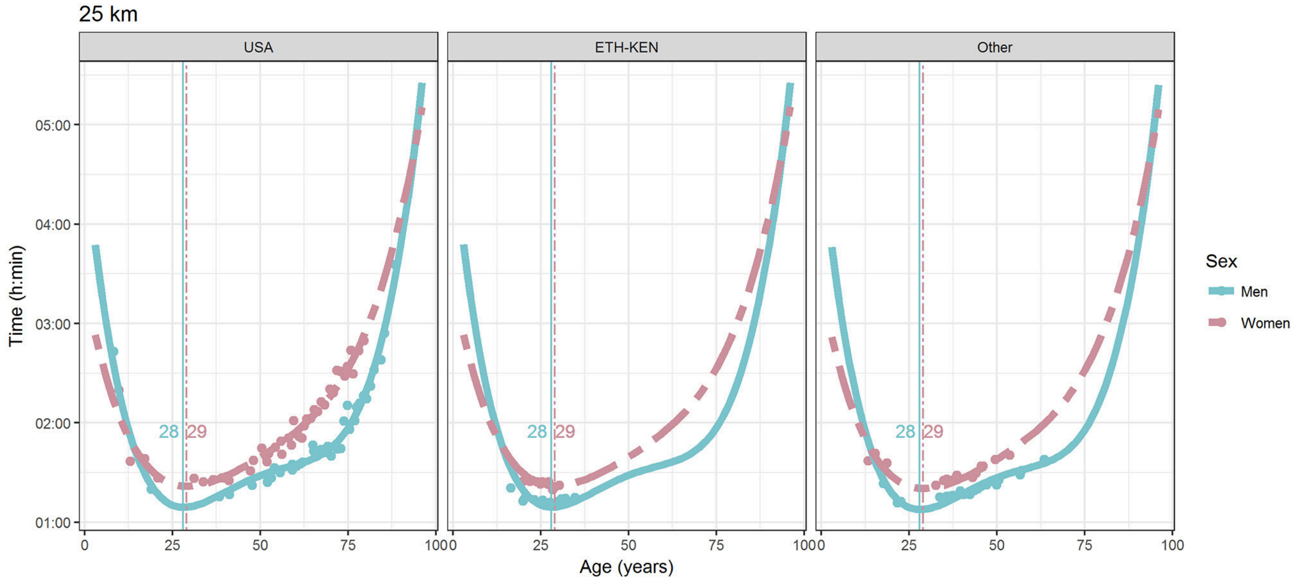

FIGURE 10 | World record in 25 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

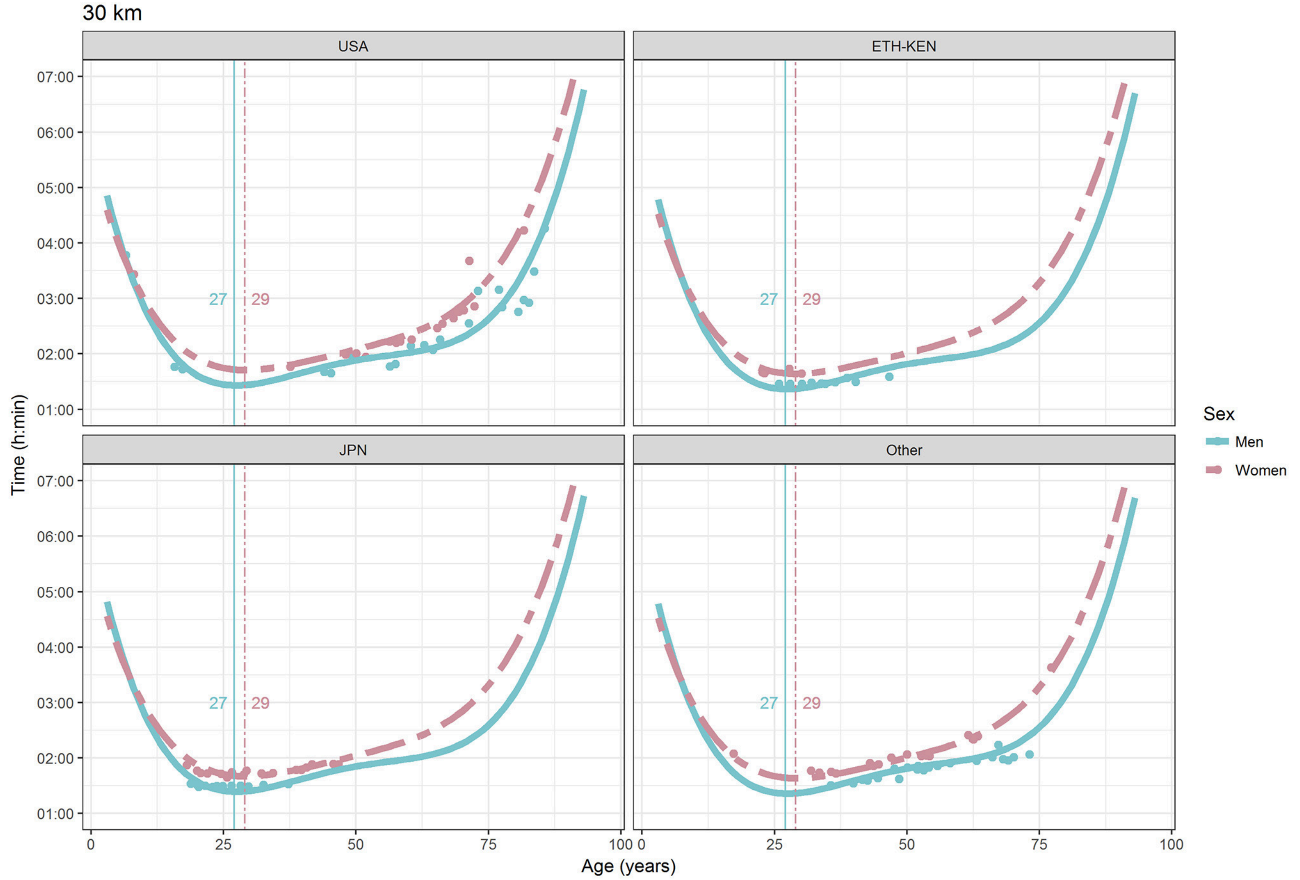

FIGURE 11 | World record in 30 km by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

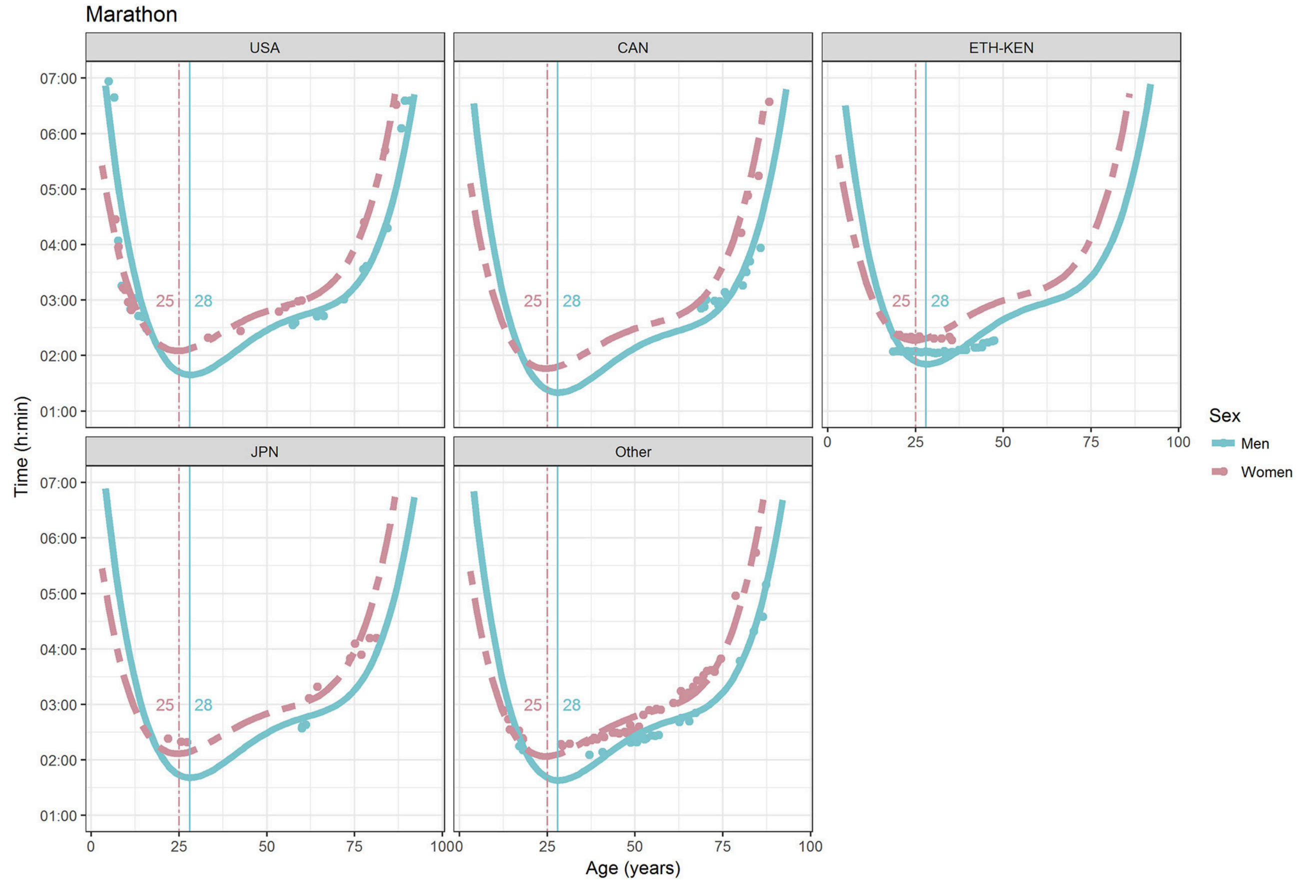

FIGURE 12 | World record in marathon by sex, age (in years), and country. Points were observations. Curves represented quartic degree polynomial regression. Vertical lines with numeric labels were the ages at peak performance.

such as half-marathon (Leyk et al., 2007) and marathon (Leyk et al., 2009; Hunter and Stevens, 2013). On the other hand, when compared with swimming, women were not slower compared to men in age groups 80–84 to 85–89 years when trends in participation, performance, and sex difference in performance of 65,584 freestyle master swimmers from 25–29 to 85–89 years competing in FINA World Masters Championships between 1986 and 2014 were investigated (Knechtle et al., 2016a). The same trends could also be observed for open-water freestyle swimming (Knechtle et al., 2017a) and other pool swimming disciplines such as breaststroke (Knechtle et al., 2016b), butterfly (Knechtle et al., 2017b), backstroke (Unterweger et al., 2016), and individual medley (Nikolaidis and Knechtle, 2018c). An explanation of this variation by exercise mode (i.e., running vs. swimming) might be that the physiological sex differences (for example, more subcutaneous fat in women) that limit women's performance more in weight-bearing exercise than non-weight bearing exercise, and more balanced participation levels of both sexes in elite swimming than marathon running (Senefeld et al., 2016; Millard-Stafford et al., 2018).

LIMITATIONS

The first limitation is related to the design of the study. Data regarding single age of world records were retrieved from the website of a non-official sport organism (ARRS). Since they are all road races, caution needs to generalize these findings to events performed in stadium (e.g., 5 or 10 km). Second, the effect of nationality, a possible confounder of age, was quantified in the intercept of the statistical model. This improved the fit of the model and highlighted some differences between countries. Nevertheless, for each race there were not enough observations, by country, age, and sex, to better dealing with confounding and to investigate a significant sex difference in performance by country. For this reason, it was not possible to consider a three-way interaction statistical model sex × age × country or a simpler two-way interactions sex × country and age × country. The summary statistics provided in **Table 1**, could only give an idea about the sex difference effect by country. Nonetheless, the significance of *t*-test statistics is limited in its nature, and is not an accurate and reliable way to make inference such as a statistical model.

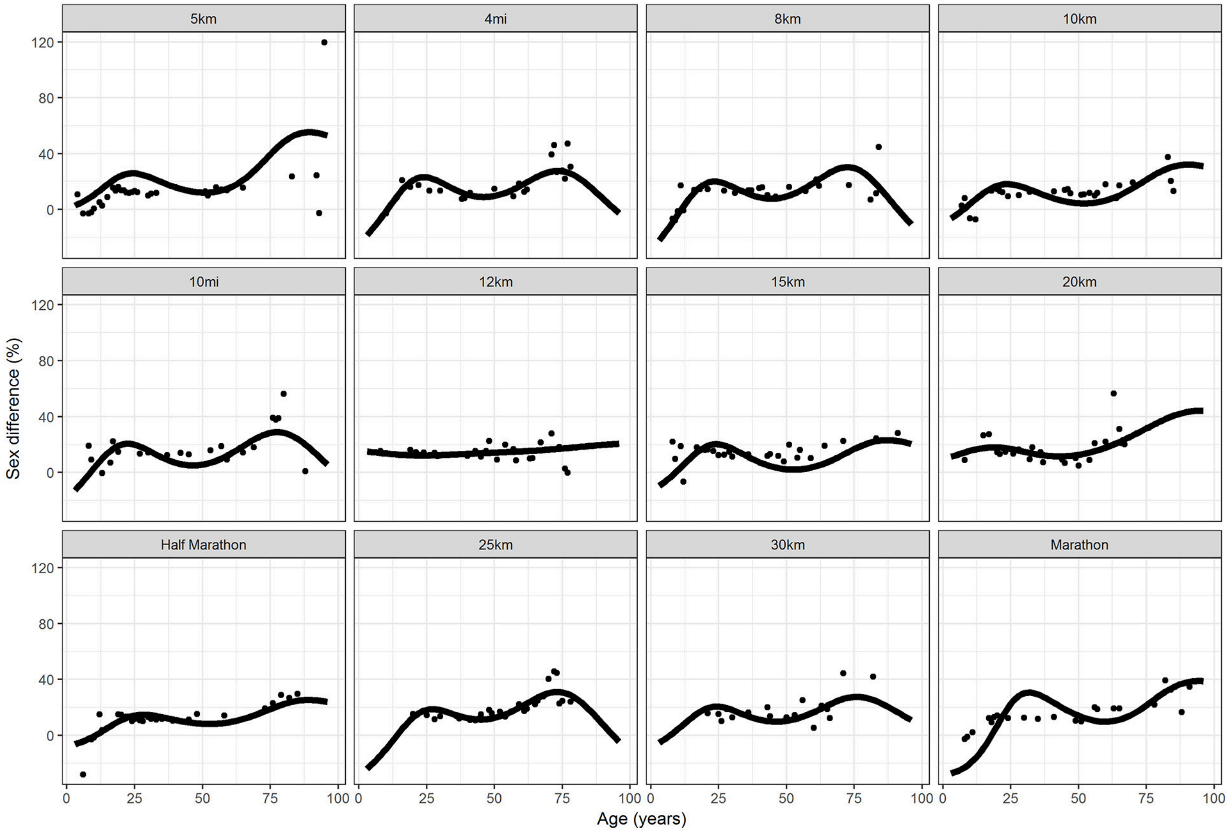

FIGURE 13 | Sex differences by age (in years) from 5 km to marathon. Points were observations. Curves represented fitted values, with country being the reference group (USA).

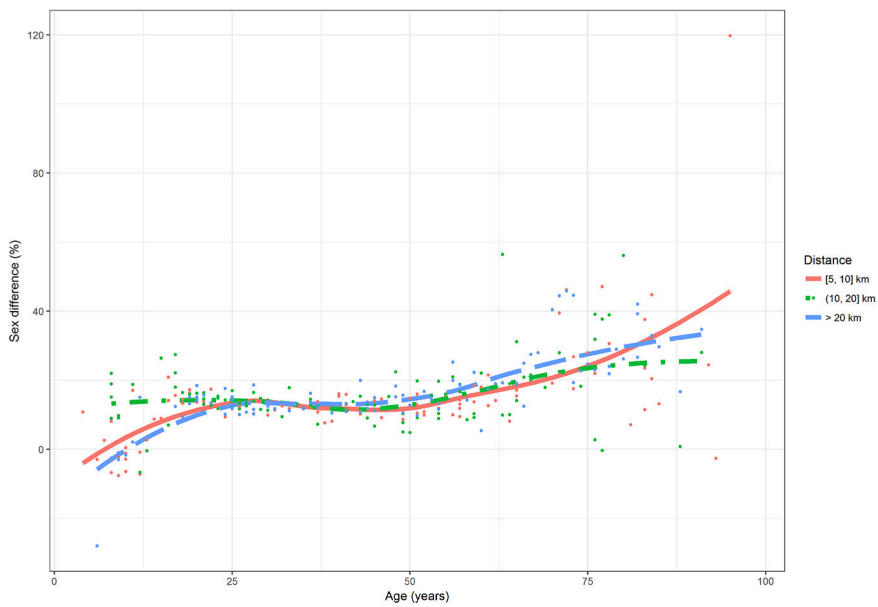

FIGURE 14 | Sex differences by age (in years) and by distance. Points were observations. Curves represented smoothed values.

CONCLUSIONS

This is the first study to investigate the age of peak performance, the sex difference in performance and the role of nationality in running distances from 5 km to marathon and it was found that differences seem to exist in the age of peak performance between women and men (e.g., women achieved their best half-marathon and marathon race time earlier in life than men), and for nearly all distances sex differences showed an absolute maximum at old ages and relative maximum near the age of peak performance. Considering the increased number of finishers in endurance running races during the last decades, the findings of the present study would have great practical interest for strength and conditioning coaches working with runners practicing endurance training regularly. Typically, a strength and conditioning coach trains runners in small groups including likely both women and men of various ages participating in endurance races that might vary for distance. Our findings highlighted the need for sex-specific training programs, especially near the age of peak performance and for elder runners. In addition, the lack of difference of the age of peak performance among race distances ranging from 5 km to marathon implied that strength and conditioning coaches of runners should set long-term performance goals considering the age of peak performance similarly for this range of distance.

AUTHOR CONTRIBUTIONS

BK provided the data from the data base. SD performed the analysis. BK and PN drafted the manuscript. All authors approved the final version of the manuscript for publication.

REFERENCES

Allen, S. V., and Hopkins, W. G. (2015). Age of peak competitive performance of elite athletes: a systematic review. *Sports Med.* 45, 1431–1441. doi: 10.1007/s40279-015-0354-3

Baker, A. B., and Tang, Y. Q. (2010). Aging performance for masters records in athletics, swimming, rowing, cycling, triathlon, and weightlifting. *Exp. Aging Res.* 36, 453–477. doi: 10.1080/0361073x.2010.507433

Berthelot, G., Len, S., Hellard, P., Tafflet, M., Guillaume, M., Vollmer, J. C., et al. (2012). Exponential growth combined with exponential decline explains lifetime performance evolution in individual and human species. *Age* 34, 1001–1009. doi: 10.1007/s11357-011-9274-9

Betik, A. C., and Hepple, R. T. (2008). Determinants of VO2 max decline with aging: an integrated perspective. *Appl. Physiol. Nutr. Metab.* 33, 130–140. doi: 10.1139/h07-174

Elmenshawy, A. R., Machin, D. R., and Tanaka, H. (2015). A rise in peak performance age in female athletes. *Age* 37:9795. doi: 10.1007/s11357-015-9795-8

Haugen, T. A., Solberg, P. A., Foster, C., Morán-Navarro, R., Breitschädel, F., and Hopkins, W. G. (2018). Peak age and performance progression in World-Class Track-and-Field Athletes. *Int. J. Sports Physiol. Perform.* doi: 10.1123/ijspp.2017-0682. [Epub ahead of print].

Hunter, S. K., and Stevens, A. A. (2013). Sex differences in marathon running with advanced age: physiology or participation? *Med. Sci. Sports Exerc.* 45, 148–156. doi: 10.1249/MSS.0b013e31826900f6

Joyner, M. J. (2017). Physiological limits to endurance exercise performance: influence of sex. *J. Physiol.* 595, 2949–2954. doi: 10.1113/JP272268

Katzel, L. I., Sorkin, J. D., and Fleg, J. L. (2001). A comparison of longitudinal changes in aerobic fitness in older endurance athletes and sedentary men. *J. Am. Geriatr. Soc.* 49, 1657–1664. doi: 10.1111/j.1532-5415.2001.49276.x

Knechtle, B., and Nikolaidis, P. T. (2017). The age of the best ultramarathon performance - the case of the "Comrades Marathon". *Res. Sports Med.* 25, 132–143. doi: 10.1080/15438627.2017.1282357

Knechtle, B., and Nikolaidis, P. T. (2018). Sex- and age-related differences in half-marathon performance and competitiveness in the world's largest half-marathon - the GoteborgsVarvet. *Res. Sports Med.* 26, 75–85. doi: 10.1080/15438627.2017.1393749

Knechtle, B., Nikolaidis, P. T., König, S., Rosemann, T., and Rüst, C. A. (2016a). Performance trends in master freestyle swimmers aged 25-89 years at the FINA World Championships from 1986 to 2014. *Age* 38:18. doi: 10.1007/s11357-016-9880-7

Knechtle, B., Nikolaidis, P. T., Rosemann, T., and Rüst, C. A. (2016b). Performance trends in age group breaststroke swimmers in the FINA World Championships 1986-2014. *Chin. J. Physiol.* 59, 247–259. doi: 10.4077/cjp.2016.bae406

Knechtle, B., Nikolaidis, P. T., Rosemann, T., and Rüst, C. A. (2017a). Performance trends in 3000 m open-water age group swimmers from 25 to 89 years competing in the FINA World Championships from 1992 to 2014. *Res. Sports Med.* 25, 67–77. doi: 10.1080/15438627.2016.1258647

Knechtle, B., Nikolaidis, P. T., Rosemann, T., and Rüst, C. A. (2017b). Performance trends in master butterfly swimmers competing in the FINA World Championships. *J. Hum. Kinet.* 57, 199–211. doi: 10.1515/hukin-2017-0061

Knechtle, B., Nikolaidis, P. T., Zingg, M. A., Rosemann, T., and Rüst, C. A. (2017). Differences in age of peak marathon performance between mountain and city marathon running - The 'Jungfrau Marathon' in Switzerland. *Chin. J. Physiol.* 60, 11–22. doi: 10.4077/cjp.2017.bae400

Knechtle, B., Valeri, F., Zingg, M. A., Rosemann, T., and Rüst, C. A. (2014). What is the age for the fastest ultra-marathon performance in time-limited races from 6 h to 10 days? *Age* 36:9715. doi: 10.1007/s11357-014-9715-3

Lara, B., Salinero, J. J., and Del Coso, J. (2014). The relationship between age and running time in elite marathoners is U-shaped. *Age* 36, 1003–1008. doi: 10.1007/s11357-013-9614-z

Lehto, N. (2016). Effects of age on marathon finishing time among male amateur runners in Stockholm Marathon 1979–2014. *J. Sport Health Sci.* 5, 349–354. doi: 10.1016/j.jshs.2015.01.008

Leyk, D., Erley, O., Gorges, W., Ridder, D., Rüther, T., Wunderlich, M., et al. (2009). Performance, training and lifestyle parameters of marathon runners aged 20-80 years: results of the PACE-study. *Int. J. Sports Med.* 30, 360–365. doi: 10.1055/s-0028-1105935

Leyk, D., Erley, O., Ridder, D., Leurs, M., Rüther, T., Wunderlich, M., et al. (2007). Age-related changes in marathon and half-marathon performances. *Int. J. Sports Med.* 28, 513–517. doi: 10.1055/s-2006-924658

Millard-Stafford, M., Swanson, A. E., and Wittbrodt, M. T. (2018). Nature versus nurture: Have performance gaps between men and women reached an asymptote? *Int. J. Sports Physiol. Perform.* 13, 530–535. doi: 10.1123/ijspp.2017-0866

Nikolaidis, P. T., Di Gangi, S., and Knechtle, B. (2018). World records in half-marathon running by sex and age. *J. Aging Phys. Act.* 26:629–636. doi: 10.1123/japa.2017-0394

Nikolaidis, P. T., and Knechtle, B. (2018a). Age of peak performance in 50-km ultramarathoners - is it older than in marathoners? *Open Access J. Sports Med.* 9, 37–45. doi: 10.2147/oajsm.s154816

Nikolaidis, P. T., and Knechtle, B. (2018b). Performance in 100-km ultramarathoners - At which age it reaches its peak? *J. Strength Cond. Res.* doi: 10.1519/jsc.0000000000002539. [Epub ahead of print].

Nikolaidis, P. T., and Knechtle, B. (2018c). Performance trends in individual medley events during FINA World Master Championships from 1986 to 2014. *J. Sports Med. Phys.Fitness* 58, 690–698. doi: 10.23736/s0022-4707.17.06992-4

Nikolaidis, P. T., Onywera, V. O., and Knechtle, B. (2017a). Running performance, nationality, sex, and age in the 10-km, half-marathon, marathon, and the 100-km ultramarathon IAAF 1999-2015. *J. Strength Cond. Res.* 31, 2189–2207. doi: 10.1519/jsc.0000000000001687

Nikolaidis, P. T., Rosemann, T., and Knechtle, B. (2018). Sex differences in the age of peak marathon race time. *Chin. J. Physiol.* 61, 85–91. doi: 10.4077/cjp.2018.bag535

Nikolaidis, P. T., Zingg, M. A., and Knechtle, B. (2017b). Performance trends in age-group runners from 100 m to marathon-The World Championships from 1975 to 2015. *Scand. J. Med. Sci. Sports* 27, 1588–1596. doi: 10.1111/sms.12821

Rogers, M. A., Hagberg, J. M., Martin, W. H. III, Ehsani, A. A., and Holloszy, J. O. (1990). Decline in VO2max with aging in master athletes and sedentary men. *J. Appl. Physiol. (1985)* 68, 2195–2199. doi: 10.1152/jappl.1990.68.5.2195

Senefeld, J., Joyner, M. J., Stevens, A., and Hunter, S. K. (2016). Sex differences in elite swimming with advanced age are less than marathon running. *Scand. J. Med. Sci. Sports* 26, 17–28. doi: 10.1111/sms.12412

Unterweger, C. M., Knechtle, B., Nikolaidis, P. T., Rosemann, T., and Rust, C. A. (2016). Increased participation and improved performance in age group backstroke master swimmers from 25-29 to 100-104 years at the FINA World Masters Championships from 1986 to 2014. *Springerplus* 5:645. doi: 10.1186/s40064-016-2209-2

Zavorsky, G. S., Tomko, K. A., and Smoliga, J. M. (2017). Declines in marathon performance: sex differences in elite and recreational athletes. *PLoS ONE* 12:e0172121. doi: 10.1371/journal.pone.0172121

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The reviewer SF and handling editor declared their shared affiliation at the time of the review.

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METHODS
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Design and Validation of an Observational Instrument for the Technical-Tactical Actions in Singles Tennis

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The competitive performance in tennis practice is determined by the effectiveness of technical tactical action. The main objective of the present study was to design and validate an observational instrument with the aim of analysing the technical-tactical in singles tennis. The instrument uses the stroke as a unit of measure, so that each time a player hits a ball, a total of 23 variables are analyzed. The variables collect information about: (a) matching context; (b) result; and (c) technical-tactical information of the stroke (five variables: sequences of the stroke of the point, kind of technical and tactical stroke, bounce area, hitting, and effectiveness area). The design and validation of the instrument consisted on five different stages: (a) review of the scientific literature and variables definition by experts, (b) pilot observation study, (c) qualitative and quantitative assessment of the instrument by experts, (d) review and confirmation of the instrument by experts (content validity), and (e) observation training and reliability evaluation. From 23 expert judges, divided into three panels, and four observers the instrument went from being composed of 38 variables (eight contextual, seven related to the result and 23 related to the game) to 23 (eight contextual variables, 10 of result and five of game), with minimum Aikens's V values of 0.94 and reliability of 0.81. The results show that the designed instrument allows obtaining valid and objective information about the technical-tactical actions of the players and their performance in singles tennis

Keywords: performance, evaluation, tennis, match analysis, observational methodology

INTRODUCTION

One of the most determining factors in sports performance is the tactical technical analysis of the competition (Cui et al., 2018; Zhang et al., 2018). This type of analysis allows coaches to obtain information about the performance indicators, apart from knowing the weaknesses and strengths from their own and the adversaries, offering the possibility of improving training processes and therefore, increasing the possibilities of performance and success possibilities from the players (O'Donoghue and Ingram, 2001; Sainz De Baranda et al., 2008). That is why many coaches and researchers use the technological advances and the different methods of sport science for this purpose (Figueira et al., 2018).

Despite the multiple and quick advances in technology (Mateus et al., 2017), observation processes are still a very important instrument when it comes to gathering information in the sports field. Proof of this is that one of the methods most used by researchers in the last decade in the field of match and notational analysis is the observational methodology (Anguera et al., 2011; Maneiro et al., 2018). Thanks to it, the multiple variables that concur and interact in motor competition can be registered, as well as all those related to the context in which they are developed, such as the type of activity (competition or training), the level of expertise (professionals or amateurs) or the different categories that exist in each sport (Anguera and Hernández-Mendo, 2015).

One of the essential aspects in any type of scientific methodology is the recording of data through an appropriate instrument that guarantees its reliability and validity (Chacón-Moscoso et al., 2018). According to Hughes et al. (2002) 70% of the papers presented in conferences in which the observational methodology is used in sports, have deficiencies in data collection and statistical treatment. This is why, in the sports field, different studies can be found which objective has been to validate a specific observational instrument from of a sport modality, such as those carried out in handball (Morillo et al., 2017), rugby (Jones et al., 2008; Villarejo et al., 2014), beach volleyball (Palao et al., 2015), basketball (Moreno and Gómez-Ruano, 2017), soccer (Larkin et al., 2016; Maneiro et al., 2018) etc. All of them describe the process in two large phases: (a) design of the instrument with the system of categories and behaviors to observe; (b) to establish and calculate the reliability and validity of the instrument.

In the case of tennis, many investigations have used observational methodology in the match and notational analysis to obtain information about aspects such as performance indicators (Djurovic et al., 2009; Katić et al., 2011; Cui et al., 2018), service effectiveness and returns (Gillet et al., 2009; Hizan et al., 2011; Martin et al., 2016), tactical aspects (Over and O'Donoghue, 2010; Cross and Pollard, 2011; Reid et al., 2016), or the displacements and the position of players on the tennis court (Martínez-Gallego et al., 2013; Pereira et al., 2017). Sometimes these data are downloaded directly from the official websites of the tournaments and in others, the researchers are the ones who perform the data collection through observation. However, in none of the cases the process of design and validation of the instrument that they have used to collect the information are explained.

Therefore, the purpose of this article was to design and validate an observational instrument that allows coaches and researchers to analyse in a reliable, objective, accurate, and valid way the technical tactical actions in singles tennis.

TABLE 1 | Questionnaire example sent to the experts.

Stroke effectiveness

- Variable: Effectiveness of the stroke performed by the player.
- Categories:

  1. Winner. Stroke made by the player with the one that gets the point directly, without his/her opponent touched the ball.
  2. Transition stroke. Stroke made by player after that, the opponent hit the ball and bounce inside the court of the first one.
  3. Previous stroke of an opponent error. Stroke made by player after that, the opponent hitting the ball and committed an error losing the point.
  4. Error. The player hit the ball sending out of the regulatory area of the court or to the net losing the point.

a) **Inclusion:** Do you consider it necessary to include this variable in the observation sheet? YES/NO

b) **Adequacy:** Do you think that the definition of the variable and its categories is adequate?

- Very inadequate 1-2-3-4-5-6-7-8-9-10 very suitable
- In the case that it would be necessary to add or delete a category, indicate which one and why.

c) **Writing:** Do you consider adequate the wording of the definition of the variable and the definition of each of the categories?

- Very poorly written 1-2-3-4-5-6-7-8-9-10 very well written
- Propose a definition if it is not clear:

d) **Observations:**

Variable stroke effectiveness.

METHODS

The design and validation of the observational instrument was carried out in five phases. In the first two, the design of the observational instrument was carried out, which consisted of a system of categories (Anguera, 2003; Anguera and Hernández-Mendo, 2015). In the third and fourth, the content validity was established and calculated, while in the fifth phase the reliability of the instrument was tested (Kinrade et al., 2010).

The objective of the first phase was to prepare a provisional list of the behaviors to be studied once the review of the scientific literature has been carried out (in the Sport Discus, Web of Science, Google Scholar, Sponet, Scielo, and Dialnet databases) with the keyword single tennis and excluding (not) the word table (**Table 1**). The result was an initial list of variables that included the definition of each of the variables and the category to which they should belong. The unit of analysis was the tennis stroke and three categories were established to group all the variables: (a) contextual variables, (b) result variables, (c) game variables. In the first group were included all those that defined the environment of a match. In the second, the variables that gave information about the score of the match were included, while in the third one there were introduced those related to the execution, result, and effectiveness of the technical-tactical actions. The provisional list of variables and categories was presented and analyzed by three experts who had at least the following characteristics: (a) have a minimum qualification of Sports Technician of the highest national category; (b) have a minimum experience of 10 years in the teaching of tennis; and (c) be graduated in Physical Activity and Sports Sciences. So that there was no modification of variables and categories, all of them had to, by consensus, give their approval to all of them.

In the second phase, a pilot observation was carried out to test the previously formed instrument with the objective of making modifications if deemed necessary. To do so, a single observer independent in relation to the investigation carried out, analyzed all the seven-set shots from three matches of the 2014 Tennis Masters Cup. The observer had a degree in sports science, had

TABLE 2 | List of variables and contextual categories that make up the observational instrument after the first two phases.

VARIABLE	CATEGORIES	
Gender of the players*	• Male • Female	• Mixed
Competition category*	• Senior • Junior • U-16 • U-15 • U-14 • U-13	• U-12 • U-11 • U-10 • U-9 • Others
Tournament level**	• Professional tournament • Semi- Professional tournament • National Tournament • Regional Tournament	• Local Tournament • Amateur Tournament • Amateur Tennis
Type of tournament*	• Copa Masters • Grand Slam • Premier Mandatory • Master 1,000/Premier 5 • ATP 500/Premier • ATP 250/WTA Internacional • Challengers • Futures	• ITF Circuit • National Championship • Regional Championship • Local Championship • Federated tournament • Unfederated tournament • Others
Game mode*	• Best of 5 sets with Tie-Break in the 5th set • Best of 5 sets without Tie-Break in the 5th set • Best of 3 sets • Two sets and Super Tie-Break if each player wins a set	• Two sets of 4 games and Super Tie-Break if each player wins a set • One Set of 4 games and Tie Break if each player wins 4 games • Others
Court surface*	• Hard court • Clay court • Grass court	• Indoor carpet • Others
Laterality of the players*	• Right handed	• Left handed
Type of backhand*	• One hand backhand	• Two hands backhand

*Suggested behaviors in the review of the scientific literature (Phase 1), **Behaviors suggested by experts (Phase 1). U, Under.*

TABLE 3 | List of variables and categories related with the result of the match that make up the observational instrument after the first two phases.

VARIABLE	CATEGORIES	
Winner or loser of the match*	• Winner of the match	• Loser of the match
Analyzed set***	• 1st set • 2nd set • 3rd set • 4th set	• 5th set • Tie Break • Super Tie Break
Winner or loser of the set***	• Winner of the analyzed set	• Loser of the analyzed set
Games won on the set*	• One game won • Two games won • Three games won	• Four games won • Five games won • Six games won
Lost games on the set*	• One game lost • Two games lost • Three games lost	• Four games lost • Five games lost • Six games lost
Game scoreboard**	• 0/0 • 15/0 • 0/15 • 15/15 • 30/15 • 15/30 • 30/30 • 40/30 • 30/40 • 40/40	• AD/40 • 40/AD • 30/0 • 40/0 • 0/30 • 0/40 • 40/15 • 15/40 • Tie-break point* • Super Tie-break point*
Winner or loser of the point**	• Winner of the analyzed point	• Loser of the analyzed point

*Suggested behaviors in the review of the scientific literature (Phase 1), **Behaviors suggested by experts (Phase 1), ***Behaviors suggested after the observational pilot test (Phase 2).*

more than 10 years' experience as a tennis coach and had the highest degree sports as a national tennis coach. The analysis and its corresponding report was reviewed by the researchers and experts previously consulted, with the aim of generating a second list of variables and categories with the modifications carried out with respect to the previous phase. This way observation is used to add sports behaviors that previously were not defined at a theoretical level, but which appeared during the game. Similarly in this phase the frequencies that occur in some categories are observed, with a view to use this data to delimit and define the size of the categories (for example after the study of the service and from the number of actions, it was divided the serve bounce areas in those noted in the instrument and no more or less areas). In this phase, an observation manual was created, in which all the variables and their categories were named and defined. On the other hand, the recording (annotation) of the information was done manually in the Excel statistical program.

In the third phase, a quantitative and qualitative evaluation of the instrument was carried out by another 10 new experts who should have the following characteristics (federated tennis coach, graduated in Physical Activity and Sports Sciences, and at least 10 years of experience as a coach). In this new evaluation the expert judges completed a questionnaire in which they were asked about each of the variables under study, including the following aspects: (a) convenience of including the behavior or variable in the observational instrument (Inclusion); (b) degree of adequacy in the definition of the variable and the categories that compose it (Adequacy); (c) level of writing of the definitions of the variable and of the categories that were part of the instrument (Writing); and (d) observations. The quantitative part of the evaluation consisted in scoring from 1 to 10 the adequacy and definition part and the qualitative part in answering with "Yes" or "No" the inclusion section. The part of observations would be completed in the case that it is considered necessary to make a contribution. The data were recorded and a descriptive analysis was made (mean, median and mode of each continuous variable and absolute and relative frequency of the categorical variables).

Later on, the content validity was calculated through of Aikens's V coefficient (Aiken, 1980; Penfield and Giacobbi, 2004). The Visual Basic 6.0 software application of Merino and Livia (2009) was used. To define the criteria for elimination or modification, the of Aikens's V coefficient (Aiken, 1985) was applied. A critical level of Aikens's V was established to reject the

TABLE 4 | List of variables and categories related with the game that make up the observational instrument after the first two phases.

VARIABLE	CATEGORIES	
Type of serve*	• 1st serve	• 2nd serve
Serve bounce area*	• Wide area of deuce side • Body area of deuce side • T area of deuce side • T area of advantage side • Body area of advantage side • Wide area of advantage side • Net error • Out of service line • Out of right singles sidelines on deuce side (view of receiver player)	• Out of center service line on deuce side (view of receiver player) • Out of left singles sidelines on advantage side (view of receiver player) • Out of center service line on advantage side (view of receiver player)
Serve effectiveness*	• Ace • Inside the service box and intercepted by the opponent	• Error
Type of stroke used by receiver player in the return, serve player after the service, receiver player after the return and penultimate and latest stroke of the point**	• Forehand ground stroke • Two hands backhand ground stroke • One hand backhand ground stroke • Forehand volley • Backhand volley • Smash • Forehand aproach • Two hands backhand approach • One hand backhand approach • Forehand Passing • Two hands backhand passing • One hand backhand passing • Forehand lob • Two hands backhand lob	• One hand backhand lob • Forehand drop • Two hands backhand drop • One hand backhand drop • Forehand counter drop • Two hands backhand counter drop • One hand backhand counter drop • Forehand half volley • Two hands backhand half volley • One hand backhand half volley • Others
Hitting area of the return, first stroke of serve player after the service, first stroke of the receiver player after the return and penultimate and latest stroke of the point**	• Behind at more than 1 m away from the baseline in the central area (+1 m) • Behind at more than 1m away from the baseline in the right area (+1 m) • Behind at more than 1 m away from the baseline baseline in the left area (+1 m) • Behind at <1 m away from the baseline in the central area (−1 m) • Behind at <1 m away from the baseline in the right area (−1 m) • Behind at <1 m away from the baseline in the left area (−1 m)	• Inside the court and behind of serve line in the central area • Inside the court and behind of serve line in the right area • Inside the court and behind of serve line in the left area • Between the service line and the net in the central area • Between the service line and the net in the right area • Between the service line and the net in the left area
Bounce area of the return, first stroke of serve player after the service, first stroke of the receiver player after the return and penultimate and latest stroke of the point** (view of the player who executes)	• The opponent hit the ball without previous bounce • Central area between net and service line • Right area between net and service line • Left area between net and service line • Central area from behind of service line until 2.74 m of baseline • Right area from behind of service line until 2.74 m of baseline	• Left area from behind of service line until 2.74 m of baseline • Central area from baseline until 2.74 m of it inside the court • Right area from baseline until 2.74 m of it inside the court • Left area from baseline until 2.74 m of it inside the court • Net error • Out of baseline • Out of right singles or dobles sideline • Out of left singles or dobles sideline
Effectiveness of return, first stroke of serve player after the service, first stroke of the receiver player after the return and penultimate and latest stroke of the point**	• Winner • Transition stroke	• Error

**Suggested behaviors in the review of the scientific literature (Phase 1), **Behaviors suggested by experts (Phase 1).*

null hypothesis, obtaining a value of 0.70 ($p = 0.05$) and 0.81 ($p = 0.01$). From these values, it was decided to eliminate the items with values lower than 0.70 and to modify the items with values between 0.70 and 0.81. The items with higher values than 0.81 were maintained. Likewise, it was considered as a minimum value for inclusion that at least 80% of the expert judges answered yes, in the inclusion question.

After the modifications made in phase three, in the fourth phase a new qualitative and quantitative analysis of the instrument was carried out to another 10 experts, who fulfilled identical characteristics to the previous ones, not repeating in any case. A descriptive analysis of all the variables (mean, median, mode, and frequencies) was carried out and the validity of the content was calculated by means of an of Aikens's V coefficient (Penfield and Giacobbi, 2004). Finally, a new and definitive list of variables and categories was created that led to the writing of the observation instrument ("Observation instrument for singles tennis" see **Supplementary Data Sheet 1**) that included the variables under study and their definition, together with all the categories that were grouped in each of them, their definitions and coding.

In the fifth phase the reliability of the instrument was tested, as it was done in other studies (Villarejo et al., 2014; Gamonales et al., 2018). Following the criteria of Anguera (2003) and Losada and Manolov (2015), three observers received a training led by the principal investigator consisting of three sessions of 2 h each with a break of 10 min once they reached the 55 from the observation. To do so, the observation manual designed in the fourth phase was used. To assess the reliability, three experts (graduates in Physical Activity and Sports Sciences and federated tennis coaches) evaluated each of them, twice, separated by a week, two sets of two men's tennis matches. For the inter-observer and intra-observer calculation Cohen's Kappa coefficient was used, recording the lowest value.

Last but not least, it's necessary to develop the protocol for the correct use of the instrument. In the first place, the view of the observer must be made behind from any baseline of the tennis court in an elevated position, which allows watching clearly all the lines (the minimum height would be above the head of the players). If the video recording is made using a video camera, the previous guidelines will be followed. The collection of observational data in relation to the variables of the bounce area and hitting area will be done according to the zones indicated in the fields of Supplementary Data Sheet 1.

The data will be recorded by means of an Excel spreadsheet previously designed, where each row is a stroke to observe the previous action of the adversary, the action of the player and the consequence of his stroke on the adversary, which will perform another action in response (see Figure 1). The objective of this record mode is to know the sequence of strokes in the interaction between player and opponent.

In order to optimize the recording time of all the variables and their categories, the order will be explained below at a temporal level: (a) variables to record each stroke [RESULTS (Game scoreboard and Winner or loser of the analyzed point) and Game development (Stroke sequence Kind of technical-tactical stroke, Bounce area Hitting area, and Stroke effectiveness)]; (b) variables to register each game [RESULTS (Games won on the set and Lost games on the set)]; (c) Variables to register each set [RESULTS (Analyzed set, Sets won, Sets lost, and Winner or loser of the analyzed set)]; (c) Variables to analyze each match [CONTEXTUAL (Gender of the players, Tournament level, Type of tournament, Tournament round, Game mode, Court surface, Laterality of the players, and Type of backhand) RESULTS (Winner or loser of the match)]

In Supplementary Data Sheet 1 you can see the definition of all variables, and all categories in detail.

TABLE 5 | Final list of variables and contextual categories that make up the observational instrument.

VARIABLE	CATEGORIES	
Gender of the players*	• Male • Female	• Mixed
Tournament level*	• Professional tournament • Semi- Professional tournament • National Tournament • Regional Tournament	• Local Tournament • Amateur Tournament • Amateur Tennis
Type of tournament*	• Copa Masters • Grand Slam • Premier Mandatory • Master 1,000/Premier 5 • ATP 500/Premier • ATP 250/WTA Internacional • Challengers • Futures	• ITF Circuit • National Championship • Regional Championship • Local Championship • Federated tournament • Unfederated tournament • Others
Tournament round**	• Round robin • Final • Semifinal • Quarter finals • Best sixteen	• Best 32 • Best 64 • Best 128 • Others
Game mode*	• Best of 5 sets with Tie-Break in the 5th set • Best of 5 sets without Tie-Break in the 5th set • Best of 3 sets • Two sets and Super Tie-Break if each of the players wins a set	• Two sets of 4 games and Super Tie-Break if each of the players wins a set • One Set of 4 games and Tie Break if each of the players wins 4 games • Others
Court surface*	• Hard court • Clay court • Grass court	• Indoor carpet • Others
Laterality of the players*	• Right handed	• Left handed
Type of backhand*	• One hand backhand	• Two hands backhand

*Behaviors selected after the first and second phase, **Behaviors suggested by experts (Phase 3 and 4).*

RESULTS

The results corresponding to the design of the observational instrument after the first two phases (review of the scientific literature, pilot study, and review of the first group of experts), can be seen in **Tables 2–4**. All the variables related to the game were established according to the suggestions of the researchers and previous studies and were the starting point to build the structure of the instrument.

After the first two phases, the list of variables that formed the observational instrument consisted of 38, 8 of which corresponded to contextual variables (7 suggested by the scientific literature and 1 by the experts), 7 to variables related to the result of the meeting (3 suggested by the scientific literature, 2 by the experts, and 2 included after the observational pilot study) and 23 to variables related to the game (3 suggested by the scientific literature and 20 by the experts).

TABLE 6 | Final list of variables and categories related with the result of the match that make up the observational instrument.

VARIABLE	CATEGORIES	
Winner or loser of the match*	• Winner	• Loser
Analyzed set**	• 1st set • 2nd set • 3rd set • 4th set	• 5th set • Tie Break • Super Tie Break
Sets won**	• One set won	• Two sets won
Sets lost**	• One set lost	• Two sets lost
Winner or loser of the analysed set**	• Winner of the set	• Loser of the set
Games won on the set*	• One game won • Two games won • Three games won	• Four games won • Five games won • Six games won
Lost games on the set*	• One game lost • Two games lost • Three games lost	• Four games lost • Five games lost • Six games lost
Winner or loser of the game **	• Winner of the game	• Loser of the game
Game score*	• 0/0 • 15/0 • 0/15 • 15/15 • 30/15 • 15/30 • 30/30 • 40/30 • 30/40 • 40/40	• AD/40 • 40/AD • 30/0 • 40/0 • 0/30 • 0/40 • 40/15 • 15/40 • Tie-break point* • Super Tie-break point*
Winner or loser of the analyzed point*	• Winner of the point	• Loser of the point

*Behaviors selected after the first and second phase, **Behaviors suggested by experts (Phase 3 and 4).*

In the third phase, a second group of experts ($n = 10$) made a new evaluation and there were a total of 10 modifications, 2 for new behaviors included and 8 for modifications in the existing ones. Of all of them, 1 corresponded to the variables related to the context, 4 to the results, and 5 to those that had to do with the game. The changes or modifications were made by low of Aikens's V values, and because <80% of the expert judges answered affirmatively that the variable should be included.

The main change was based on the sequence of the stroke and the kind of technical-tactical stroke. At first, the experts proposed analysing only the serve, return, serve player after the service, receiver player after the return, and penultimate and latest stroke of the point. From each of them analyzed their different types of strokes. Later on, the new expert judges proposed to analyse all the strokes, and replaced the moment of stroke variable (temporal sequence and type of stroke), by two variables: (a) the sequence variable of stroke; and (b) the kind of technical-tactical stroke, they change a single variable with many categories (moment of stroke), by two new variables with fewer categories.

In the fourth phase, after the modifications made in the previous phase, the new list was evaluated quantitatively and qualitatively by a third group of experts ($n = 10$). The Aikens's V values corresponding to said evaluation can be observed in **Tables 5–7**. The final list was composed of 23 variables, 8 contextual variables, 10 of result, and 5 of game (**Tables 5–7**). For it, it was considered that all those variables that had a value ≥ 0.81 of the Aikens's V were suitable to be part of the instrument (**Table 8**). In all cases, 100% of the expert judges answered affirmatively that the variable should be included.

The data from the fifth phase showed high reliability values, as it can be seen in **Table 8**, the lowest value was found in the stroking zone variable (0.81).

DISCUSSION

The study carried out shows all the phases that have been necessary to design, validate, and test the confidence of the observational instrument that analyses the technical-tactical actions in the singles tennis. The procedure has required an updated review of the literature, a pilot study, the training of the observers, and the participation of a large number of experts (Villarejo et al., 2014; Anguera and Hernández-Mendo, 2015; Serra-Olivares and García-López, 2016). The procedure followed has been very similar to that used by Villarejo et al. (2014) in rugby, Palao et al. (2015) for beach volleyball, although it differs from that of Gorospe et al. (2005); James et al. (2005), or Jones et al. (2008), mainly due to the type of participation of the experts and the pilot study.

The pilot study allowed defining, specifying, and adapting the initial list of behaviors to the real competition situation (Anguera, 2003; Anguera and Hernández-Mendo, 2015). Later on, the first observation allowed to verify the frequency of appearance of the behaviors proposed by the first group of experts, to eliminate or include in other categories those that showed little frequency of occurrence and incorporate those observed that were not initially included.

The experts have helped to significantly improve the instrument through: (a) inclusion of new specific behaviors of the game; and (b) improve and clarify the definitions of the variables and their relevance to the different categories (Mills et al., 2012). Both contributions at a qualitative level have definitely been decisive in designing and validating the instrument. It has gone from 38 initial variables of the provisional list designed by the researchers, experts and observer (8 contextual, 7 of result, and 23 of game) to 23 final variables (8 contextual, 10 of result, and 5 of the game). On the other hand, the observers have also played an important role, since once their training process has ended, they have helped to specify the criteria by which the different categories are distinguished and their contribution has simplified the registration instrument.

Different groups of experts have been used in the design and validation of the instrument. A total number of four observers and 23 experts have participated. The number of expert judges, despite being a specific observation instrument for a single sport, is much higher than those used in similar studies (Villarejo et al., 2014; García et al., 2016; Chacón-Moscoso et al., 2018; Gamonales et al., 2018). These high values provide a high

TABLE 7 | Final list of variables and categories related with the development of the game that make up the observational instrument.

VARIABLE	CATEGORIES	
Stroke sequence**	• Serve • Return • 3rd stroke of the point	• 4th stroke of the point, 5th stroke of the point… • Penultimate stroke of the point • Last stroke of the point
Kind of technical and tactical stroke**	*Category of basic strokes:* • 1st serve • 2nd serve • Forehand ground stroke • Two hands backhand ground stroke	• One hand backhand ground stroke • Forehand volley • Backhand volley • Smash
	Category of especial strokes: • Forehand lob • Two hands backhand lob • One hand backhand lob • Forehand lob return • Two hands backhand lob return • One hand backhand lob return • Forehand drop	• Two hands backhand drop • One hand backhand drop • Forehand half volley • Two hands backhand half volley • One hand backhand half volley
	Category of situation strokes: • Forehand approach Two hands backhand approach One hand backhand approach • Forehand counter drop • Two hands backhand counter drop • One hand backhand counter drop Forehand Passing	Two hands backhand passing One hand backhand passing • Forehand return • Two hands backhand return • One hand backhand return • Forehand drop return • Two hands backhand drop return • One hand backhand drop return • Forehand return approach • Two hands backhand return approach • One hand backhand return approach • Forehand passing of return • Two hands backhand passing of return • One hand backhand passing of return • Others
Bounce area **	Category of bounce area for the serve*: • Wide area of deuce side • Body area of deuce side • T area of deuce side • T area of advantage side • Body area of advantage side • Wide area of advantage side • Net error	• Out of service line • Out of right singles sidelines on deuce side (view of receiver player) • Out of center service line on deuce side (view of receiver player) • Out of left singles sidelines on advantage side (view of receiver player) • Out of center service line on advantage side (view of receiver player)
	Category of bounce area for return, third stroke, fourth stroke penultimate and last stroke **: The opponent hit the ball without previous bounce Central area between net and service line Right area between net and service line Left area between net and service line Central area from behind of service line until 2.74 m of baseline • Right area from behind of service line until 2.74 m of baseline	• Left area from behind of service line until 2,74 m of baseline Central area from baseline until 2.74 m of it inside the court Right area from baseline until 2.74 m of it inside the court Left area from baseline until 2.74 m of it inside the court • Net error • Out of baseline • Out of right singles sideline • Out of left singles sideline
Hitting area** (view of player who executes the stroke)	• Behind from the baseline in the central area • Behind from the baseline in the right area • Behind from the baseline in the left area • Inside the court and behind of serve line in the central area	• Inside the court and behind of serve line in the right area • Inside the court and behind of serve line in the left area • Between the service line and the net in the central area • Between the service line and the net in the right area • Between the service line and the net in the left area
Stroke effectiveness**	• Ace • Winner • Transition stroke**	• Previous stroke of an opponent error** • Error

**Behaviours selected after the first and second phase, **Behaviors suggested by experts (Phase 3 and 4).*

consistency in the content validity of the observation instrument. In this sense, the high qualification of the different expert judges stands out, following all of them the three criteria of inclusion: graduates in Sports Sciences and Sport, with federated degree as coaches and with more than 10 years of experience as trainers. This high training has allowed them to provide theoretical, but

TABLE 8 | Values of pertinence, definition (Aiken's V) and reliability (Cohen's kappa) of definitive variables and categories of the observational instrument.

Variables	Pertinence (V Aiken)	Definition (V Aiken)	Reliability Inter-Observer (Cohen's kappa)	Reliability Intra-Observer (Cohen's kappa)
CONTEXTUAL				
Gender of the players	1	1	1	1
Tournament level	0.97	0.97	1	1
Type of tournament	0.96	0.96	1	1
Tournament round	0.96	0.96	1	1
Game mode	0.99	0.99	1	1
Court surface	0.97	0.97	1	1
Laterality of the players	0.99	0.99	1	1
Type of backhand	0.98	0.98	1	1
RESULT				
Winner or loser of the match	0.98	0.95		
Analyzed set	0.94	0.94	1	1
Sets won	0.99	0.94	1	1
Sets lost	1	0.96	1	1
Winner or loser of the analyzed set	0.99	0.97	1	1
Games won on the set	0.99	0.97	1	1
Lost games on the set	0.99	0.97	1	1
Game scoreboard	1	0.95	1	1
Winner or loser of the analyzed point	0.99	0.99	1	1
GAME DEVELOPMENT				
Stroke sequence			1	1
Kind of technico-tactical stroke	0.97	0.95	0.9	1
Bounce area	0.96	0.94	0.86	0.9
Hitting area	0.97	0.95	0.81	0.9
Stroke effectiveness	0.96	0.97	1	1

especially practical knowledge, of their sport experiences. Their quantitative and qualitative contributions have been the basis for the design of this instrument.

Finally, with respect to the expert judges, it is remarkable that the different expert judges have been participating in different phases, without any expert judge repeating in any of the phases. So it could be noted that there have been three panels of expert judges. The first panel of expert judges was formed by the first three experts who initially designed the instrument, the second panel was composed of 10 other experts who contributed the first modifications; and finally, a third panel formed by 10 other experts who have ratified the previous proposals. During the whole process there has been no communication between the different panels, but they have been acting one after another (in cascade process). This has allowed them to act with total independence (Escobar-Pérez and Cuervo-Martínez, 2008; Kimberlin and interstein, 2008; Drost, 2011).

At the statistical level, it is demonstrated that the instrument is prepared to measure the technical-tactical behaviors in singles tennis, and the Aiken's V values show a positive evaluation of the content of the different items (Gómez et al., 2014; Zartha et al., 2018). The values of the quantitative evaluation contributed by the third group of experts were superior in all cases to the value of 0.81, so no new modification had to be made. The fact that a large number of experts have participated in the design of the observation instrument, together with the statistical treatment and the pilot study, has minimized the subjective opinion of the coaches on how they understand the game.

The possibility of establishing a link between previous and subsequent actions (Reid et al., 2016), as in the case of the return, serve player after the service, receiver player after the return and penultimate and latest stroke of the point, allows knowing how the game is conditioned and affects the result of the point.

Observers training increased the effectiveness of the observation and improved the coding criteria. The level of agreement between observers (inter and intra observer), allowed to affirm that the observation carried out is reliable (Liu et al., 2013). The observation manual carried out helped the observers, to acquire the necessary skills to carry out the observation (Losada and Manolov, 2015).

The design of the instrument has some limitations, as it only analyses the position of the player who is in the hitting phase, but not the one of the player who is in the waiting phase. This information could be useful and influence the decision of the player who is about to impact the ball, since as Lebed (2006) states, the behaviors in sport are influenced by an infinite number of factors. Due to the complexity of this system, it is difficult to apply collection information systems with the aim of assessing players' performance in competition (Villarejo et al., 2014). Besides, the instrument does not record data about the game or rest times or about physical components, such as the number or direction of the displacements. However, and under our knowledge, this tool will greatly facilitate the work of researchers and coaches, becoming a valid instrument to assess technical-tactical actions in a sport such as singles tennis.

CONCLUSIONS

Therefore, the instrument designed is valid to analyse from a technical-tactical perspective the service, return, strokes in the middle of rally, penultimate and latest stroke of the point. In this way it is possible to check the possible relationships between them and with respect to the result of the point, thus assessing the differences that may exist between winners and losers.

PRACTICAL APPLICATIONS

This information can be used by players and coaches to evaluate their own actions and their opponents from a technical-tactical perspective. This would help to increase performance through: (a) the improvement of training programs aimed at the specific improvement of technical-tactical skills; and (b) the analysis of the technical-tactical qualities of the rivals.

ETHICS STATEMENT

This study respected the ethical principles established by the UNESCO Declaration on Bioethics and Human Rights. The parents or guardians of the players were informed of the study and gave their written consent in accordance with the Declaration of Helsinki. The study was approved by the Ethics Committee of University of Murcia (Spain) with ID 1925/2018.

AUTHOR CONTRIBUTIONS

GT-L, and EO-T contributed with the conception and design of the study. AF-G and DC-M organized the database. JG-E and EO-T performed the statistical analysis. EO-T, GT-L, AF-G wrote the first draft of the manuscript. JG-E, DC-M, GT-L, and EO-T wrote sections of the manuscript. All the authors contributed to the revisión of the manuscript, and read and approved the presented version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.02418/full#supplementary-material

REFERENCES

Aiken, L. R. (1980). Content validity and reliability of single items or questionnaires. *Educ. Psychol. Meas.* 40, 955–959. doi: 10.1177/001316448004000419

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educ. Psychol. Meas.* 45, 131–142.

Anguera, M. T. (2003). Observational methods (general). *Encyclopedia Psychol. Assess*. 2, 632–637. doi: 10.4135/9780857025753.n136

Anguera, M. T., Blanco, A., Hernandez-Mendo, A., and Losada, J. L. (2011). Diseños observacionales: ajuste y aplicación en psicología del deporte. *Cuadernos de Psicol. del Deporte* 11, 63–76.

Anguera, M. T., and Hernández-Mendo, A. (2015). Técnicas de análisis en estudios observacionales en ciencias del deporte. *Cuadernos de psicol. del Deporte* 15, 13–30. doi: 10.4321/S1578-84232015000100002

Chacón-Moscoso, S., Sanduvete-Chaves, S., Anguera, M. T., Losada, J. L., Portell, M., and Lozano-Lozano, J. A. (2018). Preliminary checklist for reporting observational studies in sports areas: content validity. *Front. Psychol.* 9:291. doi: 10.3389/fpsyg.2018.00291

Cross, R., and Pollard, G. (2011). El tenis en los Grand Slams individuales de varones entre 1995 y 2009. Parte 2: Puntos, Juegos y Sets. *Coaching Sport Sci. Rev*. 19, 3–6.

Cui, Y., Gómez, M. Á., Gonçalves, B., and Sampaio, J. (2018). Performance profiles of professional female tennis players in grand slams. *PLoS ONE* 13:e0200591. doi: 10.1371/journal.pone.0200591

Djurovic, N., Lozovina, V., and Pavicic, L. (2009). Evaluation of tennis match data-new acquisition model. *J. Hum. Kinet.* 21, 15–21. doi: 10.2478/v10078-09-0002-9

Drost, E. A. (2011). Validity and reliability in social science research. *Educ. Res. Perspect.* 38, 105–121.

Escobar-Pérez, J., and Cuervo-Martínez, A. (2008). Validez de contenido y juicio de expertos: una aproximación a su utilización. *Avd. Med*. 6, 27–36.

Figueira, B., Gonçalves, B., Folgado, H., Masiulis, N., Calleja-González, J., and Sampaio, J. (2018). Accuracy of a basketball indoor tracking system based on standard bluetooth low energy channels (NBN23®). *Sensors* 18:E1940. doi: 10.3390/s18061940

Gamonales, J. M., León, K., Muñoz, J., González-Espinosa, S., and e Ibáñez, S. J. (2018).Validation of the IOLF5C Instrument for the Efficacy of Shooting on Goal in Football for the Blind. *Rev. Int.Med. Ciencias Actividad Física Dep*. 18, 361–381. doi: 10.15366/rimcafd2018.70.010

García, A., Antúnez, A., and Ibáñez, S. J. (2016). Analysis of expert players' training process: validation of tools. *Rev. Int. Med. Ciencias Actividad Física Dep*. 16 157–182. doi: 10.15366/rimcafd2016.61.012

Gillet, E., Leroy, D., Thouvarecq, R., and Stein, J.-F. (2009). A notationalal analysis of elite tennis serve and serve-return strategies on slow surface. *J. Strength Cond. Res*. 23, 532–539. doi: 10.1519/JSC.0b013e31818efe29

Gómez, P., Ortega, E., Contreras, O. R., Olmedilla, A., and Sainz de Baranda, P. (2014). Diseño y validación de un cuestionario sobre la percepción del deportista respecto a su reincorporación al entrenamiento tras una lesión. *Rev. Psicol. Dep*. 23, 479–487.

Gorospe, G., Hernández-Mendo, A., Anguera, M. T., and Martínez de Santos, R. (2005). Desarrollo y optimización de una herramienta observacional en el tenis de individuales. *Psicothema* 17, 123–127.

Hizan, H., Whipp, P., and Reid, M. (2011). Comparison of serve and serve return statistics of high performance male and female tennis players from different age-groups. *Int. J. Perform. Anal. Sport* 11, 365–375. doi: 10.1080/24748668.2011.11868556

Hughes, M., Cooper, S.-M., and Nevill, A. (2002). Analysis procedures for non-parametric data from performance analysis. *J. Perform. Anal. Sport* 2, 6–20. doi: 10.1080/24748668.2002.11868257

James, N., Mellalieu, S., and Jones, N. (2005). The development of position-specific performance indicators in professional rugby union. *J. Sports Sci.* 23, 63–72. doi: 10.1080/02640410410001730106

Jones, N. M., James, N., and Mellalieu, S. D. (2008). An objective method for depicting team performance in elite professional rugby union. *J. Sports Sci.* 26, 691–700. doi: 10.1080/02640410701815170

Katić, R., Milat, S., Zagorac, N., and urović, N. (2011). Impact of game elements on tennis match outcome in Wimbledon and Roland Garros 2009. *Coll. Antropol.* 35, 341–346.

Kimberlin, C. L., and interstein, A. G. (2008). Validity and reliability of measurement instruments used in research. *Am. J. Health-Syst. Pharm*. 65, 2276–2284. doi: 10.2146/ajhp070364

Kinrade, N. P., Jackson, R. C., Ashford, K. J., and Bishop, D. T. (2010). Development and validation of the decision-specific reinvestment scale. *J. Sports Sci.* 28, 1127–1135. doi: 10.1080/02640414.2010.499439

Larkin, P., O'Connor, D., and Williams, A. M. (2016). Establishing validity and reliability of a movement awareness and technical skill (MATS) analysis instrument in soccer. *Int. J. Perform. Anal. Sport* 16, 191–202. doi: 10.1080/24748668.2016.11868880

Lebed, F. (2006). System approach to games and competitive playing. *Eur. J. Sport Sci.* 6, 33–42. doi: 10.1080/17461390500422820

Liu, H., Hopkins, W., Gómez, A. M., and Molinuevo, S. J. (2013). Inter-operator reliability of live football match statistics from OPTA Sportsdata. *Int. J. Perform. Anal. Sport* 13, 803–821. doi: 10.1080/24748668.2013.11868690

Losada, J. L., and Manolov, R. (2015). The process of basic training, applied training, maintaining the performance of an observer. *Qual. Quantity* 49, 339–347. doi: 10.1007/s11135-014-9989-7

Maneiro, R., Amatria, M., Moral, J. E., and Lopez, A. (2018). Análisis observacional de las relaciones interlíneas de la Selección Española de Fútbol, mediante coordenadas polares. *Cuadernos Psicol. Dep*. 18, 18–32.

Martin, C., Bideau, B., Delamarche, P., and Kulpa, R. (2016). Influence of a prolonged tennis match play on serve biomechanics. *PLoS ONE* 11:e0159979. doi: 10.1371/journal.pone.0159979

Martínez-Gallego, R., Guzmán, J. F., James, N., Pers, J., Ramón-Llin, J., and Vuckovic, G. (2013). Movement characteristics of elite tennis players on hard courts with respect to the direction of ground strokes. *J. Sports Sci. Med.* 12, 275–281.

Mateus, N., Leite, N., and Sampaio, J. (2017). Team sports in special groups and the use of technology: a review. *Motricidade* 13:221.

Merino, C., and Livia, J. (2009). Intervalos de confianza asimétricos para el índice la validez de contenido: un programa visual basic para la V de Aiken. *Anales psicol*. 25, 169–171.

Mills, A., Butt, J., Maynard, I., and Hardwood, C. (2012). Identifying factors perceived to influence the development of elite youth football academy players. *J. Sport Sci*. 30, 1593–1604. doi: 10.1080/02640414.2012.710753

Moreno, E., and Gómez-Ruano, M. A. (2017). Validación herramienta observacional para el análisis de rachas de lanzamiento en baloncesto. *Rev. Psicol. Dep*. 26, 87–93.

Morillo, J. P., Reigal, R. E., Hernández-Mendo, A., Montaña, A., and Morales-Sánchez, V. (2017). Decision-making by handball referees: design of an ad hoc observation instrument and polar coordinate analysis. *Front. Psychol.* 8:1842. doi: 10.3389/fpsyg.2017.01842

O'Donoghue, P., and Ingram, B. (2001). A notationalal analysis of elite tennis strategy. *J. Sports Sci.* 19, 107–115. doi: 10.1080/026404101300036299

Over, S., and O'Donoghue, P. (2010). Analysis of strategy and tactics in tennis. *Int. Tennis Fed. Coach. Sport Sci. Rev*. 50, 15–16.

Palao, J. M., Manzanares, P., and Ortega, E. (2015). Design and validation of an observational instrument for technical and tactical actions in beach volleyball. *Motriz* 21, 137–147. doi: 10.1590/S1980-65742015000200004

Penfield, R. D., and Giacobbi, J. (2004). Applying a score confidence interval to Aiken's item content-relevance index. *Meas. Phys. Educ. Exerc. Sci.* 8, 213–225. doi: 10.1207/s15327841mpee0804_3

Pereira, T. J. C., Nakamura, F. Y., de Jesus, M. T., Vieira, C. L. R., Misuta, M. S., de Barros, R. M. L., et al. (2017). Analysis of the distances covered and technical actions performed by professional tennis players during official matches. *J. Sports Sci.* 35, 361–368. doi: 10.1080/02640414.2016.1165858

Reid, M., Morgan, S., and Whiteside, D. (2016). Matchplay characteristics of Grand Slam tennis: implications for training and conditioning. *J. Sports Sci.* 34, 1791–1798. doi: 10.1080/02640414.2016.1139161

Sainz De Baranda, P., Ortega, E., and Palao, J. M. (2008). Analysis of goalkeepers' defence in the World Cup in Korea and Japan in 2002. *Eur. J. Sport Sci.* 8, 127–134. doi: 10.1080/17461390801919045

Serra-Olivares, J., and García-López, L. M. (2016). Design and validation of the soccer tactical knowledge test (STKT). *Rev Int. Med. Ci. Actividad Física Dep.* 16, 521–536. doi: 10.15366/rimcafd2016.63.008

Villarejo, D., Ortega, E., Gómez, M. Á., and Palao, J. M. (2014). Design, validation, and reliability of an observational instrument for ball possessions in rugby union. *Int. J. Perform. Anal. Sport* 14, 955–967. doi: 10.1080/24748668.2014.11868771

Zartha, J. W., Montes, J. M., Vargas, E. E., Palacio, J. C., Hernández, R., and Hoyos, J. L. (2018). Methods and techniques in studies related to the delphi method, innovation strategy, and innovation management models. *Int. J. Appl. Eng. Res*. 13, 9207–9214.

Zhang, S., Lorenzo, A., Gómez, M. A., Mateus, N., Gonçalves, B., and Sampaio, J. (2018). Clustering performances in the NBA according to players' anthropometric attributes and playing experience. *J. Sports Sci.* 36, 2511–2520. doi: 10.1080/02640414.2018.1466493

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Data-Driven Visual Performance Analysis in Soccer: An Exploratory Prototype

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In soccer, understanding of collective tactical behavior has become an integral part in sports analysis at elite levels. Evolution of technology allows collection of increasingly larger and more specific data sets related to sport activities in cost-effective and accessible manner. All this information is minutely scrutinized by thousands of analysts around the globe in search of answers that can in the long-term help increase the performance of individuals or teams in their respective competitions. As the volume of data increases in size, so does the complexity of the problem and the need for suitable tools that leverage the cognitive load involved in the investigation. It is proven that visualization and computer-vision techniques, correctly applied to the context of a problem, help data analysts focus on the relevant information at each stage of the process, and generally lead to a better understanding of the facts that lie behind the data. In the current study, we presented a software prototype capable of assisting researchers and performance analysts in their duty of studying group collective behavior in soccer games and trainings. We used geospatial data acquired from a professional match to demonstrate its capabilities in two different case studies. Furthermore, we successfully proved the efficiency of the different visualization techniques implemented in the prototype and demonstrated how visual analysis can effectively improve some of the basic tasks employed by sports experts on their daily work, complementing more traditional approaches.

Keywords: football association, visual analytics, performance analysis, information visualization, collective tactical behavior

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INTRODUCTION

Soccer performance is a multifactorial process requiring high-level interaction analysis within physiological, technical, and tactical performances. At the elite level, technical staffs need to capture, process, and analyze great amounts of data, in order to measure performance in their respective teams and opponents, as well as assess potential prospects. Recently, the time pressure of this process and the constant increase in the amount of available data has demanded for a major emphasis in the visualization methods. In fact, technical staffs are nowadays expected to capture, process, analyze, and visualize data to provide fast assimilated information for coaching purposes. Current technology allows capturing data from players' positions, either in competition or training scenarios, with very acceptable degrees of accuracy. These technological advances can use radio frequency systems (Frencken et al., 2010), semi-automated computer vision systems (Di Salvo et al., 2006), or differential and non-differential GPS units (Varley et al., 2012). This GPS technology has contributed to change how performance analysis is carried out in outdoor and indoor team sports by providing objective and reliable data on player's activity. Technically, these systems use the earth-orbiting satellites that emit constant coded signals to track the position of a receiver (Larsson, 2003). Using the accurate positions from the receivers such systems can process real-time distance and speed. These measurement systems are portable and relatively less expensive when compared to any other systems. At the end of these processes, positional data containing the players' positions is obtained.

Research and practical applications resulting from positional data are much focused on the descriptions from the activity profiles, such as quantifying the physical and physiological demands of soccer players (Cummins et al., 2013; Abade et al., 2014). Although, these are certainly very important determinants of performance, recent research also focuses on describing collective tactical behavior aiming to reveal new insights and a better understanding of players' performances and soccer complexity (Gonçalves et al., 2014, 2018; Sampaio et al., 2014). There are several team and individual key variables suggested as key performance indicators to address the collective tactical behavior (Memmert et al., 2016). Nevertheless, their apparent utility is strongly diminished by the lack of any structured software tool capable of providing easy comprehension of such variables. In fact, data is usually processed using non-specific scientific-based software and therefore the task often becomes unbearable for soccer technical staffs. Sports analysis workflow requires tools and techniques that ideally would provide a way to effectively filter the data being analyzed on demand and display this data in a way that enhances the experts' analysis capabilities in the context of the problem. Under this scope, researchers could easily identify repeated patterns in the data over the course of a game and the global understanding of key events would be largely augmented.

PROBLEM DESCRIPTION

There is a great interest among Sports Science scholars in explaining how a group of players collectively perform at a given sports event. In the same way as it occurs in other areas of knowledge, researchers have turned their eyes to computers with the hope of obtaining valuable information that can help them to answer their particular research questions. As a consequence, computer-supported team tactics analysis is an emerging topic that has generated important publications in recent years. From a computational perspective, different authors have tried to explain collective behavior in sports employing diverse techniques such as statistical (Bialkowski et al., 2014), trajectory (Perin et al., 2013), or network analysis based on passes (Passos et al., 2011), among others—see (Gudmundsson and Horton, 2017) for a complete list. All these tools are specifically designed to capture and automate many of the tasks that are required to obtain satisfactory analyses and ensure a correct interaction between the analyst and the machine.

There are times however, when these techniques have not been implemented in an interactive application due perhaps to their novelty in the field. In these cases, the otherwise automated tasks must be manually performed by the analysts employing general-purpose scientific software such as *Matlab* or *Mathematica,* where the algorithms at play are run. The results of these algorithms are then captured in static charts, graphs, or pieces of text which can be crossed with other information that is available to the analyst such as in-game video recordings in order to form hypotheses. Using this new knowledge, the analyst may vary the input data (e.g., the players' positional data, analyzed period of time) and specific parameters of the algorithms and rerun the computations. He or she will repeat this procedure as many times as necessary in a series of progressive refinements until enough evidence to support or refuse a hypothesis has been found.

When these series of informational exchanges between the human and the computer have not been optimized, the whole process may become highly time-consuming, inefficient and frustrating for the user as some authors have pointed out in the past (Nielsen, 1993).

To the best of our knowledge, there are no examples of interactive tools in the literature that make use of movement patterns and complex inter-player coordination metrics to explain collective tactical behavior in soccer games (Sampaio and Maçãs, 2012). Therefore, our proposal tries to fill that void by offering the analyst an interactive dashboard that (a) exposes physical and inter-player metrics in a visual manner to the final user, (b) enables a spatiotemporal and multivariate analysis of the game and (c) generally reduces the cognitive load of the analysis task by ensuring an adequate interaction with the computer. Unlike other alternatives, our approach does not rely on the ball's position and therefore we did not consider it in our study, although we are aware of its usefulness in the analysis and therefore we plan to introduce it in further developments (we refer the reader to the final section for a full list of future lines of research).

KEY METRICS

The dynamic variables employed in the pilot tool and that serve as a basis for the expert analysis task are outlined in this section. Firstly, we present those regarding the collective aspect of the game, (i.e., they measure characteristics of a group of players). Later in this section the individual variables affecting single players are introduced. These variables are considered secondary and are meant to support the more complex group analysis of the game.

Collective Analysis

Team Center

Also known as centroid, gravity center, or geometrical center. The centroid is the average position of the outfield players. It is calculated as the mean lateral and longitudinal position of all outfield players' coordinates at a specific time, each of them contributing equally to the computation (Sampaio and Maçãs, 2012; Folgado et al., 2014a; Gonçalves et al., 2014, 2016; Sampaio et al., 2014). Based on the mean point of players' locations, this variable captures oscillatory movements in a group of players such as movements toward or away from the goal lines or the sidelines (Duarte et al., 2012a,b). The centroid of the attacking team moves forward. The defending team tries to prevent the attacking team from scoring by moving backward. Thus, its centroid will move backward. It is employed to measure intra and inter team coordination in a group of players and it reveals important facts about team tactics and other valuable data for the analyst. The relative distance between opposing teams' centroid positions in the longitudinal direction (i.e., considering the distance to the goal) seems to be related to goal scoring opportunities (Frencken et al., 2011; Folgado et al., 2014b). From the centroid position of both teams three measures can be calculated: (i) distance to centroid, as measured by the absolute distance of each player to the geometric center of the team, plotted against time; (ii) distance to opponents' centroid, as measured by the absolute distance of each player from the geometric center of the opposite team, plotted against time; and (iii) distance between teams' centroids, as measured by the absolute distance between the geometric centers of the two teams plotted against time. **Figure 2** presents a group of four players with its association centroid and radial distances to it.

Team Dispersion

Among the parameters related to the expansion and contraction of a group of players in a time interval is also worth noting the **Stretch Index.** It is defined as the average radial distance of the players' positions to the team centroid (Frencken et al., 2011; Folgado et al., 2014b). This variable captures the synergistic counter-phase relation of contraction and expansion behaviors of teams as a function of exchanges in ball possession. First derivate of this measure may also evidence the speed at which teams stretch or shorten their dispersion on the field (Duarte et al., 2012b). Several studies have validated the Stretch Index as a revealing parameter to interpret the dynamics of team tactics (Duarte et al., 2013; Travassos et al., 2014).

Another popular measure of Team Dispersion is the ***effective playing space or surface area***, calculated as the area of a polygon drawn by linking the externally positioned player in each team's formation (Gonçalves et al., 2017a). This variable expresses the relation between the shapes and the occupied spaces of the two teams, and how they change over time. Overlapped areas can also be obtained. The Surface Area of a group of players provides valuable information to the analyst regarding the portion of the field that is being occupied by the team while attacking or defending and it is intimately linked to the concept of stretch index previously presented. Derived from the later it can be measured the **team spread** (Ric et al., 2016), a value defined as the maximum difference between players' positions in the longitudinal—**team length**—and transverse—**team width**—axes. The team length captures the compactness of the whole team and its variation as a function of changes in performance constraints. It can be used in the monitoring of specific reference values for team length, or to evaluate depth differences between teams. When in defense, the width of a team may reveal the potential for the opponents to find inner or outer spaces to penetrate. When attacking, it may indicate the lateral spread of the team.

Team Synchrony

Recent studies employed phase analysis to identify inter-player coordination (Folgado et al., 2014a, 2015, 2018; Gonçalves et al., 2017a). This is a signal processing statistic that describes synchronization in a non-linear manner, by providing a quantitative measure of coordination between 2 oscillators. The relative phase calculation is done by using a Hilbert transform and the obtained values are expressed in angles. The values close to 0° correspond to simultaneous patterns of coordination, often referred to as moving in-phase, whereas relative phase values close to 180° correspond to asynchronous patterns of coordination, often referred to as moving in anti-phase (Sampaio and Maçãs, 2012). As tactical training is often directed to achieve symmetrical movements between individuals in certain attacking or defending situations, it is commonly used as an estimation of the degree of assimilation of such training by the athletes. Related to this approach, *ApEn* is also employed in this type of analysis. *ApEn* can be used to identify regularity in players' movement patterns (Sampaio and Maçãs, 2012; Silva et al., 2016; Gonçalves et al., 2017b). This is an adequate statistic to analyze non-linear time series data that holds both deterministic chaotic and stochastic processes. The *ApEn* algorithm quantifies regularity in a time series, by measuring the logarithmic likelihood that runs from patterns that are close (within tolerance wide r) to m contiguous observations and remain close (with the same r) on subsequent incremental comparisons. The obtained values are unitless real numbers ranging from 0 to 2, with lower values corresponding to more repeatable sequences of data points (Pincus, 1991; Stergiou et al., 2004; Harbourne and Stergiou, 2009; Yentes et al., 2013)

Individual Analysis

It is frequent that players are responsible for specific pitch areas which they are supposed to control during the game, according to tactical schemes, game rules, and other constraints. Team behavior is an emergent result of many individual labors in interaction, each one performed in different parts of the game field and consequently, its analysis can be done in a geospatial manner. Heat maps suppose a simple yet useful way to visualize these phenomena, as several studies corroborate. As we will discuss in the next section, we use this technique to represent not only positional data for each player, but also changes in pace, which are of major importance in team sports.

PROPOSED WORKFLOW

According to the ideas introduced in section Problem Description, our visual analytics tool proposes an interactive workflow that seeks to accelerate current expert methodologies in the field and to assist the analyst in finding meaningful facts about group behavior contained in the positional data under study. There are two main operation modes for this workflow: In the first mode, the user starts with a known hypothesis that wants to validate (for example, the low level of synchronization between two defenders motivated a goal by the opposing team). In the second mode, the analyst explores the data without a previously known hypothesis and this hypothesis is formed

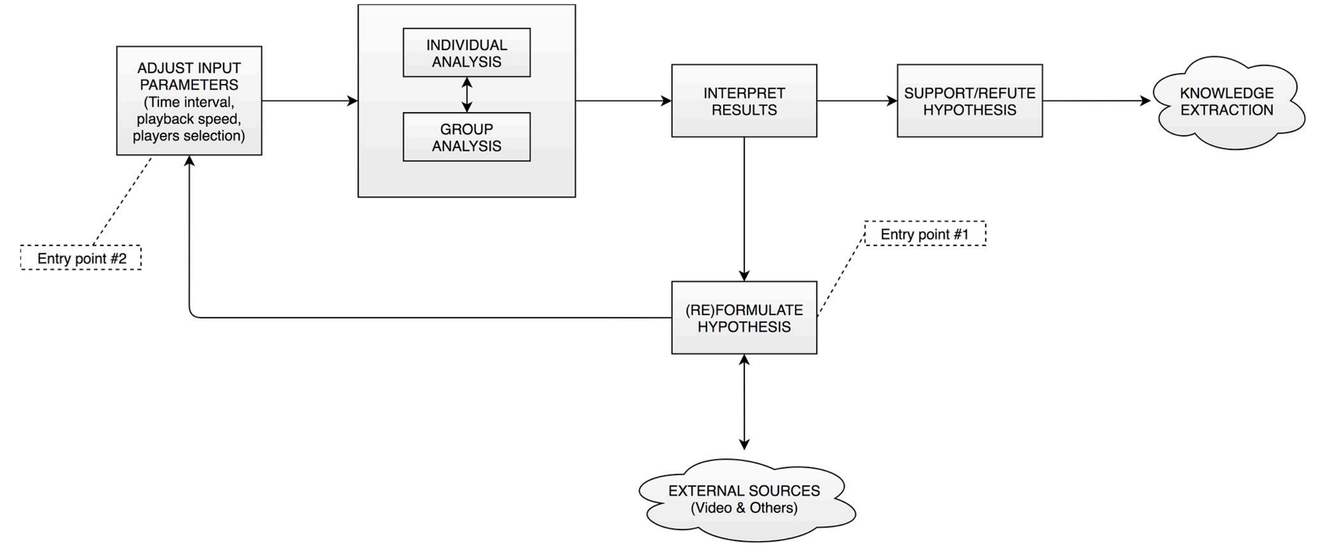

FIGURE 1 | Proposed workflow. The user starts the analysis tasks at either of the two entry points to the tool.

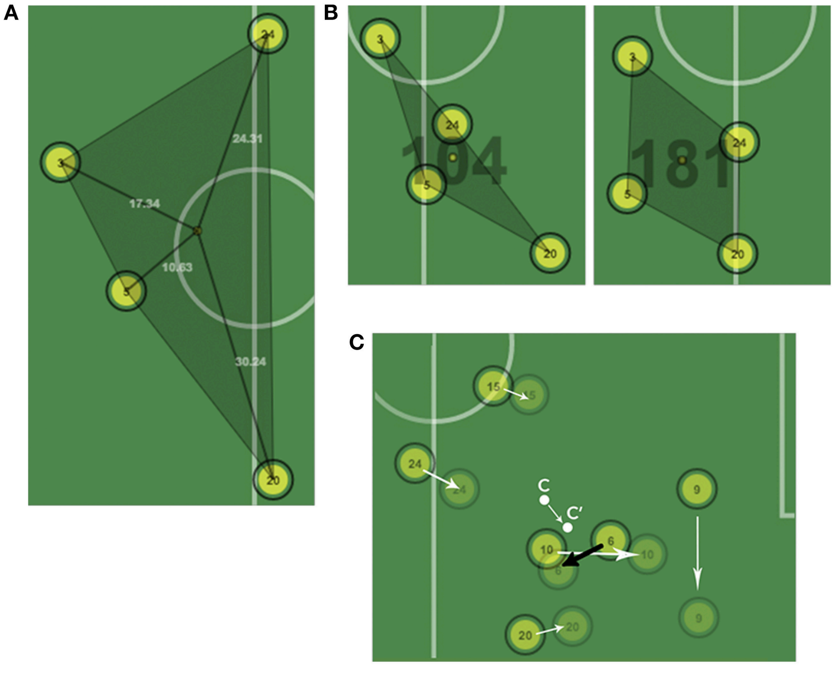

FIGURE 2 | (A) Centroid of a group of players with radial distances. **(B)** The same group of players captured at two different instants of the game. Despite being equally dispersed, the players on the right covered a larger effective playing space. **(C)** Intra-group coordination in a series of movements. Player number 6 performs in the opposite direction of his group.

once a particular event in the visualizations is spotted. (see **Figure 1** and explanation below).

Stage 1: Data Exploration

In this stage, the expert makes use of the application to identify key events in the game by measuring and comparing different multivariate attributes of an individual or a group of players. It starts by selecting the desired system configuration, which initially is based solely on expert knowledge and external resources (i.e., real in-game video and others). The selected interval can correspond to a whole period or to a specific section of interest (e.g., last 15 min). We have focused on analyzing the progression of attributes during a period of time and also on revealing significant variations of different variables to the analyst. Once evidence that supports a possible explanation of a key game event has been found, the analyst's attention is drawn to a specific slice of data (temporal interval, set of players, portion of the pitch). At this point of the workflow, a new set of key events and facts has been identified and the analyst can proceed to the second stage.

Stage 2: Hypothesis Validation

At this stage, the analyst acquires knowledge to update his or her set of hypotheses, which will serve as input for the first stage of the new iteration. The analyst then tunes the system using new settings according to the hypothesis he or she wants to test, this including time intervals (usually a sub-interval of the previously selected time interval), virtual player playback speed, combination of visualizations, and a selection of players. More feedback from external sources can be incorporated to help in the selection of the configuration parameters in the new iteration. Once the system has been configured, the data is filtered accordingly to reflect the analysts' mental model in the investigation process.

The visualizations employed in this second approach usually correspond to a higher level of granularity and are oriented to allow effective detection of subtle variations in the observed parameters. Once this process has been completed, the analyst starts a new iteration by exploring data using the system, in a continuous cycle that will end with the final set of hypotheses being tested.

VISUAL ANALYTICS INTERFACE

In **Figure 3,** we identify the three main components of our prototype: (1) The virtual player, that provides a real-time playback of the game and depicts the players' positions at all times. It serves the analyst to browse through the game looking for interesting in-game situations. As seen in the image, other representations of the different metrics are also embedded in the animation. (2) Position and speed analysis area, in which these values are presented in the form of two different charts; and (3) group analysis area, in which line charts corresponding to some of the metrics employed in the virtual player can be generated.

Our pilot tool gives analysts the chance of evaluating performance at both individual and group levels. Each level focuses on different characteristic parameters and metrics related to the nature of each type of analysis (group or individual). Individual analysis supports group analysis and is the key to provide efficient knowledge acquisition within the proposed tool and workflow, and also is a key step in the process of finding meaningful game plays or explanations for observed group behavior. One of the major achievements of the pilot tool is to be successful in visually exposing the links between group and individual traits that otherwise would remain hidden to the analyst's eyes.

According to the collective characteristics previously explained in this paper, great emphasis was placed on producing visualizations that could reliably represent such traits by means of a combination of (1) animations; (2) graphs, and (3) glyphs. We considered of great importance to help the user to connect specific elements in these visualizations to real game situations and vice versa. In a similar way, it is also relevant to establish bidirectional relationships between group and individual traits, in an attempt to explain phenomena of interest occurring in the teams' dynamics and tactics. The visuals in the application follow were designed to effectively represent the concept of shared cognition in a group and how it affects to the individuals conforming it. In the following paragraphs, we discuss the different representations given for each group metric explained in section Key Metrics, and how the proposed visualizations effectively enhance the analyst's knowledge acquisition process.

Team Center

The process of selecting the players can be done using expert knowledge based or other individual metrics obtained in exploratory analysis. Based on these assumptions our example application allows the analyst to freely compose the study groups in the way he or she prefers, being the only constraint the minimum number of players that can conform a group. This way we enable the expert to focus only on the relevant individuals involved in a game play (i.e., 3 forwards vs. 4 defenses) and thus we effectively remove unwanted positions that could alter the resulting team center. In the case studies proposed at the end of this paper we elaborate further on this aspect.

Stretch Index

In the proposed animation, players' distances are drawn as a line linking the centroid with the correspondent positions along with its numerical value (in meters) in a similar fashion to the surface area representation. By interacting with the interval selection handle, the analyst can select a game play of his or her interest or a whole period. The stretch index for the two groups of study is calculated and immediately presented on the analysis pane of the tool for further comparison. As we will see in the upcoming sections, these measures are especially important for group coordination studies. In our implementation, team center is intimately linked to the surface area covered by the group, and, in particular to the convex hull resulting of the players' positions, that is presented in the next section.

Surface Area

Given that this animation is updated every frame according to the changes in the different positions we chose the Graham Scan algorithm to perform the convex hull computation because of the following two reasons: (a) it performs in logarithmic time $O(n \log n)$ and (b) the algorithm is especially well-suited for calculations that involve a small amount of points, as is our case (maximum 10 points for 10 different players). In our proposed animation, we draw a shadow polygon to remark the area that is being occupied by the team at a certain time. We also project the points to the real field measures, so we can also present the value in square meters (m2) drawn on top of the polygon's centroid. Furthermore, we represent inter-player distances in a similar way to what we did for radial distances in the previous section. These representations can be shown or hidden up to the analyst's discretion, following the approach taken in the rest of the example application.

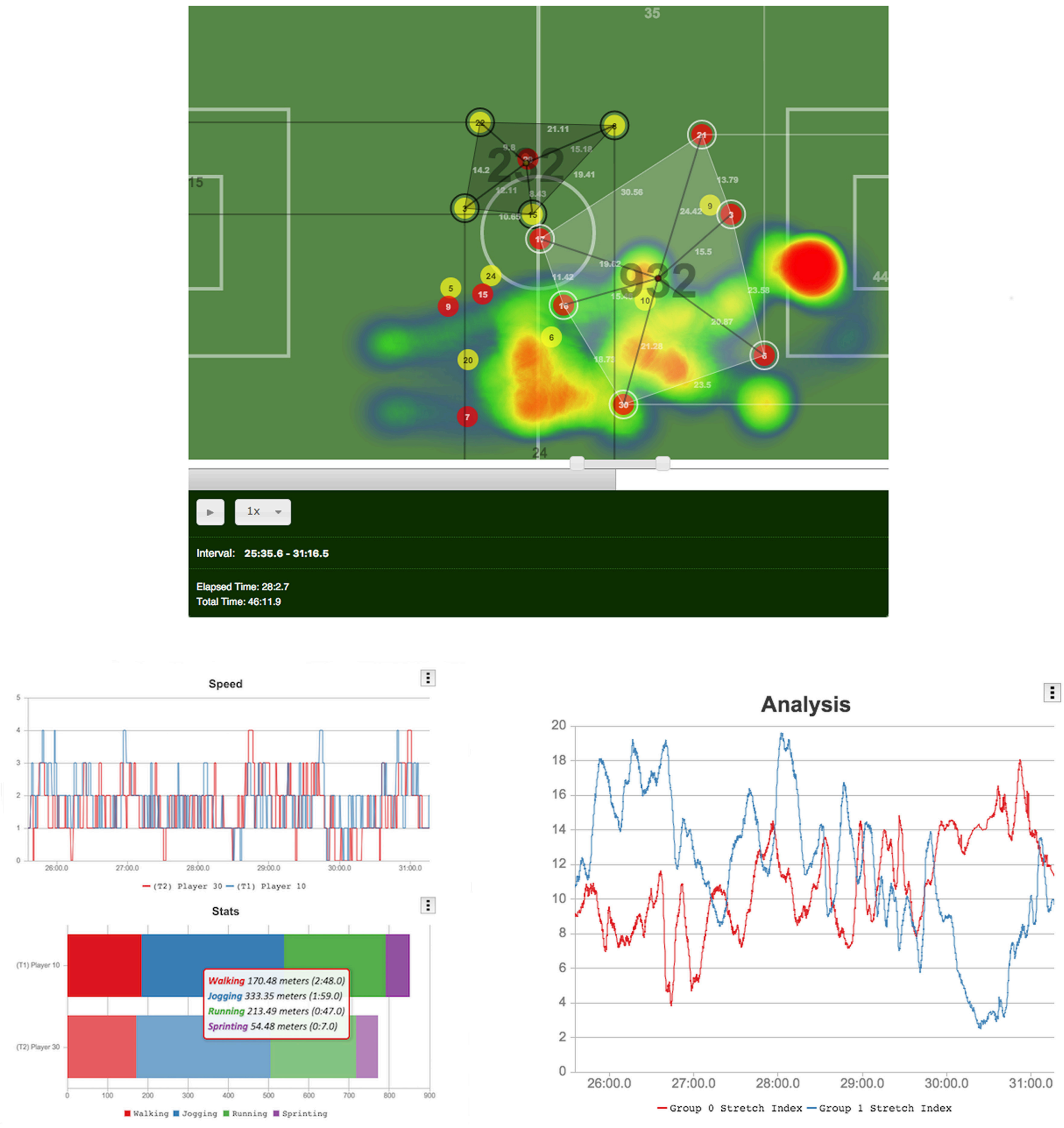

FIGURE 3 | Top: Virtual player and group analysis. Bottom-**left**: A Comparison in the speed and distance covered by two different players. Bottom-**right**: Line chart showing the evolution of each group's stretch index in the selected period.

Team Length and Width

In our implementation, we use the four sides of the field as planes in which the two polygons corresponding to the two groups will be projected. First group will employ the left and bottom sides and the second group will make use of the upper and right ones. We also draw numerical values, so the analyst is informed of the real measure at all times.

Team Synchrony

In previous sections we measured team coordination by applying phase analysis to two or more oscillating functions. Once an analysis group has been established and the time interval selected, the pilot tool is able to compute time-dependent functions from the continuous values given by the distances to the centroid of the group of each player, which can be added to the phase calculation. As a consequence, the analyst is able to explore how coordination between pairs evolves in such given period. The tool also offers the possibility to calculate the *ApEn*, a measure that informs on the unpredictability of the phase. High values represent a more chaotic coordination in the movements of the players in relation to the centroid.

TABLE 1 | Description from the speed intervals used in the application.

Pace	Speed Interval
Standing	Less than 0.2 m/s
Walking	Between 0.2 and 2.1 m/s.
Jogging	Between 2.1 and 3.8 m/s.
Running	Between 3.8 and 6.1 m/s.
Sprinting	More than 6.1 m/s.

Individual Analysis

It is of major interest for analysts to inspect traits related to certain players in the group when searching for events that could justify certain group behaviors. In our work flow, the expert can compare information from these two different sources in a visual manner to speed up the finding of meaningful conclusions as opposed to traditional, manual techniques.

Speed Evolution Chart

Given the different players' positions and their evolution in time we are able to calculate the speed, which is later discretized in five intervals or paces, represented in **Table 1**. Discretization of the speed variable occurs only once per match data set and in the data import phase. During an analysis session, the user can add players to the individual analysis zone using the mouse secondary button.

Change of Pace Chart

This line chart, reflects the different changes of pace for one or more players in the given analysis interval. The analyst can browse through the data evaluating the speed progression in the selected time interval. In line with other visualizations presented in this paper, this chart is also interactive in the way that it allows the researcher to navigate to the detected key event in the virtual player, effectively reducing the cognitive load that is involved in the analysis process.

Distance Covered Comparison Chart

We employ a stacked bars chart to allow fast visual comparison of the distance covered by players in a time interval. Each stack represents the portion of the total distance performed at each one of the different speed intervals presented above. This enables the analyst to have a bird's eye perspective of the effort performed by the different players in a group, giving the analyst the perception about the time periods in which a player performed at a certain pace.

Heatmaps

Spatial distribution maps or heat maps are a popular means to visualize spatio-temporal variables such as position or speed. As a companion visualization for the stacked bars chart, the analyst also has the possibility to generate this kind of visualization on demand. By employing heatmaps we are able to provide a better picture of a player's performance through any given period of time.

Distance to a Point

Finally, the pilot tool allows analysts to make in-map measures among one or more players to a specific coordinate point in the field, as shown in **Figure 3**.

CASE STUDIES

A real elite soccer match was examined to demonstrate the capabilities of the proposed pilot tool. Positional data of the two teams was acquired using player visual tracking at 10 Hz resolution, resulting in ∼27,000 coordinate entries per player per time. Firstly, a significative event—in this case a goal-, which is known by the user prior the analysis task, is presented. Then the prototype is used to search for other secondary events within the relevant play build-up that support a certain hypothesis that explains the final outcome of the play. The other example proposes a free exploration of the dataset. By employing phase analysis, the analyst is able to identify significative events that generate different kinds of situations of interest in the game.

Case Study #1: Analyzing a Goal Scored Build-up Play

As an operational example, **Figure 4** includes the original video footage and the two-dimensional visual representation as seen in the tool of three different moments of a scoring play. The key players intervening in the play are three attackers of the yellow team and three defenders of the red team. Covered area by the two groups is shown in the tool. At the center of each area there is a dot filled with the color of the team. This allows us to know where the centroid of the three players is, allowing the user to see their average positions at all times. It is known there is an increase in the chances of scoring a goal when the attacking group's centroid surpasses that of the defenders. In this use case, we verify how this technical event can be easily detected in our pilot tool to explain a real game event.

The first moment depicted in **Figure 4** shows the start of the build-up, where Player 15 (red) gets the ball in the offense phase. In the second moment, he has surpassed a midfielder and is approached by two of the three highlighted defenders, which creates an opportunity for Player 7 (red) to get a scoring chance. In the last moment, Player 15 has already passed the ball to Player 7, who will finish easily and score a goal due to the defenders being stuck in more advanced positions, making it impossible to catch him. The second moment represents the key to the scoring chance and ultimately the goal. By exploring the positioning data, we better understand the impact of the two defenders (20 and 5, yellow) on the play. They decide to close onto the attacker with the ball (15, red) and that causes the centroids of both groups to get at practically the same position. What is more, this triggers an unbalanced situation in which players 9 and 7 of the attacking team (red) are left alone against Player 3 of the defending one (yellow). When the two defenders that tried to prevent the pass, start recovering and running back, it is late enough for Player 7 (red) to be on a clear scoring position, as depicted in the third moment. The

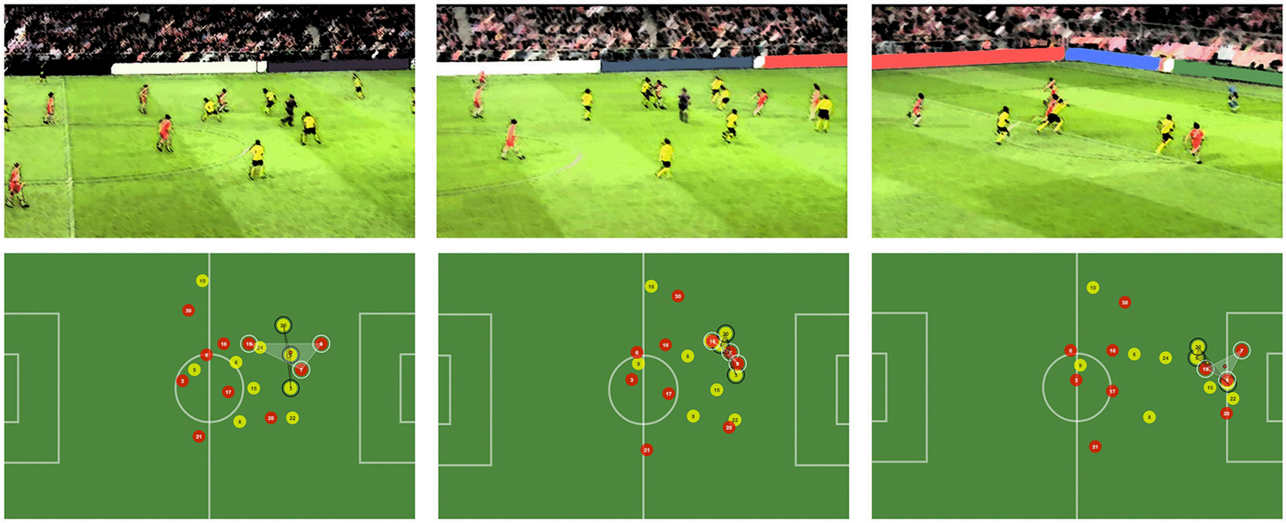

FIGURE 4 | Build-up phases of a scored goal. The area covered by attackers and defenders is depicted in the system.

FIGURE 5 | Speed comparison between players 7 (attacking) and 3 (defending) during the analyzed play.

difference between both centroids at this point is the largest of the sequence. This fact is in line with the proposals from other authors previously explained (Duarte et al., 2013), since from the moment the average position of the attackers was more advanced than that of the defenders, the play went their way and they ended up scoring.

Further explanatory facts can be found using individual analysis, for example if the speed evolution graphs of two of the players are considered: Player 7 (attacker, red) and Player 3 (defender, yellow). As depicted in **Figure 2**, Player 7 maintained a higher speed over Player 3 during the 8 analyzed seconds. The most important moments stand between the 1:34 and 1:35 marks, as Player 7 sprinted toward the goal a second after the defender started his movement. This allowed him to gain sufficient advantage to be alone in a scoring position later, as seen in the last moment depicted in **Figure 5**.

Case Study #2: Studying Inter-player Coordination With Relative Phase Analysis

Relative phase can also be used to identify inter-player coordination. Two instants between minutes 28 and 38 are highlighted in **Figure 6** depicting the times when the coordination between Player 3 and 6 of the red team (defending) was low. This implies that one defender moved toward the centroid while the other moved away from it, creating an unbalanced situation in the defense which has important implications on the outcome of the play (for example the first instant corresponds to a goal score by the opposing team).

The two instants of the sequence are depicted in **Figure 7**. By reproducing the play, we can see how the two defenders go back to cover Player 8 (yellow) as he surpasses them, trying to prevent a scoring chance. This attacking player then passes the ball back and that causes the defenders to lose their coordination, as one stays still at the goal line and the other runs to prevent the shot from the attacking player (number 15, yellow) who is outside of the goalkeeper's area. Moments of low coordination between defenders of the red team are generated in situations where the defenders are close together and an unexpected action (such as a back pass) happens. This unpredictable situation forces the defenders to lose synchronization with the rest of his teammates meaning each one of them took different directions, as it happened in the presented situation: In this concrete case, one decided to stay put in the goal line and the other to cover the shot, thus creating completely opposite movements from the centroid of the whole defense.

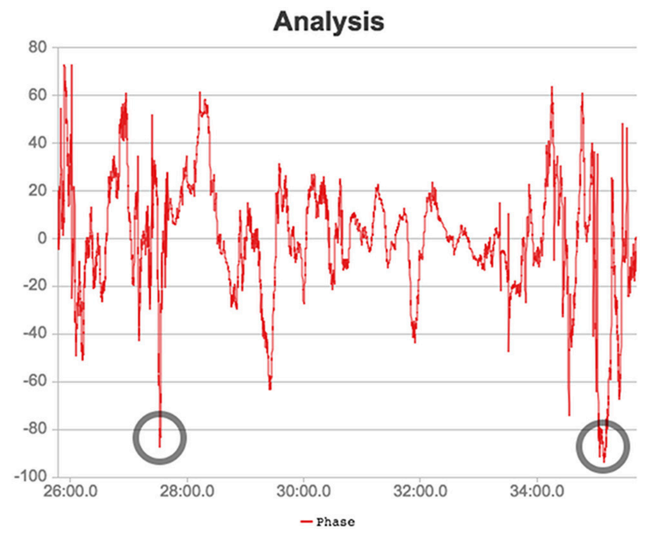

FIGURE 6 | Phase analysis for the two defenders between minutes 26 and 38 of the second half. The two lowest moments of coordination are rounded in the image.

The second point of low coordination is depicted in **Figure 8**. In this case, the play did not result in a scoring chance, although we comment on other interesting aspects of the game that generated this situation. In this play, player 5 passes the ball to Player 20 (both attacking, in yellow), and Player 30 (defending, red) is not fast enough to stop the attack, making Player 6 (red) to leave its defense position to cover the area left by his team mate. It becomes clear that bad defense by Player 30 caused a break in the coordination of both central defenders (3 and 6, red). While Player 3 had to remain covering the attacker (Player 9, yellow), Player 6 had to go out of his zone of influence to stop Player 20 and prevent a cross or any other potentially dangerous play on offense. This special situation could also be easily identified in the pilot tool by employing

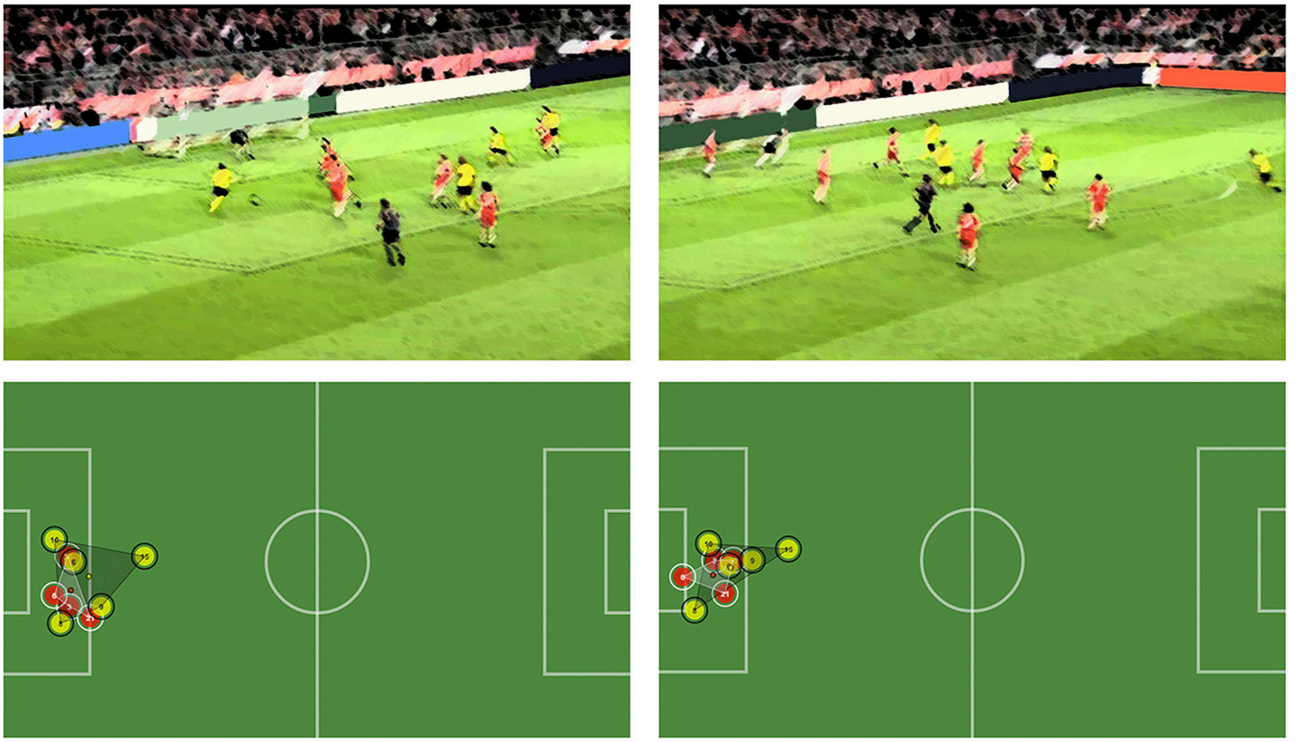

FIGURE 7 | First moment of low coordination between two defenders (Players 3 and 6, red). The outcome is a goal by the attacking team.

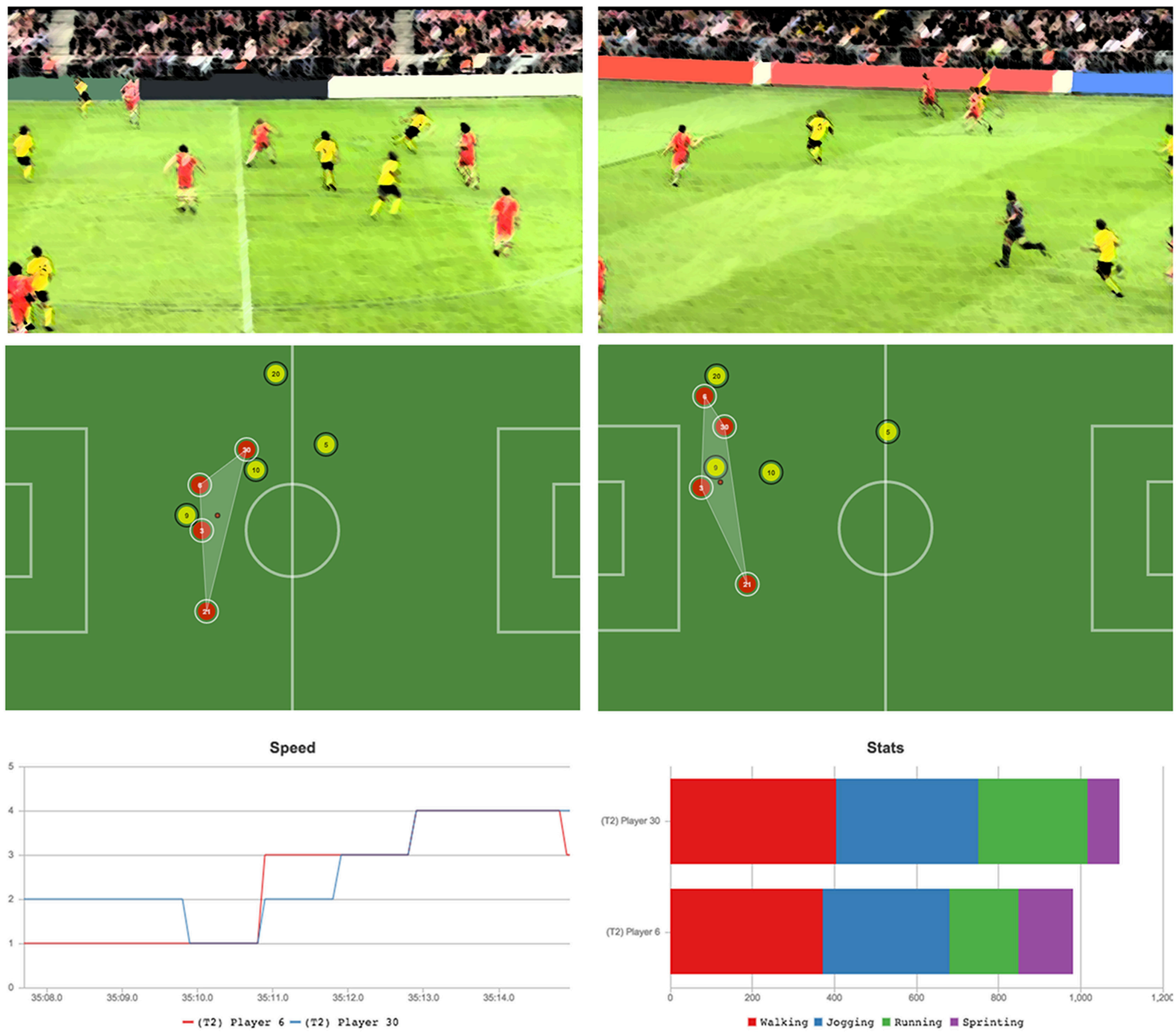

FIGURE 8 | Top: Second moment of low coordination between two defenders (players 3 and 6, red). Bad defending from another player causes the disruption. Bottom: Speed and movement comparison between the two defenders involved in the opposition advantage play.

the line graph, without the need to visualize the entire 6 min of game.

CONCLUSIONS

In this study, we demonstrate that including visual analysis techniques in sports group behavior analysis can produce both high quality results and a satisfactory experience with the computer at the same time (see **Supplementary Video 1**). We designed an iterative workflow companion to this tool that effectively captures and accelerates many expert workflows that had to be performed manually or semi-automatically in the past. We found that the application of data visualization and user-centered design techniques helps to maintain the overall learning curve of the system flat without compromising the accuracy or efficiency of the analysis. In the provided examples, we could also appreciate how the proposed workflow can scale to many different game situations and combinations of analysis types - collective or individual. By following a top-down approach that goes from the general to the specific, the analyst can navigate the positional data by progressively tuning the interface controls and reach to conclusions of interest. Furthermore, the advantages of combining the proposed workflow with a visual tool could be noticed in the implementation of two different use cases that employed geospatial data acquired from a professional match in a very similar setting to what many sports scientists have in their daily work.

Despite of these promising first results, the ideas presented in this paper require of further validation and more complex user studies that we expect to implement in future research, along with the following lines of future work that we compiled during our research:

Positional Data of the Ball

As it has been commented before in this paper, some authors take the ball position into account when calculating different group metrics. Given the recent advances in positioning technologies, we expect to be able to work with more data sets that include this feature.

Social Network Analysis

As a result of the incorporation of the ball position, we plan to generate social network visualizations that depict associations of players during the game, extracting statistical data related to the number of passes between players, direction of the pass and other traits, which will be used as inputs for our system. This information should be presented to the user by employing dynamic network analysis and other complex network visualization techniques.

Visualization of Biomechanical Variables

In our current implementation, we discretize the speed variable according to five predefined clusters. In a similar way, we could employ other non-geospatial variables gathered using different equipment attached to the athlete's body, such as a pulsometer.

Visualization of Labor Division and Areas of Influence

Different studies divide the effective playing space of a group of players in several areas of influence (one per player). There are previous attempts to achieve this functionality in visual terms by making use of Delaunay triangulations and Voronoi cells.

Real Video Playback

The pilot tool is able to link incoming metrics data with real in-game situations by establishing an interactive relationship between the virtual player and the two analysis zones. During analysis sessions, analysts tend to complement the usage of these prototypes with real video playback of the game under study. Currently this process must be performed manually, but it would be interesting to reduce the number of steps needed to reach to relevant parts of the video in a similar way to how the virtual player performs in the current tool.

AUTHOR CONTRIBUTIONS

RT, JS, and CL-P: Conceptualization; JS and CL-P: Funding acquisition; AB, RT, JS, and CL-P: Methodology; CL-P: Project administration; AB, RT, and AL: Software; AB, RT, and AL: Visualization; AB, RT, AL, JS, and CL-P: Writing—original draft.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.02416/full#supplementary-material

Supplementary Video 1 | Overview video. In this video, we present the proposed prototype to the interested reader. It gives an overview of all the features presented in this paper and depicts the usage of the tool to perform individual and group visual analysis employing real in-game data.

REFERENCES

Abade, E., Gonçalves, B., Leite, N., and Sampaio, J. (2014). Time–motion and physiological profile of football training sessions performed by under-15, under-17, and under-19 elite portuguese players. *Int. J. Sport Physiol.* 9, 463–470. doi: 10.1123/ijspp.2013-0120

Bialkowski, A., Lucey, P., Carr, P., Yue, Y., Sridharan, S., Matthews, I., et al. (2014). "Identifying team style in soccer using formations learned from spatiotemporal tracking data," in *En: 2014 IEEE International Conference on Data Mining Workshop*, Shenzhen, 9–14.

Cummins, C., Orr, R., O'Connor, H., and West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Med.* 43, 1025–1042. doi: 10.1007/s40279-013-0069-2

Di Salvo, V., Collins, A., McNeill, B., and Cardinale, M. (2006). Validation of Prozone ®: a new video-based performance analysis system. *Int. J. Perform Anal. Sport* 6, 108–119. doi: 10.1080/24748668.2006.11868359

Duarte, R., Araújo, D., Davids, K., Travassos, B., Gazimba, V., and Sampaio, J. (2012a). Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes in youth soccer. *J. Sports Sci.* 30, 871–877. doi: 10.1080/02640414.2012.675081

Duarte, R., Araujo, D., Folgado, H., Esteves, P., Marques, P., and Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *J. Syst. Sci. Complex* 26, 62–72. doi: 10.1007/s11424-013-2290-3

Duarte, R., Araujo, D., Freire, L., Folgado, H., Fernandes, O., and Davids, K. (2012b). Intra- and inter-group coordination patterns reveal collective behaviors of football players near the scoring zone. *Hum. Mov. Sci.* 31, 1639–1651. doi: 10.1016/j.humov.2012.03.001

Folgado, H., Duarte, R., Fernandes, O., Sampaio, J. (2014a). Competing with lower level opponents decreases intra-team movement synchronization and time-motion demands during pre-season soccer matches. *PLoS ONE* 9:e97145. doi: 10.1371/journal.pone.0097145

Folgado, H., Duarte, R., Marques, P., and Sampaio, J. (2015). The effects of congested fixtures period on tactical and physical performance in elite football. *J. Sports Sci.* 33, 1238–1247. doi: 10.1080/02640414.2015.1022576

Folgado, H., Gonçalves, B., and Sampaio, J. (2018). Positional synchronization affects physical and physiological responses to preseason in professional football (soccer). *Res. Sports Med.* 26, 51–63. doi: 10.1080/15438627.2017.1393754

Folgado, H., Lemmink, K., Frencken, W., and Sampaio, J. (2014b). Length, width and centroid distance as measures of teams tactical performance in youth football. *Eur. J. Sport Sci.* 14 (Suppl. 1), S487–S492. doi: 10.1080/17461391.2012.730060

Frencken, W., Lemmink, K., Delleman, N., and Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *Eur. J. Sport Sci.* 11, 215–223. doi: 10.1080/17461391.2010.499967

Frencken, W., Lemmink, K., and Delleman, N. J. (2010). Soccer-specific accuracy and validity of the local position measurement (LPM) system. *J. Sci. Med. Sport* 13, 641–645. doi: 10.1016/j.jsams.2010.04.003

Gonçalves, B., Coutinho, D., Santos, S., Lago-Peñas, C., Jimenez, S., and Sampaio, J. (2017a). Exploring team passing networks and player movement dynamics in Youth Association Football. *PLoS ONE* 12:e0171156. doi: 10.1371/journal.pone.0171156

Gonçalves, B., Esteves, P., Folgado, H., Ric, A., Torrents, C., and Sampaio, J. (2017b). Effects of pitch area-restrictions on tactical behavior, physical, and physiological performances in soccer large-sided games. *J. Strength Cond. Res.* 31, 2398–2408. doi: 10.1519/JSC.0000000000001700

Gonçalves, B., Figueira, B., Macãs, V., and Sampaio, J. (2014). Effect of player position on movement behaviour, physical and physiological performances during an 11-a-side football game. *J. Sports Sci.* 32, 191–199. doi: 10.1080/02640414.2013.816761

Gonçalves, B., Folgado, H., Coutinho, D., Marcelino, R., Wong, D., Leite, L., et al. (2018). Changes in effective playing space when considering sub-groups of 3 to 10 players in professional soccer matches. *J. Hum. Kinet.* 62, 145–155. doi: 10.1515/hukin-2017-0166

Gonçalves, B., Marcelino, R., Torres-Ronda, L., Torrents, C., and Sampaio, J. (2016). Effects of emphasising opposition and cooperation on collective movement behaviour during football small-sided games. *J. Sports Sci.* 34, 1346–1354. doi: 10.1080/02640414.2016.1143111

Gudmundsson, J., and Horton, M. (2017). Spatio-temporal analysis of team sports. *ACM Comput Surv*. doi: 10.1145/3054132

Harbourne, R. T., and Stergiou, N. (2009). Movement variability and the use of nonlinear tools: principles to guide physical therapist practice. *Phys. Ther.* 89, 267–282. doi: 10.2522/ptj.20080130

Larsson, P. (2003). Global positioning system and sport-specific testing. *Sports Med*. 33, 1093–1101. doi: 10.2165/00007256-200333150-00002

Memmert, D., Lemmink, K., and Sampaio, J. (2016). Current approaches to tactical performance analyses in soccer using position data. *Sports Med*. 47, 1–10. doi: 10.1007/s40279-016-0562-5

Nielsen, J. (1993). *Usability Engineering*. San Francisco, CA: Morgan Kaufmann Publishers Inc.

Passos, P., Davids, K., Araújo, D., Paz, N., Minguéns, J., and Mendes, J. (2011). Networks as a novel tool for studying team ball sports as complex social systems. *J. Sci. Med. Sport*. 14, 170–176. doi: 10.1016/j.jsams.2010.10.459

Perin, C., Vuillemot, R., and Fekete, J. (2013). SoccerStories: a kick-off for visual soccer analysis. *IEEE Trans. Visual. Comp. Graph*. 19:2506–2515. doi: 10.1109/TVCG.2013.192

Pincus, S. M. (1991). Approximate entropy as a measure of system-complexity. *Proc. Natl. Acad. Sci. U. S. A*. 88, 2297–2301. doi: 10.1073/pnas.88.6.2297

Ric, A., Torrents, C., Gonçalves, B., Sampaio, J., and Hristovski, R. (2016). Soft-assembled multilevel dynamics of tactical behaviors in soccer. *Front. Psychol.* 7:1513. doi: 10.3389/fpsyg.2016.01513

Sampaio, J., Lago, C., Gonçalves, B., Maçãs, V. M., and Leite, N. (2014). Effects of pacing, status and unbalance in time motion variables, heart rate and tactical behaviour when playing 5-a-side football small-sided games. *J. Sci. Med. Sport* 17, 229–233. doi: 10.1016/j.jsams.2013.04.005

Sampaio, J., and Maçãs, V. (2012). Measuring tactical behaviour in football. *Int. J. Sports Med*. 33, 395–401. doi: 10.1055/s-0031-1301320

Silva, P., Duarte, R., Esteves, P., Travassos, B., and Vilar, L. (2016). Application of entropy measures to analysis of performance in team sports. *Int. J. Perform. Anal. Sport* 16, 753–768. doi: 10.1080/24748668.2016.11868921

Stergiou, N., Buzzi, U., Kurz, M., and Heidel, J. (2004). "Nonlinear tools in human movement," in *Innovative Analyses of Human Movement*, ed N Stergiou (Champaign, IL: Human Kinetics), 63–90.

Travassos, B., Gonçalves, B., Marcelino, R., Monteiro, R., and Sampaio, J. (2014). How perceiving additional targets modifies teams' tactical behavior during football small-sided games. *Hum. Mov. Sci*. 38, 241–250. doi: 10.1016/j.humov.2014.10.005

Varley, M. C., Fairweather, I. H., and Aughey, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *J. Sports Sci.* 30, 121–127. doi: 10.1080/02640414.2011.627941

Yentes, J. M., Hunt, N., Schmid, K., Kaipust, J. P., McGrath, D., and Stergiou, N. (2013). The appropriate use of approximate entropy and sample entropy with short data sets. *Ann. Bio Eng*. 41, 349–365. doi: 10.1007/s10439-012-0668-3

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Interpersonal Coordination in Soccer: Interpreting Literature to Enhance the Representativeness of Task Design, From Dyads to Teams

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Interpersonal coordination in soccer has become a trending topic in sports sciences, and several studies have examined how interpersonal coordination unfolds at different levels (i.e., dyads, sub-groups, teams). Investigations have largely focused on interactional behaviors at micro and macro levels through tasks from dyadic (i.e., 1 vs. 1) to team (i.e., 11 vs. 11) levels. However, as the degree of representativeness of a task depends on the magnitude of the relationship between simulated and intended environments, it is necessary to address a discussion on the correspondence between competitive and practice/experimental settings in soccer. The aims of this paper are to: (i) provide a brief description of the main concepts underlying the subject of interpersonal coordination in sports teams; (ii) demonstrate, through exemplar research findings, how interpersonal coordination in soccer unfolds at different scales; and (iii), discuss how coaches and researchers may ensure representativeness for practice and experimental tasks. We observed that papers addressing the analysis of interpersonal coordination tendencies in soccer often resort to dyadic (one vs. one) or sub-group (many vs. many) experimental tasks, instead of full-sized (11 vs. 11) games. Consequently, the extent to which such patterns reflect those observed in competition is somewhat uncertain. The design of practice and/or experimental tasks that rely on sub-phases of the game (e.g., 1 vs. 1, 4 vs. 4) should ensure the preservation of players' behavior patterns in intended match conditions (11 vs. 11). This can be accomplished by measuring the level of action fidelity of the task, ensuring correspondence and successful transfer across contexts.

Keywords: soccer, interpersonal coordination, task representativeness, behavioral correspondence, action fidelity

INTRODUCTION

Coordination dynamics incorporates several concepts deemed relevant for investigating the intricate mechanisms that underpin performance behaviors in sports (Araújo et al., 2006). Analysis of sports performance through a dynamic perspective seeks to shed light on how the continuous interactions between elements of a system unfold at a microscopic level (i.e., player-player) and how they influence the emergence of macroscopic patterns (i.e., team collective structures) (Davids et al., 2005; Vilar et al., 2012). In order to address this issue, the investigation of interpersonal coordination tendencies in team games (e.g., soccer) has drawn the attention of sports scientists in recent years.

Research addressing the identification of the principles underpinning the interaction dynamics between players and teams has largely focused on behavior patterns at different system scales (i.e., dyads: 1 vs. 1, sub-groups: e.g., 3 vs. 3, teams: 11 vs. 11). Studies have uncovered the importance of collective variables – higher-level parameters that describe the emerging order of a system through the analysis of the functional behaviors of the elements that comprise this system (Kelso, 1995) – to interpersonal coordination at system and sub-system levels. However, it is still unclear whether the behaviors observed in dyadic tasks relate to those in competitive contexts, for instance (Duarte et al., 2012b; Clemente et al., 2013; Folgado et al., 2014). As the representativeness of a particular task refers to the correspondence between simulated and intended environments (Stoffregen et al., 2003), it is necessary to address a thoughtful discussion on this topic in soccer, as the utilization of tasks at the sub-system levels (e.g., small-sided and conditioned games) is widespread in training and research contexts (Araújo et al., 2007).

Therefore, the aims of this article are to: (i) provide a brief description of essential concepts about interpersonal coordination in sports teams; (ii) demonstrate, through exemplar research findings, how interpersonal coordination in soccer unfolds at different scales (i.e., dyads, sub-groups and teams); and (iii) discuss how coaches and researchers may ensure representativeness when designing practice and experimental tasks in soccer.

INTERPERSONAL COORDINATION

Over the years, several scientific fields have attempted to provide a clear definition of the term coordination, as it has been used to outline processes specific to particular disciplines. In animal physiology, for instance, coordination is regarded as "the processes involved in the reception of sensory information, the integration of that information, and the subsequent response of the organism" (Martin and Hine, 2008, p. 155). As for the subject of motor control, Bernstein (1967, p. 167) defined coordination as "the organization of the control of the motor apparatus," i.e., how the multitude of micro-components of the system become coordinated into a controllable organization with the purpose of achieving task goals.

Hereupon, Schmidt et al. (1999) suggested that interpersonal coordination may be better understood through the mechanism of inherent self-organization, i.e., system tendencies that can be manipulated to generate order and structure within complex adaptive systems. Hence, the theoretical framework underpinning the function of such systems reveals that interpersonal coordination tendencies do not emerge uniquely from internalized cognitive or neural organization in individuals, but also from the way in which the elements of an organism interact. Furthermore, there is still evidence suggesting that interpersonal coordination can emerge subconsciously, even at an elite level of athletic performance (Stevens, 1976; Varlet and Richardson, 2015).

Kelso suggested that complex adaptive systems possess analogous structural features irrespective of their scales of function (Kelso, 1995). This is an important idea to guide performance in team sports, as it provides a theoretical foundation for understanding behaviors at all system levels. Accordingly, investigations have indicated that athletes' behaviors need to be observed and understood in light of the same principles, both in individual and team sports competitions (McGarry and Franks, 1996; Grehaigne et al., 1997; Bourbousson et al., 2010). Supported by these principles, individual sports encompass inter-individual coupling between two opponents or between an athlete and an object/surface/element within the environment, whereas research on team sports individual system components, such as competing players, can entrain the behavior of the whole complex system, incorporating one or several dyads that combine to generate intra- and inter-team couplings (Bourbousson et al., 2010).

Correspondingly, the coupling interactions between oscillating elements in a collective system yields dynamic characteristics that equally describe the interactions in sports teams (McGarry et al., 2002; McGarry, 2005). Thus, systems and sub-systems in team sports (e.g., basketball, rugby union and soccer) are likely to display both competitive and cooperative characteristics. Consequently, every player within a team coordinates his/her actions with teammates in search for a solution for a joint performance purpose during competition. In addition, opposing players and teams must coordinate their actions between each other, in an attempt to create scoring opportunities for their respective sides and to prevent the opposition from scoring (McGarry et al., 2002; Glazier, 2010). Therefore, in team sports, analyses of performances of individual players and teams should take into account the influence of opponents on individual and collective actions (Duarte et al., 2012a). Hence, performance in team sports may be better understood as an outcome of the interpersonal relations between teammates and opponents and, consequently, such interactions should be considered inextricable for the analysis of match behaviors (Bourbousson et al., 2010).

With the purpose of identifying and describing the continuous, complex interactions between players and teams, a notable portion of the research on interpersonal coordination in soccer has largely analyzed the distinct interactional scales that comprise a complex adaptive system. This perspective considers all players as elements that oscillate around a mutual locus, and is based on the assumption that team vs. team interactions comprise numerous one vs. one interactions (McGarry, 2005).

INTERPERSONAL COORDINATION IN SOCCER – FROM DYADS TO TEAMS

Soccer is a team sport with an essentially tactical nature, and thus demands from coaches, performance analysts and researchers an appropriate level of knowledge about the interactions between its elements (i.e., players and teams) (Davids et al., 2005). A soccer team can be described as a complex system whose interrelating elements generate a large variety of patterns at a macro scale, which differ from the micro-scaled behavior of each element considered in isolation (Passos et al., 2016b). Hence, the dynamic structures that comprise a soccer match should be contemplated in their entirety, rather than analyzed in a fragmented fashion because decomposing such deeply integrated systems for analysis can lead to artificial behaviors being observed (Grehaigne et al., 1997).

For this reason, seeking to understand how coordination between players and teams arises (and which are the resultant patterns), researchers have investigated interactions at various scales (between dyads – in 1 vs. 1 situations – sub-groups – attacking and defending units of players – and teams), in addition to proposing variables capable of explaining the emergence of collective behavior.

Thus, with the purpose of identifying these key collective patterns of behavior, some order parameters (e.g., surface area, centroids, distance to goal) were proposed, which addressed the analysis of these parameters from dyadic to team levels. In the following section, we attempt to provide a brief, though potentially thoughtful analysis of some of the studies that investigated one or more of these variables, according to the scale of analysis (i.e., dyads, sub-groups, and teams). In addition, we examine how the behavior of the collective variables proposed vary across the distinct scales.

Dyads

Dyads (player–player interactions) are the basic unit of analysis for studying interpersonal coordination in team sports (Passos et al., 2015). Also, dyadic relations in competitive matches have been deemed essential to support the analysis of playing performance (McGarry, 2009). As a result, a considerable amount of research has sought to identify coordination patterns in attacker-defender dyads in team sports, particularly in soccer.

In team sports, athletes need to learn how to interact with teammates and opponents to achieve their goals (Gréhaigne and Godbout, 1995; McGarry et al., 2002). This process of continuous interaction is founded on players' co-adaptive behaviors, which are constrained by locally created information (Passos et al., 2016a). This information emerges from different task constraints, including field markings and boundaries, and rules, which act as constraints on the co-positioning of teammates and opponents. Nevertheless, while markings and rules remain unchanged during competitive performance, players' co-positioning in a match is continuously modified due to the presence and location of significant others. For example, studies in team sports (Passos et al., 2009; Correia et al., 2011) have revealed the relevance of key collective performance variables – such as territorial gain or the distance of the dyad to the scoring target – for the identification of dynamic patterns that emerge from dyadic relations.

Orth et al. (2014) investigated the characteristics of dyads in soccer, by examining the effects of defensive pressure on players' running velocity during the approach to kick a football. Players were observed as they ran toward a football to cross it to a receiver in the penalty area who would try to score against a goalkeeper. Defensive pressure was manipulated in three conditions: without defenders; with a defender positioned far away; and with a defender positioned close to the player crossing the ball. Overall, findings suggested that the regulation of kicking is specific to a performance context and that some features of movement organization will not actually emerge unless the presence of a key information variable (e.g., a defender's position) is manipulated as a task constraint during practice.

Headrick et al. (2012) examined how field location constrained the regulation of players' movements. They sought to determine whether spatiotemporal relations between players and the ball in 1 vs. 1 sub-phases were constrained by their distance to the goal area. The experiment consisted of each participant performing the role of attacker (i.e., player in possession) and defender in settings designed to replicate actual match conditions. It was found that the modification of the dyads' distance to goal influenced players' behaviors and intentionality in relation to the ball. Specifically, they suggested that the variable "defender-to-ball distance" might be considered a critical collective variable, since the percentage of successful trials for the player in possession revealed higher success rates in positions closer to the goal.

Sub-Groups

Although dyads represent the basic scale of interaction within the game, the analysis of more complex sub-phases has become relevant for understanding the coordination patterns emerging when players form groups (McGarry et al., 2002; Duarte et al., 2012a). Research (Passos et al., 2011; Headrick et al., 2012; Orth et al., 2014) suggest that, as small-sided and conditioned games can be viewed as a subscale of the formal game, these constrained game forms could be deemed useful for the investigation of structural and functional patterns in competitive settings.

Aiming to identify behavioral patterns in 3 vs. 3 sub-groups during creation and prevention of goal-scoring opportunities, Duarte et al. (2012b) analyzed group coordination through centroid (i.e., average team position) and surface area (i.e., occupied space) measures, obtained by manual video tracking procedures and 2-D reconstruction (Duarte et al., 2010). They reported that the centroids of both teams approached and moved away from each other's defensive lines in a rather entwined (ebbing and flowing) manner, particularly at the moments that preceded the 3 vs. 3 system's loss of stability (i.e., in attempts of goal assists). These findings suggest that both sub-groups moved synchronously in relation to each other. The emergence of such characteristics was influenced to a prominent degree by the distance between the attacking unit and the defensive line (Duarte et al., 2012b). On the other hand, the surface area did not reveal the existence of clear patterns of coordination between the teams. The fact that this measure did not uncover emergent patterns between sub-groups indicates that its utilization in small-sided and conditioned experimental and practice tasks, to understand and regulate collective behaviors in competitive contexts, demands further investigation. This is because sudden variations in this variable might occur due to more frequent turnovers of ball possession and increased player speed in the 3 vs. 3, in comparison to 11 vs. 11 contests (Duarte et al., 2012b).

Likewise, Frencken et al. (2011) aimed to identify emergent playing patterns in 4 vs. 4 SSCGs through centroid positions and surface area, acquired by positional data obtained through a transponder and antennas placed in a vest worn by players (Frencken et al., 2010). Results confirmed that teams' centroid values display a tendency to move in the same directions. Also, findings revealed a stronger association between centroid forward-backward oscillations and lateral oscillations. Nonetheless, like Duarte et al. (2012b); Frencken et al. (2011) did not observe associations between teams' surface area values. They attributed this outcome to the type of design of the experimental task. However, these studies raise doubts on whether the dynamics of some collective variables (e.g., surface area), analyzed in small-sided and conditioned games with a fewer players (e.g., 3 vs. 3, 4 vs. 4), correspond to those of a formal game.

Teams

In soccer, some recent studies have been conducted in order to verify whether the patterns observed at lower scales (i.e., dyads and sub-groups) might also characterize behavior tendencies in competitive play.

For example, Frencken et al. (2012) examined whether the variability of inter-team distances related to critical periods of a match, as well as whether these periods were associated to key events (i.e., goals and goal attempts), by analyzing the variability of longitudinal and lateral distances between teams' centroids. They acknowledged that, although in small-sided and conditioned games great variability of a positional measure often leads to key match events like goal-scoring opportunities, highly variable periods in inter-team distance values preceded only two out of fourteen goal attempts. Actually, results indicated that periods of high variability in inter-team distances emerged from changes in ball position. From this observation one may infer that ball dynamics in small-sided and conditioned games, particularly during crucial events, may differ from those observed in full-sized competitive matches. Also, it may be that inter-team distance (at least on the timescale analyzed by these investigators) may not be an accurate measure to capture the variability that precedes key match events in competitive contexts.

Also with respect to the variability of inter-team coordination, Vilar et al. (2013) analyzed emergent patterns of play in soccer, based on the assumption that locally outnumbering the opposing team is essential for defensive and offensive success. They utilized entropy measures (Shannon, 1948) to examine the uncertainty of the number of players of each team in sub-areas of play within what has been termed the effective-play space – an imaginary polygonal area with lines linking all outfield players located at the periphery of play at any given instant (Mérand, 1977). They observed that, in the course of a match, the teams seldom allocated more players than their opponents in sub-areas of play closer to the opposition goal. Moreover, entropy measures indicated that the central midfield sub-area of play was more unstable than all the other sub-areas, suggesting that numerical dominance within this sub-area is highly unpredictable. Nevertheless, as enlightening as these results may appear, such an approach has not been employed in the investigation of numerical instability at sub-system levels (i.e., dyads and sub-groups).

IMPLICATIONS FOR TASK REPRESENTATIVENESS

Research on interpersonal coordination in soccer may potentially provide coaches with relevant information on how players and teams interact with each other, thus ensuring that skills acquired in practice are appropriately transferred to the competitive environment (Carling et al., 2005). Hence, the design of representative tasks – practice and/or experimental activities that preserve the unique properties of the intended environment (Hammond and Stewart, 2001) – is necessary to ensure successful transfer of individual and collective performances from learning/practice to competitive contexts (Pinder et al., 2011). However, the investigation of coordination patterns in soccer has often resorted to dyadic (one vs. one) and/or group (many vs. many) experimental tasks, and, consequently, the degree to which the interaction tendencies observed at these scales represent the behavioral dynamics in the intended environment is still somewhat uncertain (Bartlett et al., 2012).

This uncertainty is due to the fact that some studies, in an attempt to substantiate their findings, claim that the behavior of the variables that describe a given dynamic system comply with the same rules, regardless of the scale of analysis (i.e., dyads, sub-groups, and teams) (Frencken et al., 2011, 2012). However, these studies fail to acknowledge that the characteristics of each element or sub-unit can only be understood through the identification of the principles that describe the system at the ecological scale, rather than simply analyzing the properties of any given isolated parts (Capra, 1996). In addition, literature has already indicated that behavior in competitive contexts is highly dependent on situational constraints, particularly on the amount of system elements involved (Garcia et al., 2013; Passos et al., 2016a). Neglecting such constraints may result in loss of representativeness and, consequently, prompt emergent behaviors entirely different from those intended in competition.

In this respect, research data obtained in competition could certainly ensure action fidelity in practice/experimental tasks, through measurement and comparison of performance outcomes between both contexts. Action fidelity refers to the relation between the performance observed in a simulator (e.g., experimental or practice task), as well as in the intended system (e.g., team game) (Stoffregen et al., 2003). Therefore, designing practice tasks or test trials without taking into account the structural and functional correspondence with the competitive context may threaten the accurate interpretation of key aspects of performance, as well as the effectiveness of training activities and coaching interventions (Pinder et al., 2011). This is because in experimental and practice tasks, players may exhibit behaviors that do not resemble those displayed in a intended environment. This usually occurs when the sampling of constraints is not sufficiently thorough, and therefore does not enable the onset of certain perceptual demands (e.g., awareness of the possibility of a counterattack by the opposing team during a practice task) that are essential in competition (Araújo et al., 2007). Consequently, more research is necessary to validate appropriate measures of action fidelity (i.e., measures of task performance) that ensure that the essential behavioral characteristics inherent to the game will be preserved in practice and experimental contexts (Araújo et al., 2007).

Therefore, coaches and researchers should ensure that the dynamics of the intended environment (e.g., collective movement tendencies, relative strengths of both teams) are preserved, by comparing performance outcomes between practice/experimental settings and competition. Also, this approach could warrant that individual performances are reproducible (Stoffregen et al., 2003). Coaches could use this knowledge to design training activities that provide appropriate transfer of performance across training and competitive settings, thus ensuring that players are adequately adapted to constraints that are inherent to the sport itself, and not to a given random task.

In summary, the design of dyadic or sub-group experimental and practice tasks should account for both structural and functional characteristics of performance – which capture how players continuously regulate their behaviors in competitive settings. This approach should enable researchers and coaches to, respectively, increase the possibility for generalization of research findings and facilitate the application of acquired knowledge to performance in training contexts.

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RS and RD drafted and wrote the paper. KD and IT wrote the paper.

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REFERENCES

Araújo, D., Davids, K., and Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychol. Sport Exerc.* 7, 653–676. doi: 10.1016/j.psychsport.2006.07.002

Araújo, D., Davids, K., and Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: comment on rogers, kadar, and costall (2005). *Ecol. Psychol.* 19, 69–78. doi: 10.1080/10407410709336951

Bartlett, R., Button, C., Robins, M., Dutt-Mazumder, A., and Kennedy, G. (2012). Analysing team coordination patterns from player movement trajectories in soccer: methodological considerations. *Int. J. Perform. Anal. Sport* 12, 398–424. doi: 10.1080/24748668.2012.11868607

Bernstein, N. (1967). *The Co-ordination and Regulation of Movements*. London: Pergamon Press.

Bourbousson, J., Sève, C., and McGarry, T. (2010). Space–time coordination dynamics in basketball: part 1. Intra- and inter-couplings among player dyads. *J. Sports Sci.* 28, 339–347. doi: 10.1080/02640410903503632

Capra, F. (1996). *The Web of Life: A New Understanding of Living Systems*. New York, NY: Anchor Books.

Carling, C., Williams, A. M., and Reilly, T. (2005). *Handbook of Soccer Match Analysis*. New York, NY: Routledge.

Clemente, F. M., Santos Couceiro, M., Martins, F. M. L., Dias, G., and Mendes, R. (2013). Interpersonal dynamics: 1v1 sub-phase at Sub-18 football players. *J. Hum. Kinet.* 36, 179–189. doi: 10.2478/hukin-2013-0018

Correia, V., Araújo, D., Davids, K., Fernandes, O., and Fonseca, S. (2011). Territorial gain dynamics regulates success in attacking sub-phases of team sports. *Psychol. Sport Exerc.* 12, 662–669. doi: 10.1016/j.psychsport.2011.06.001

Davids, K., Araújo, D., and Shuttleworth, R. (2005). "Applications of dynamical systems theory to football," in *Science and Football V: The Proceedings of the Fifth World Congress on Science and Football*, eds T. Reilly, J. Cabri, and D. Araújo (New York, NY: Routledge), 556–569.

Duarte, R., Araújo, D., Correia, V., and Davids, K. (2012a). Sports Teams as Superorganisms. *Sport. Med.* 42, 633–642. doi: 10.1007/bf03262285

Duarte, R., Araújo, D., Freire, L., Folgado, H., Fernandes, O., and Davids, K. (2012b). Intra- and inter-group coordination patterns reveal collective behaviors of football players near the scoring zone. *Hum. Mov. Sci.* 31, 1639–1651. doi: 10.1016/j.humov.2012.03.001

Duarte, R., Araújo, D., Fernandes, O., Fonseca, C., Correia, V., Gazimba, V., et al. (2010). Capturing complex human behaviors in representative sports contexts with a single camera. *Medicina* 46, 408. doi: 10.3390/medicina46060057

Folgado, H., Duarte, R., Fernandes, O., and Sampaio, J. (2014). Competing with lower level opponents decreases intra-team movement synchronization and time-motion demands during pre-season soccer matches. *PLoS One* 9:e97145. doi: 10.1371/journal.pone.0097145

Frencken, W., Lemmink, K., Delleman, N., and Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *Eur. J. Sport Sci.* 11, 215–223. doi: 10.1080/17461391.2010.499967

Frencken, W., Poel, H., de Visscher, C., and Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *J. Sports Sci.* 30, 1207–1213. doi: 10.1080/02640414.2012.703783

Frencken, W. G. P., Lemmink, K. A. P. M., and Delleman, N. J. (2010). Soccer-specific accuracy and validity of the local position measurement (LPM) system. *J. Sci. Med. Sport* 13, 641–645. doi: 10.1016/j.jsams.2010.04.003

Garcia, S. M., Tor, A., and Schiff, T. M. (2013). The psychology of competition. *Perspect. Psychol. Sci.* 8, 634–650. doi: 10.1177/1745691613504114

Glazier, P. S. (2010). Game, set and match? substantive issues and future directions in performance analysis. *Sport. Med.* 40, 625–634. doi: 10.2165/11534970-000000000-00000

Grehaigne, J.-F., Bouthier, D., and David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *J. Sports Sci.* 15, 137–149. doi: 10.1080/026404197367416

Gréhaigne, J.-F., and Godbout, P. (1995). Tactical knowledge in team sports from a constructivist and cognitivist perspective. *Quest* 47, 490–505. doi: 10.1080/00336297.1995.10484171

Hammond, K. R., and Stewart, T. R. (2001). *The Essential Brunswik: Begginings, Explications, Applications*. New York, NY: Oxford University Press.

Headrick, J., Davids, K., Renshaw, I., Araújo, D., Passos, P., and Fernandes, O. (2012). Proximity-to-goal as a constraint on patterns of behaviour in attacker–defender dyads in team games. *J. Sports Sci.* 30, 247–253. doi: 10.1080/02640414.2011.640706

Kelso, J. A. S. (1995). *Dynamic Patterns: The Self-Organization of Brain Behavior*. Cambridge, MA: The MIT Press.

Martin, E., and Hine, R. (2008). *Oxford Dictionary of Biology*. Oxford: Oxford University Press. doi: 10.1093/acref/9780199204625.001.0001

McGarry, T. (2005). "Soccer as a dynamical system: some theoretical considerations," in *Science and Football V: The Proceedings of the Fifth World Congress on Science and Football*, eds T. Reilly, J. Cabri, and D. Araújo (London: Routledge), 570–579.

McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in sport: scientific issues and challenges. *Int. J. Perform. Anal. Sport* 9, 128–140. doi: 10.1080/24748668.2009.11868469

McGarry, T., Anderson, D. I., Wallace, S. A., Hughes, M. D., and Franks, I. M. (2002). Sport competition as a dynamical self-organizing system. *J. Sports Sci.* 20, 771–781. doi: 10.1080/026404102320675620

McGarry, T., and Franks, I. M. (1996). In search of invariant athletic behaviour in sport: an example from championship squash match-play. *J. Sports Sci.* 14, 445–456. doi: 10.1080/02640419608727730

Mérand, R. (1977). *L'Éducateur Face a la Haute Performance Olympique*. Paris: Éditions Sport et Plein Air.

Orth, D., Davids, K., Araújo, D., Renshaw, I., and Passos, P. (2014). Effects of a defender on run-up velocity and ball speed when crossing a football. *Eur. J. Sport Sci.* 14, S316–S323. doi: 10.1080/17461391.2012.696712

Passos, P., Araújo, D., and Davids, K. (2015). "Dyadic systems as dynamic systems in individual and team sports," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (London: Routledge), 64–73.

Passos, P., Araújo, D., and Davids, K. (2016a). Competitiveness and the process of co-adaptation in team sport performance. *Front. Psychol.* 7:1562. doi: 10.3389/fpsyg.2016.01562

Passos, P., Davids, K., and Chow, J.-Y. (2016b). *Interpersonal Coordination and Performance in Social Systems*. Oxon: Routledge. doi: 10.4324/9781315700304

Passos, P., Araújo, D., Davids, K., Gouveia, L., Serpa, S., Milho, J., et al. (2009). Interpersonal pattern dynamics and adaptive behavior in multiagent neurobiological systems: conceptual model and data. *J. Mot. Behav.* 41, 445–459. doi: 10.3200/35-08-061

Passos, P., Milho, J., Fonseca, S., Borges, J., Araújo, D., and Davids, K. (2011). Interpersonal distance regulates functional grouping tendencies of agents in team sports. *J. Mot. Behav.* 43, 155–163. doi: 10.1080/00222895.2011.552078

Pinder, R. A., Davids, K., Renshaw, I., and Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *J. Sport Exerc. Psychol.* 33, 146–155. doi: 10.1123/jsep.33.1.146

Santos, R. (2015). *Padrões de Coordenação Interpessoal no Futebol: Análise das Relações Numéricas Relativas em Sequências Ofensivas Finalizadas em Gol*. Master's thesis, Universidade Federal de Viçosa, Brazil.

Schmidt, R. C., O'Brien, B. A., and Sysko, R. (1999). Self-organization of between-persons cooperative tasks and possible applications to sport. *Int. J. Sport Psychol.* 30, 558–579.

Shannon, C. E. (1948). A mathematical theory of communication. *Bell Syst. Tech. J.* 27, 623–656. doi: 10.1002/j.1538-7305.1948.tb00917.x

Stevens, P. S. (1976). *Patterns in Nature*. Westminster: Penguin Books.

Stoffregen, T. A., Bardy, B. G., Smart, L. J., and Pagulayan, R. (2003). "On the nature and evaluation of fidelity in virtual environments," in *Virtual and Adaptive Environments: Applications, Implications, and Human Performance*, eds L. J. Hettinger and M. W. Haas (Mahwah, NJ: Lawrence Erlbaum Associates, Inc.), 111–128. doi: 10.1201/9781410608888.ch6

Varlet, M., and Richardson, M. J. (2015). What Would Be Usain Bolt's 100-Meter Sprint World Record Without Tyson Gay? Unintentional Interpersonal Synchronization Between The Two Sprinters. *J. Exp. Psychol. Hum. Percept. Perform.* 41, 36–41. doi: 10.1037/a0038640

Vilar, L., Araújo, D., Davids, K., and Bar-Yam, Y. (2013). Science Of Winning Soccer: emergent Pattern-Forming Dynamics In Association Football. *J. Syst. Sci. Complex.* 26, 73–84. doi: 10.1007/s11424-013-2286-z

Vilar, L., Araújo, D., Davids, K., and Button, C. (2012). The Role of Ecological Dynamics in Analysing Performance in Team Sports. *Sport. Med.* 42, 1–10. doi: 10.2165/11596520-000000000-00000

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GENERAL COMMENTARY
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Commentary: Interpersonal Coordination in Soccer: Interpreting Literature to Enhance the Representativeness of Task Design, From Dyads to Teams

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Keywords: interpersonal coordination, task representativeness, Soccer, sense-making activities, enactive approach

A Commentary on

Interpersonal Coordination in Soccer: Interpreting Literature to Enhance the Representativeness of Task Design, From Dyads to Teams
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This commentary discusses and extends the ideas in the perspective paper, "Interpersonal coordination in soccer: Interpreting literature to enhance the representativeness of task design, from dyads to teams" (Santos et al., 2018). Our goal is to mention missing parts such as the athlete's experience and how athletes use it to adjust their activity to the interpersonal coordination dynamics.

Although not explicitly mentioned, the authors' interpretation of the literature was based on the ecological dynamics framework (e.g., Silva et al., 2013). Within this framework, interpersonal coordination is assumed to result from self-organizing processes that encompass interacting parts like the players, ball, and environment in soccer. To understand how interpersonal coordination emerges, is sustained or disrupted, and changes during performance, researchers record players' behaviors during competition. From these positional data, they analyze the behavioral dynamics of interpersonal coordination through collective variables (e.g., relative phase). Variations in these measures describe the influence of informational constraints—like ball displacement dynamics—on the process of interpersonal coordination. As behavioral dynamics show statistical consistencies, they are interpreted as factors of this coordination. These informational constraints are also defined as possibilities for controlling goal-directed activity with others or affordances (Gibson, 1979). These affordances are subsets of the spatio-temporal structure of light converging at the eyes (Seifert et al., 2018) that each player's perceptual system may or may not detect. As a reminder, the pedagogical outcome in a realistic learning environment is the athletes' placement such that their perceptual systems become increasingly sensitive to the spatio-temporal information that specifies affordances (e.g., Chow et al., 2016).

With this brief summary, we acknowledge our surprise that the authors cited Bourbousson, Sève and McGarry (2010b) study, yet overlooked other studies from Bourbousson and colleagues within the enactive framework of their research program (e.g., Bourbousson et al., 2010a, 2012; Bourbousson and Fortes-Bourbousson, 2016). These works are nevertheless of great interest and relevance to the topic of their paper. In this commentary, we therefore (re)present the theoretical assumptions of the enactive framework and suggest how data collected within this design might contribute to improving task design representativeness.

The enactive framework assumes that agents actively build meanings through their actions and interactions with the environment, enabling them to develop other understandings of an unfolding situation (e.g., Varela et al., 1991; Di Paolo et al., 2011). Meanings are thus not mere affordances in the environment that specify properties of the individual-environment relationship. Instead, they are outcomes of interactions between individuals acting and the dynamics of their environment. For instance, Bourbousson et al. (2012) characterized how five basketball players shared concerns in a real match situation. The concerns corresponded to what made sense simultaneously for each of the players in the situation, thereby delimiting their embedded activities (i.e., the environmental information they were sensitive to in order to act). This sensitivity to environmental information was linked to what was relevant to the players at a given instant in relation to their activity. In another example, a soccer player who wanted to make a quick counterattack on the opponent's goal was sensitive to the opponent's poor positioning and perceived an opportunity to forward pass to a teammate (Gesbert and Durny, 2017). Within this framework, the players were actively adjusting the conditions for their exchanges with the environment, highlighting the autonomy of their activity (Froese and Di Paolo, 2011). And as they adjusted their activity, this gave rise to an experience expressing that each was the author of his own actions (e.g., Buhrmann and Di Paolo, 2015). Such experience is not considered an epiphenomenon that reduces the player-environment interaction to sensorimotor adjustments in order to detect affordances. Instead, it describes "a coherent set of habitual embodied actions, feelings and sensations" (Hauw, 2018, p. 56) that accounts for the phenomenological fraction of the player-environment interaction (Thompson, 2007).

Special attention should therefore focus on how players experience their ongoing interactions and dynamically adjust their interpersonal coordination. Thus, recent studies have shown how soccer players use their experience to actively adjust activity to the collective behavior dynamics (Gesbert et al., 2017; Feigean et al., 2018) and how team members are sensitive to environmental information as they monitor the ongoing interpersonal coordination through the feeling of being together with others (Lund et al., 2012; Himberg et al., 2018). Notably, Lund et al. (2012) described how rowers are sensitive to the tension they feel in their movements as they mutually adjust their activity. The traditional methods are retrospective phenomenological interview techniques like the elicitation or self-confrontation techniques, which aim to access and describe agents' lived experience at the level of pre-reflective consciousness: What is he/she trying to do? What is drawing his/her attention? (Gesbert et al., 2017; Hauw, 2018; Rochat et al., 2018). To illustrate, Gesbert et al. (2017) performed an enactive phenomenological analysis to characterize the environmental information that soccer players were attuned to as they adapted their activity to contextual demands during competition.

To conclude, we suggest extending and enriching the behavioral perspective (how do athletes act in the world?) described by Santos et al. (2018) with a phenomenological perspective (how do athletes experience their engagement with the world?) in order to enhance task representativeness in soccer. As Seifert et al. (2016, p. 110) suggested: *"the use of an ecological dynamics framework could be enriched by the analysis of performers' experience because it gives experiential meaning to the (. . .) behavioral patterns."* By accessing the environmental information that players are sensitive to as they adjust their activity and by understanding how this information shapes players' sense-making processes (i.e., phenomenological data), coaches would be better equipped to manipulate task constraints and increase the degree to which athletes' behaviors during training tasks replicate those of competition. From this co-adaptive relationship between coaches' and players' experiences, new opportunities for acting and learning would emerge.

AUTHOR CONTRIBUTIONS

VG and DH co-wrote the manuscript.

REFERENCES

Bourbousson, J., and Fortes-Bourbousson, M. (2016). How do co-agents actively regulate their collective behavior states? *Front. Psychol.* 7:1732. doi: 10.3389/fpsyg.2016.01732

Bourbousson, J., Poizat, G., Saury, J., and Sève, C. (2010a). Team coordination in basketball: description of the cognitive connections among teammates. *J. Appl. Sport Psychol.* 22, 150–166. doi: 10.1080/10413201003664657

Bourbousson, J., Poizat, G., Saury, J., and Sève, C. (2012). Temporal aspects of team cognition: a case study on concerns sharing within basketball. *J. Appl. Sport Psychol.* 24, 224–241. doi: 10.1080/10413200.2011.630059

Bourbousson, J., Sève, C., and McGarry, T. (2010b). Space–time coordination dynamics in basketball: part 1. Intra- and inter-couplings among player dyads. *J. Sports Sci.* 28, 339–347. doi: 10.1080/02640410903503632

Buhrmann, T., and Di Paolo, E. (2015). The sense of agency–a phenomenological consequence of enacting sensorimotor schemes. *Phenomenol. Cogn. Sci.* 16, 207–236. doi: 10.1007/s11097-015-9446-7

Chow, J., Davids, K., Button, C., and Renshaw, I. (2016). *Nonlinear Pedagogy in Skill Acquisition: An Introduction*. New York, NY: Taylor & Francis Group.

Di Paolo, E., Rohde, M., and De Jaegher, H. (2011). "Horizons for the enactive mind: values, social interaction, and play," in *Enaction: Toward a New Paradigm for Cognitive Science*, eds J. Stewart, O. Gapenne, and E. Di Paolo (London: MIT Press), 33–88.

Feigean, M., R'Kiouak, M., Seiler, R., and Bourbousson, J. (2018). Achieving teamwork in naturalistic sport settings: An exploratory qualitative study of informational resources supporting football players' activity when coordinating with others. *Psychol. Sport. Exerc.* 38, 145–166. doi: 10.1016/j.psychsport.2018.06.008

Froese, T., and Di Paolo, E. (2011). The enactive approach: theoretical sketches from cell to society. *Pragmat. Cogn.* 19, 1–36. doi: 10.1075/pc.19.1.01fro

Gesbert, V., and Durny, A. (2017). A case study of forms of sharing in a highly interdependent soccer team during competitive interaction. *J. Appl. Sport Psychol.* 29, 466–483. doi: 10.1080/10413200.2017.1287787

Gesbert, V., Durny, A., and Hauw, D. (2017). How do soccer players adjust their activity in team coordination? An enactive phenomenological analysis. *Front. Psychol*. 8:854. doi: 10.3389/fpsyg.2017.00854

Gibson, J. (1979). *The Ecological Approach to Visual Perception*. Boston, MA: Houghton Mifflin.

Hauw, D. (2018). Énaction et intervention en psychologie du sport chez les sportifs élites et en formation [Enaction and intervention in sports psychology among elite athletes and in training]. *Can. J. Behav. Sci. Rev. Can. Sci. Comport*. 50, 54–64. doi: 10.1037/cbs0000094

Himberg, T., Laroche, J., Bigé R., Buchkowski, M., and Bachrach, A. (2018). Coordinated interpersonal behaviour in collective dance improvisation: the aesthetics of kinaesthetic togetherness. *Behav. Sci*. 8:e23. doi: 10.3390/bs8020023

Lund, O., Ravn, S., and Christensen, M. (2012). Learning by joining the rhythm: apprenticeship learning in elite double sculls rowing. *Scand. Sport Stud. Forum* 3, 167–188. Available online at: https://portal.findresearcher.sdu.dk/da/publications/learning-by-joining-the-rhythm-apprenticeship-learning-in-elite-d

Rochat, N., Gesbert, V., Seifert, L., and Hauw, D. (2018). Enacting phenomenological gestalts in ultra-trail running: an inductive analysis of trail runners' courses of experience. *Front. Psychol*. 9:2038. doi: 10.3389/fpsyg.2018.02038

Santos, R., Duarte, R., Davids, K., and Teoldo, I. (2018). Interpersonal coordination in soccer: interpreting literature to enhance the representativeness of task design, from dyads to teams. *Front. Psychol.* 9:2550. doi: 10.3389/fpsyg.2018.02550

Seifert, L., Adé, D., Saury, J., Bourbousson, J., and Thouvarecq, R. (2016). "Mix of phenomenological and behavioural data to explore interpersonal coordination in outdoor activities: examples in rowing and orienteering," in *Interpersonal Coordination and Performance in Social Systems*, eds P. Passos, K. Davids, and J. Y. Chow (London: Routledge, Taylor & Francis Group), 109–125.

Seifert, L., Orth, D., Mantel, B., Boulanger, J., Hérault, R., and Dicks, M. (2018). Affordance realization in climbing: learning and transfer. *Front. Psychol*. 9:820. doi: 10.3389/fpsyg.2018.00820

Silva, P., Garganta, J., Araújo, D., Davids, K., and Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Med*. 43, 765–772. doi: 10.1007/s40279-013-0070-9

Thompson, E. (2007). *Mind in Life: Biology, Phenomenology, and the Sciences of Mind*. Cambridge MA: MIT Press.

Varela, F., Thompson, E., and Rosch, E. (1991). *The Embodied Mind*. Cambridge: MIT Press.

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Training and Competition Load Monitoring and Analysis of Women's Amateur Basketball by Playing Position: Approach Study

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Currently, the number of women involved in sport is increasing. Although, research on their characteristics and performance is scarce. A great amount of research on men's basketball is available, but it is unknown if it can be applied to women's basketball. The objective of this research was to characterize the internal and external load performed by female basketball players during training and sports competition according to playing positions through inertial devices. The participants in the following study were 10 amateur basketball players who competed at regional level (21.7 ± 3.65 years; 59.5 ± 12.27 kg, and 168.5 ± 3.56). Data were collected in games of the final phase ($n = 8$) and from 5 vs. 5 training tasks ($n = 47$). All the analyses were run according to playing positions. Each player was equipped with a Garmin^{TM} Heart Rate Band and Wimu^{TM} inertial device that monitored physical activity and movement in real time. The results obtained showed that the load experienced during competition was significantly higher ($p < 0.001$) than during training (Heart Rate, Player Load, Steps, Jumps, and Impacts). There were also differences according to playing positions, mainly between the backcourt and frontcourt players ($p < 0.001$). The players must work in higher areas of heart rate during training, mainly in Z4 and Z5, increasing their HRmáx y HRavg. The training doesn't equal the load supported and the distance performed in competition, so it is necessary to pay more attention during training. This information allows us to develop adequate training protocols adjusted to the specific individual requirements of the sports competition.

Keywords: performance analysis, women, basketball, internal load, external load

INTRODUCTION

The load experienced by athletes in competition is one of the most important research topics in sports science. Knowing the physical and physiological demands of sports competition is the key to determining optimum training processes (Torres-Ronda et al., 2016). The physical demands of team sports are difficult to quantify due to the unpredictable and intermittent nature of the sport (Caetano et al., 2015), in basketball, intense actions are combined with periods of rest, and these do not follow temporal patterns. There are studies seek to understand what happens during competition in order to replicate it in training; however there are few studies that compare what happens in training with what happens in actual competition (Reilly et al., 2009).

Previous research has already reported the different methods used to quantify and measure load in training and matches, mainly employing internal training load analysis (iTL) and external training load (eTL) measurement by Time Motion Analysis (Matthew and Delextrat, 2009; Scanlan et al., 2012). With external training loads representing the physical work performed during the training session or internal training loads that are the biochemical (physical and physiological) and associated biomechanical stress responses (Impellizzeri et al., 2005). Besides, associations between internal and external measures of load and intensity are important for understanding the competition and training process (Vanrenterghem et al., 2017).

Different means exist to facilitate the description and analysis of the load that athletes endure in training and competition. The monitoring of external load measurements derived from triaxial accelerometers is currently considered a viable tool in indoor team sports (Chambers et al., 2015). In turn, the use of micro-technological sensors such as accelerometers has also allowed the analysis of body movements representing an unspecific assessment of the quantity and magnitude of high-intensity activities without measurable movements on the court surface (i.e., jumps, screens, rebounds, etc.,) which can't be registered by GPS (Puente et al., 2017). From a practical point of view, the use of technology in official competitions allows a more accurate control of the athlete's load during a match, providing an important reference for training prescription besides allowing trainers and scientists to identify the level of fatigue by detecting the changes in individual players' movement mechanics due to fatigue (Barrett et al., 2016; Barreira et al., 2017).

Basketball is a sport that comprises complex technical-tactical abilities that have a direct influence on the physiological requirements imposed on the player during competition (Drinkwater et al., 2008; Ziv and Lidor, 2009). There are many studies which consider that it is hybrid in nature, where most of the energy mobilized has an aerobic origin (McInnes et al., 1995; Abdelkrim et al., 2007; Narazaki et al., 2009). However, as occurs in other collective sports, the explosive actions, such as direction changes, jumps, or maximum intensity movements, as well as some specific game actions, such as shots, getting unmarked, or dribbling, are anaerobic dependent and are decisive for the final performance of the athletes (McInnes et al., 1995; Ostojic et al., 2006; Chaouachi et al., 2009; Narazaki et al., 2009).

Sallet et al. (2005) carried out a study with French basketball players, and concluded that the anaerobic capacity could be considered to be one of the most important performance factors in this sport, regardless of the fact that, quantitatively, aerobic work was more important for the energy supply. The study of the load experienced by the athlete helps to understand the efforts that lead to different energy requirements. The iTL and eTL of basketball players makes it possible to understand the training process, its effects on the athlete and the validity of specific internal measures (Weaving et al., 2014; McLaren et al., 2017). In men's basketball, intensity differences have been found in the play actions regarding the player's position (Abdelkrim et al., 2007). In team sports, it is essential to identify the most appropriate exercise to promote the best performance adaptations. For this, the differentiation of specific game positions is necessary (Stiffler et al., 2015; Vitale et al., 2016, 2018). In women's basketball, differences in the distance covered have been found according to teams' styles of play, but not as a function of match periods (Conte et al., 2015). Besides, it has been confirmed that physiological demands are different according to competitive level and playing position (Rodriguez-Alonso et al., 2003).

With regard to the external load, the distance covered by the female basketball players is similar (5–6 km per match) but there are differences among categories relating to intensity. The players in higher categories spend more time, in an intermittent fashion, in the more intense work zones (Scanlan et al., 2012). During a match the female players carry out between 576 and 652 movement patterns, which implies a change every 3 s (Matthew and Delextrat, 2009; Conte et al., 2015; Delextrat et al., 2015). Regarding the most explosive actions in the game, the players carry out between 1 and 2 jumps per minute and about 45 sprints per match (Matthew and Delextrat, 2009; Conte et al., 2015; Delextrat et al., 2015). In relation to the internal load in women's basketball, the authors have found a mean HR of 162–173 bpm, a HRmax of 188–195 bpm and a %HRmax of 82.4–92.5% (Rodriguez-Alonso et al., 2003; Matthew and Delextrat, 2009; Scanlan et al., 2012; Abad et al., 2016; Reina et al., 2017). With respect to training, there are no ecological studies that assess it, without the intervention of the researcher, although it is considered essential to carry out this type of studies.

When analyzing sports competition together with training, it has been found that the type of training situations has been evaluated in order to compare them with demands generated by competition and in an attempt to try to match them. However, it has only been found that the demands of training equal or exceed those in matches or conditioning exercises (Petersen et al., 2011). Reina et al. (2017) showed that kinematic demands, as well as the more intense cardiac values, depend on the type of playing situation, the loads more similar to the competition are given in the 5 vs. 5 training tasks; however, higher values were always recorded in competition.

In addition, the literature establishes the importance of psychological factors such as motivation, stress or fatigue in sports performance. Coaches use technology to track players throughout the season, real-time monitoring provides data to minimize factors such as fatigue and the risk of injury (Fox et al., 2017). Marcora et al. (2009) state that mental fatigue is a psychobiological state caused by prolonged periods of demanding cognitive activity and is characterized by subjective feelings of fatigue and lack of energy that could decrease performance.

Research that describes women's competition is relatively scarce (Matthew and Delextrat, 2009; Narazaki et al., 2009; Scanlan et al., 2012). It is not clear how to address the individual needs of female players in order to optimize performance while following the principles of sports training, such as individuality and specificity (Boyle et al., 1994; Bompa and Haff, 2009). There are no studies about the work base performed during training, and no studies have been done comparing the load variables recorded by inertial systems, between training and official competition in women's basketball. Thus, the main goal of this research was to analyze the existing differences in the iTL and eTL between a 5 vs. 5 match in an official competition and 5 vs. 5 in female basketball training, as a function of the specific position of each player. Secondly, to know which physical and physiological capacities are the most influential for performance during competition. It was hypothesized that the training load was different from the competition load, being superior in competition. The same would be true of the specific playing positions, each one will have specific characteristics.

MATERIALS AND METHODS

Experimental Approach to the Problem

This investigation follows an associative strategy (Ato et al., 2013) where an attributive variable is utilized and differences between groups are examined. It is a longitudinal observational study performed with amateur athletes participating in official Spanish Regional competitions.

The data was collected after the qualifying phase of the competition. Only games played during the final phase (last 2 months of the season) were analyzed. In this phase, teams of similar characteristics compete among themselves (the six best teams in competition). All players took part in the pre-seasons conditioning program to ensure a good standard of fitness at the start to the championship. Competition habits were established by this time, therefore avoiding the possibility of untrained athletes (Matthew and Delextrat, 2009). In addition, data was collected from training carried out during this period. All the analyses were run according to playing positions. Overall, data sets were collected from 22 training sessions and eight official competitive matches (**Figure 1**). Only the 5 vs. 5 tasks were used for the analysis, therefore, 47 tasks per position were used (235 statistic units). The purpose was to analyze and compare the full game situation in training and competition. Knowledge of the load that female basketball players reach in training compared with competition, would allow coaches to design sessions with the specific demands of competition for each playing position.

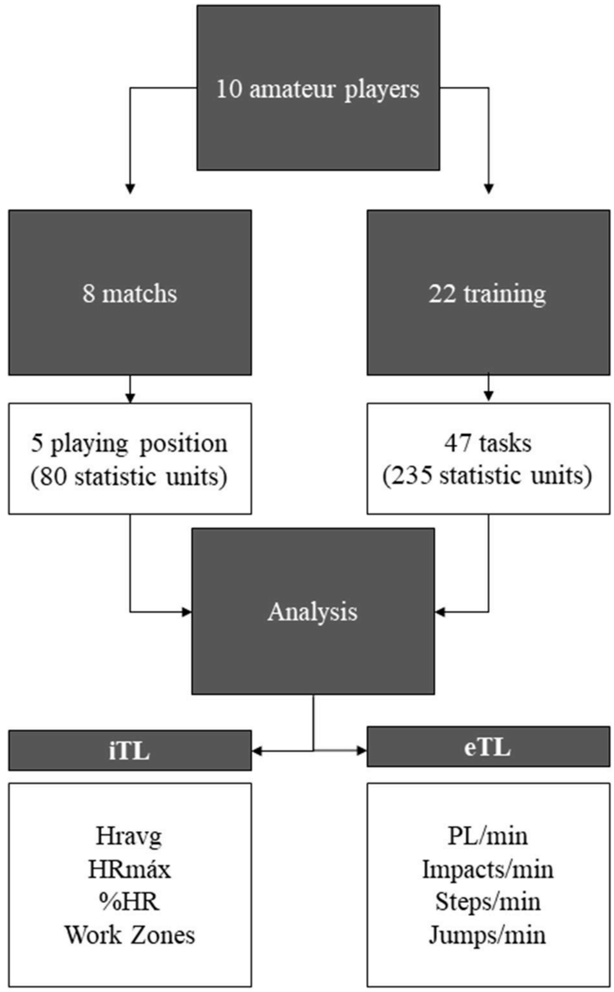

FIGURE 1 | Methods flow chart.

Subjects

The population to which this study was oriented were senior female Spanish basketball players (>18 years). The team is amateur because they don't receive remuneration. It is a senior team, in which each player has already defined its predominant role in the game. It is true that the general game dynamics may cause them to perform other specific functions during training and competition. The participants in the following study were 10 basketball players (2 Point Guards, 2 Shooting Guards, 2 Small Forwards, 2 Power Forwards, and 2 Centers) who compete at regional level (21.7 ± 3.65 years; 59.5 ± 12.27 kg and 168.5 ± 3.56). All the players belonged to the same club and team, and completed an 8-week pre-season conditioning program consisting of a combined training plan of agility, plyometric, anaerobic, and endurance components, ensuring adequate fitness for the beginning of the competitive season. All players and trainers were informed about the research protocol, requisites, benefits, and risks, and their written consent was obtained before the start of the study. The ethics committee of the University of Extremadura approved the study (n° 67/2017).

Instruments

To collect the iTL and eTL variables, each player was equipped with a Garmin^{TM} Heart Rate Band and a Wimu^{TM} inertial device (Muyor et al., 2017) that monitors physical activity and movement. The SPro^{TM} software automatically analyzes all the data gathered by the inertial device and sends it to the computer screen in real time. The Wimu^{TM} inertial device was turned on and placed in a specific customized vest pocket located on the posterior side of the upper torso fitted tightly to the body, as is typically used in games. Both the inertial device and the software come from the same organization (RealTrack Systems, Almería, Spain).

Variables

The independent variable was Game situation (GS), defined as the specific demands and the number of players involved in the training situation (Ibáñez et al., 2016). The 5 vs. 5 training situations with the characteristics of real competition, Full Game (FG), and 5 vs. 5 in official league games (C) were used for the analysis. In addition, four dependent variables were established, iTL; eTL; playing position and time.

Internal Training Load

These variables were collected from a heart rate monitor. Heart Rate (HR) was measured in beats per minute. The values were expressed as: Average Heart Rate (HRavg), Maximum Heart Rate (HRmax), %Maximum Heart Rate (%HRmax) and Work zones (Makivić et al., 2013). The work zones were the time that players spent in each zone during the task. Work zones were established as the percentage of the maximum heart rate that each game situation implied. The work zones were Z1 (50–60%), Z2 (60–70%), Z3 (70–80%), Z4 (80–90%), Z5 (90–95%), and Z6 (>95%). These work zones are calculated automatically and individually by the SPRO™ software. For this, the HRmáx presented by each player in each session is taken into account.

External Training Load

These variables were recorded with the accelerometers using WIMU™ inertial devices. The specific software SPRO™ processes data raw from the accelerometer automatically. This step avoids possible errors by researchers. The following neuromuscular variables were selected:

- Impacts: Measuring the g force to which the body is subjected in the different play actions being the vector sum of the g forces that a player endures in the three planes (x, y, z). The value of an impact is established when the G force of the movement is higher than 5 Gs (Puente et al., 2017). The manufacturer's software (SPRO™) uses these reference measurements.
- Steps: Movement that implies advancing with a flight time of <400 ms.
- Jumps: Movement that consists in elevating oneself from the court with an impulse that implies more than 400 ms of flight time before landing again, in the same or another place. The manufacturer's software (SPRO™) reference measurements have been used (Pino-Ortega et al., 2018).
- Player Load: Is a vector magnitude derived from the triaxial accelerometry data that quantifies movement with high resolution. It is the vector sum of the accelerations of the device on its three axes (vertical, antero-posterior and lateral), and is calculated from the following equation where (Z) is acceleration on the antero-posterior axis, (X) is acceleration on the medium-lateral axis; (Y) is acceleration on the vertical axis, (t) is time and (n) is number. Accelerations and decelerations are used to build a cumulative measurement of the acceleration change rate. We use a cumulative measurement (PL) and an intensity measurement (PL.min-1), which can, therefore, indicate the stress rate that the player's body is subjected to during a determined time period. The Player Load as a load unit has a moderate-high grade of reliability and validity (Barreira et al., 2017).

Equation 1. Accumulated PlayerLoad™ used in the quantification of loads in sport. Where: Z, acceleration of the anterior-posterior axis; X, acceleration of the medial-lateral axis; and, vertical axis acceleration; t, time; n, number.

Playing Position

Specific position of the player in the team (Point Guard, Shooting Guard, Small Forward, Power Forward, Center).

Time

Time in minutes in each 5 vs. 5 training and competition. Rest periods between quarters and time out were excluded from the study.

The data obtained from the selected kinematic variables for this study come from the internal sensors of an inertial device (accelerometers, pedometers, radiofrequencies) and do not rely on data from global positioning systems (GNSS), since for this study the position of the players on the court was not analyzed. For the statistical analysis, all the kinematic data were normalized to the practice time (repetitions per minute).

Procedures

Once the sample and the competitive phase were selected, data was collected by monitoring each of the players in every training session and matches played during that period. All players took part in the pre-season conditioning program to ensure a good standard of fitness at the start of the competition, avoiding the possibility of having untrained athletes (Matthew and Delextrat, 2009). Players always trained and played in their specific position. The data collection in training and competition was not performed in the same manner, differing in the following way:

Training Analysis

Each training week included 3 sessions of an hour and a half each, totaling four and a half weekly training hours, plus the corresponding match. All training sessions in the final competition phase began with 15 standardized minutes based on dynamic stretching exercises, reactivation and racing. The players were allowed to drink water during recovery periods. All training sessions were designed, directed and supervised by the coaching staff. The training sessions were based principally on contesting shot exercises, small sided games, tasks with number superiority or inferiority and 5 vs. 5 tasks. In this study, the demands generated by the FG in training were analyzed to subsequently compare it with the real game. 5 vs. 5 tasks in training took place at the end of the session, with an average total duration of 18.76 min. The tactical instructions were the same as those performed in matches and fluctuated depending on the opponent (Abdelkrim et al., 2010). It has been stated that time-motion variables do not vary according to different defensive tactics (Sampaio et al., 2016). The tasks of 5 vs. 5 respected the rules of the competition and the scoreboard was used to control time, fouls, free-throws.

$$PlayerLoad_{t=n} \sum_{t=0}^{t=n} \sqrt{(Z_{t=i+1} - Z_{t=i})^2 + (X_{t=i+1} - X_{t=i})^2 + (Y_{t=i+1} - Y_{t=i})^2} \quad (1)$$

TABLE 1 | Descriptive and inferential results as a function of game situation.

		5 vs. 5 in Training	5 vs. 5 in Competition	*F*	*d*
iTL	HRMax	175.18	192.33	33.23***	1.01
	HRAvg	145.91	169.18	65.16***	1.32
	%HRMax	72.95	84.59	65.16***	1.32
	Z1 (50–60%)	17.78	3.66	23.83***	0.84
	Z2 (60–70%)	19.32	6.30	44.47***	1.13
	Z3 (70–80%)	23.28	12.35	26.42***	0.92
	Z4 (80–90%)	27.38	37.74	15.89***	0.62
	Z5 (90–95%)	9.19	31.84	130.92***	1.64
	Z6 (>95%)	1.27	8.09	69.53***	0.87
eTL	PL/min	0.94	2.82	814.84***	2.37
	Impacts/min	1.69	1.65	0.02	0.02
	Steps/Min	39.15	53.96	63.37***	1.15
	Jumps/Min	1.43	1.76	5.12**	0.32

*$p < 0.05$; **$p < 0.01$; ***$p < 0.000$.

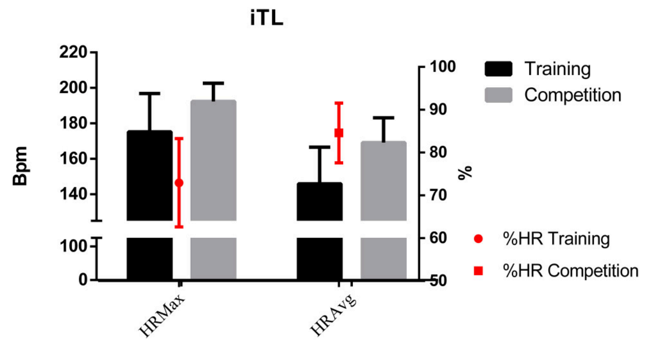

FIGURE 2 | Internal load by game situation.

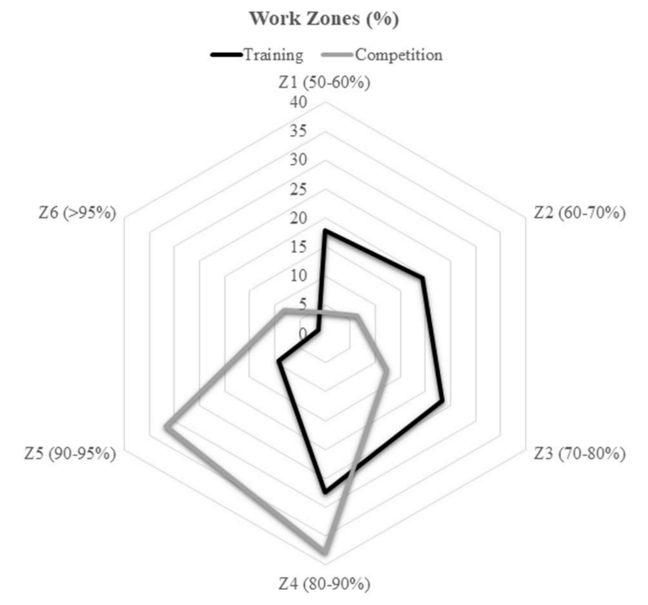

FIGURE 3 | Work zones by game situation.

Match Analysis

A real time analysis was made for the four quarters in every competitive game, excluding the rest intervals between quarters (Torres-Ronda et al., 2016). Training and competitive 5 vs. 5 quarters lasted 10 min. Quarters lasted a total of 16 to 19 min. Only the players on the court were analyzed. Analyses were performed during the whole time the quarter lasted. All variables were normalized to minutes.

Statistical Analyses

First of all, the normal distribution of the data was analyzed with the Kolmogorov-Smirnov test (Field, 2009), to select the subsequent statistical analysis. Next, the kinematic variables were normalized to action per min, due to the difference shown in the time duration of determined tasks and compared to competition. A descriptive analysis of the data was performed with means and standard deviation of all the collected variables in the study both in training and competition. Next, a one-factor ANOVA, with the effect size according to Cohen's *d,* was used to identify the differences between groups and the effect magnitude of training or competition. Effects sizes were calculated by Cohen's *d* from the F-test where effect sizes of 0.20 are small, 0.50 are medium and 0.80 are considered large (Thalheimer and Cook, 2002). Statistical analyses were performed using SPSS v.21 software (Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

RESULTS

Table 1 presents the descriptive and inferential results of all variables according to Game Situation (5 vs. 5 in training and competition). The main descriptive results show the higher demand of official matches, as reflected by the results of the iTL variables (maximum, average, heart rate, or the time percentage spent in each zone) (**Figures 2**, **3**).

Besides, they reveal variations in the number of actions per minute when assessing the eTL variables (PL, Steps and Jumps per minute), except regarding the number of impacts per minute (**Figure 4**).

A large size effect was found in those variables that show a statistically significant difference. This effect size is >0.80 in the variables HRmáx, HRavg, %HRMáx, Z1, Z2, Z3, Z5, Z6, PL, and Steps per minute.

Secondly, **Table 2** shows results from the analysis of differences between positions and the variables analyzed in training and competition. The results of the analysis on the basis of the specific playing position using a one-factor ANOVA and the effect size through Cohen's *d* show that there are statistically significant differences in the iTL, *Player Load* and *steps per minute* variables ($p < 0.005$), in all specific playing positions, comparing training and competition. In the case of the *impacts* and *jumps per minute* variables, there are statistically significant differences only for the Center role. The center is the player

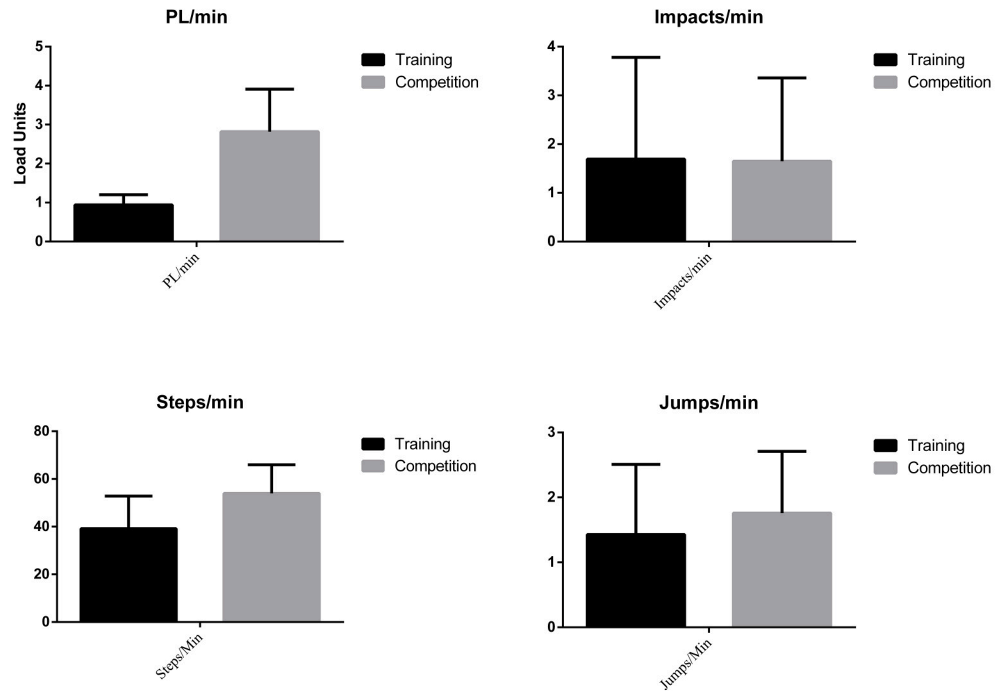

FIGURE 4 | External load by Game Situation.

performing the least jumps and receiving the least impacts. The Shooting Guard supports a greater internal load, having values of 88.18% HRMax. In addition, the Power Foward is the one that accumulates the most external load, having values of 3.45 PL (**Figures 5**, **6**). In addition, large effect sizes are shown except for the *impacts per minute* and *jumps per minute* variables, which are small.

DISCUSSION

The present investigation, as far as we know, is the first one to combine an internal and external load in women's basketball during training and competition according to a specific playing position. It was considered relevant to perform an inferential analysis according to playing position in order to guarantee specificity and individualized training principles, and differences were found. It has emerged that the load supported by the players during competition is higher, except for the number of impacts per minute. The players perform more steps and jumps per minute and their PL value is higher in competition. The shooting guard role is the one that has the highest %HR in competition, and its values of PL are greater than for the rest of the game positions. In the case of the power forward, she is the one who receives the most impacts per minute and performs more steps and jumps per minute. In addition, the competition imposes a greater physiological requirement than training.

When practicing basketball, the players have to experience similar demands to the ones experienced in competition, therefore, the trainers have to know and be able to reproduce them (Matthew and Delextrat, 2009; Conte et al., 2015; White and MacFarlane, 2015; Tee et al., 2016; Torres-Ronda et al., 2016). From the training standpoint it is useful to know if the workload has been below or above the real game reference loads, according to individual needs.

Regarding the load experienced by the athletes, there are different means that allow it to be defined in both training and sports competition. The monitoring of the external load measurements derived from triaxial accelerometers is currently considered a viable tool in team sports (Paul et al., 2010; Arruda et al., 2015). Besides, the evaluation of physical qualities through the use of different tests can also be useful to establish training programs, as well as to monitor it (Attene et al., 2016; Padulo et al., 2016). Previous studies have examined load using video Time Motion Analysis (Bishop and Wright, 2006; Scanlan et al., 2012; Hulka et al., 2014) and have presented controversial results in basketball studies as outcomes have varied according to the investigation (Bishop and Wright, 2006; Abdelkrim et al., 2007; Scanlan et al., 2012). Because of this, Arruda et al. (2015) suggest that using measurements derived from accelerometers could be an alternative, objective and reliable method to assess external load in training.

Player Load has been measured as a reliable and reproducible metric in the quantification of cumulative motion for indoor sports (Peterson and Quiggle, 2017). The use of inertial devices, such as accelerometers also makes it possible to analyze body impacts. This measurement represents an unspecific assessment of the amount and magnitude of specific high-intensity movements in basketball which cannot be registered

TABLE 2 | Inferential results as a function of the game situation and specific position.

		GS*	Point guard (n = 16 competition) (n = 235 Training)	Shooting guard (n = 16 competition) (n = 235 Training)	Small forward (n = 16 competition) (n = 235 Training)	Power forward (n = 16 competition) (n = 235 Training)	Center (n = 16 competition) (n = 235 Training)
iTL	HRMax	Training	171.97**	184.46**	180**	161.33*	180.34**
		Competition	191.33	196.83	193.67	187.43	193.25
	HRAvg	Training	141.82**	152.87**	147.52**	134.87*	154.18**
		Competition	169.76	176.36	173.14	157.04	173.09
	%HRMax	Training	70.91**	76.44**	73.76**	67.44*	77.09**
		Competition	84.88	88.18	86.57	78.52	86.55
eTL	PL/min	Training	0.94**	0.91**	0.95**	0.96**	0.92**
		Competition	2.64	3.45	2.78	2.92	2.12
	IMPACTS/min	Training	1.41	3.73	1.64	1.62	0.27**
		Competition	1.63	1.83	1.62	2.06	0.83
	STEPS/min	Training	36.58**	47.05*	35.14**	43.81**	33.44**
		Competition	48.03	56.91	50.51	60.28	52.65
	JUMPS/min	Training	1.32	1.73	1.6	1.77	0.68**
		Competition	1.65	2.12	1.51	2.15	1.13

*$p < 0.05$; **$p < 0.01$; ***$p < 0.000$.*

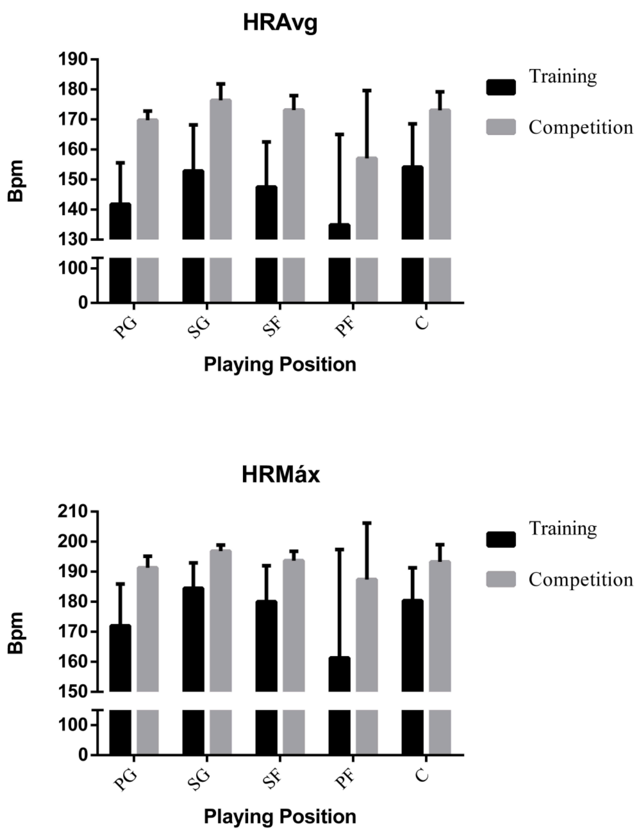

FIGURE 5 | Internal load by playing position.

by GPS (Weaving et al., 2014; Puente et al., 2017). The impacts per minute variable suggests the number of changes of direction, and actions involving the use of the body such as blocking, rebounding or defending (Barbero et al., 2014), which are an essential measure of physical load (Chambers et al., 2015). Per example, numerous short sprints might occur in successive different directions, therefore the development of a multi change of direction is expected to help fitness trainers and coaches for training evaluation purposes, among others (Padulo et al., 2016). The training with multiple changes of direction reproduces more closely the kinds of movements typical of basketball and should be preferred from an ecological point of view during training (Attene et al., 2016).

Physical fatigue using the variable PlayerLoad has been analyzed, but mental fatigue has not been taken into account. Marcora et al. (2009) establishes that subjects with mental fatigue qualify the perception of effort during exercise as significantly greater compared to the control condition. Therefore, it limits tolerance to exercise in humans through greater perception of effort. Besides (Padulo et al., 2018), confirm through their study the need for a good recovery by the players during breaks, waiting times, and substitutions since the increase in metabolic conditions, such as the increase in HR, decreases the jump performance.

Statistically significant differences between training and competition were found for the analyzed team regarding this kind of variables. Higher values were found in the PlayerLoad variable and the number of steps per minute in all the specific playing positions was higher in competition. In the case of impacts and jumps per minute, only the Center position revealed differences between training and sports competition. The Center players received more impacts and performed more jumps per minute in official matches. Therefore, the competition demands obtained a directly influence in the neuromuscular load of centers in relation to training sessions, not found this influence in the rest of playing roles. This effect could be produced due to a higher intensity of specific skills with physical contact (rebound, picks, to buttock down, etc.) during competition due to a higher level opposition. In this sense

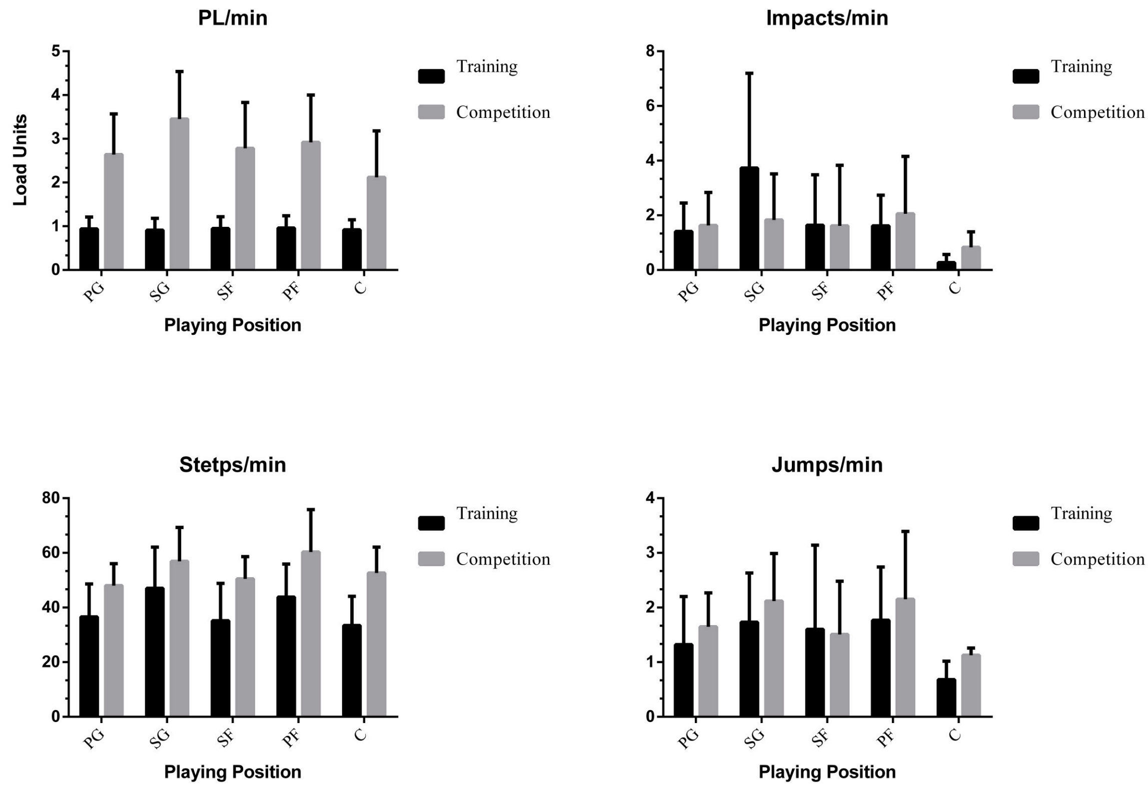

FIGURE 6 | External load by playing position.

(Gabbett, 2016), claim that pre-competition sessions with a high load generate positive adaptations that reduce the risk of injury. So it is recommended to adjust the demands of competition to training.

Regarding the internal load, the specialized literature states that this kind of variables allow a more adequate control of the different responses of the organism toward training and competition (Makivić et al., 2013), therefore it is a vital complement when characterizing load. Compared to competition, Torres-Ronda et al. (2016) have shown that more similar cardiac responses to the ones in competition appear with 5 vs. 5 training, however, higher values were registered in men's basketball competition. Likewise, regarding women's basketball, Matthew and Delextrat (2009) obtained a HRAvg of 165 and a maximum of 170 in matches and Scanlan et al. (2012) obtained mean values of 162 bpm. In this study, HRAvg and HRMax during competition were 171 and 193 bpm while during training they were 145 and 175 bpm. The available literature shows lower values of HR, probably due to the sample studied. In Elite players have better fitness and conditioning, expressed as a lower HR in competition (Drinkwater et al., 2008), therefore it is necessary to specify the age, competitive level, gender and characters of the players.

Differences according to playing position are mainly due to the specificity and specialization of players, how they relate with their teammates or the needs of the competition (Sampaio et al., 2008, 2015). An understanding of these differences is essential for designing training sessions adequate for competitive demands. Some players may reach a higher volume of work for the entire session, while others may do less work overall but consistently reach higher intensities. Guards have to perform at high intensity on the whole court, whereas centers have to do so near the basket. These variations in demands are evident between playing positions and level of anaerobic and aerobic fitness (Abdelkrim et al., 2007; Tee et al., 2016). Monitoring volume and intensity during training and competition, and reporting data individually better than jointly appears to be essential (Howatson and Milak, 2009) for designing specific training sessions for the competitive demands of each player.

In this study, shooting guards are the players that face the greatest physical demand, both in 5 vs. 5 training and in competition. Their mean and maximum HR values are higher than the rest, as well as *Player Load*, impacts and steps per minute, while in jumps per minute maximum values are shown by the power forwards. According to Delextrat et al. (2015) shooting guards and small forwards cover more distance in offense without the ball than point guards, who demonstrate more ball control and have greater passing abilities. Regarding the internal load, differences were found in HRAvg and %HRMax between shooting guards and small forwards compared to power-forwards. Therefore, the outside players are the ones that show a higher physical demand through the HR. Based on this, Puente et al. (2017) affirm that the centers cover less distance and achieve a lower peak velocity than the outside players, revealing lower external and internal demands than the outside players.

Significant differences were found between the inside players (power forwards and centers). The centers have higher cardiac responses, while the power forwards cover greater distances, and perform more jumps and impacts per minute, both in training and competition. In other studies the difference between inside players and outside players has been noted (Torres-Ronda et al., 2016). Besides, players in these positions are clearly differentiated by their anthropometric characteristics in high-performance basketball (Ostojic et al., 2006), but not as clearly in trainees or non-professional players (Nikolaidis et al., 2014). It is possible that in this study, due to the non-professional status of the players, the anthropometric differences between the inside players imply differences in the physical demands, when previous research stated that they perform at a similar level (Delextrat et al., 2015; Torres-Ronda et al., 2016). Delextrat et al. (2015) characterize the inside players as performing more jumps and static efforts (blocking, positioning for the rebound…). In this study, significant differences were found between centers and other specific playing positions, showing less jumps per minute (1.13 jumps/min) and a lower *Player Load* variable (2.12 Player Load/min) supported by the inside players. However, power forwards achieved more jumps per minute and, with the shooting guards, were the ones that experienced a higher Player Load (2.29 Player Load/min). Inside players, due to their anthropometry, possibly do not need to perform some actions in play. For example, due to their physical dominance and height, centers do not need to jump for rebounding or blocking. On the other hand, power forwards record the highest number of impacts and jumps both in training and in competition. Therefore, this playing position would imply a greater effort during the game in order to achieve a better performance; hence, different conditioning training has to be planning according to playing position.

Competition presents higher demands regarding iTL and eTL compared to 5 vs. 5 training. Statistically significant differences were shown in every analyzed variable except for the number of impacts per minute. Differences were found in the demands generated by the different playing positions, but in all cases they were higher in competition. Training sessions usually do not exceed the time of an official match so the same requirements could apply, but, as observed, they are not of the same quality. Hence, the existing differences in the rest of the variables imply a higher game intensity and, thus, the needs of competition are not being met making it essential to generate an optimal load in the prior training so the athlete can face the demands of competition and be physically ready to compete without the risk of an injury.

CONCLUSION

This is the first study to describe the internal and external load demands experienced by senior female basketball players during training and sports competition. Results show the importance of developing specific training plans and conditioning programs adapted to each player at every sport level. If training does not reach the specific demands of competition, a lower competitive performance will be achieved. In addition, rest and tapering periods should be established according to the load experienced by the athletes. Player Load is related with injury risk (Barreira et al., 2017). High intensity accelerations and decelerations are related with muscular damage and are not perceived by athletes until 24 h later (Howatson and Milak, 2009; Barreira et al., 2017). Regarding this point, the shooting guard and power forward experienced higher loads than the rest of the team; therefore, they would need more physical conditioning in training in order to maintain an optimal performance in competition. On the other hand, they also need resting periods to avoid the risk of injury.

Some of the main limitations of the work are those related to the size of the sample. Although a considerable number of games and training tasks have been used, only players from the same team participated, so it is unknown whether these physical profiles are generalizable to other teams of the same competitive level. Obtaining data in a massive way in a real situation of training and competition through the use of inertial devices is very expensive. On the one hand, the need to provide an IMU to each player. On the other hand, the limitations that some sport modalities establish, special permits being necessary. Therefore, a team that was willing to be monitored during a competitive period was contacted, while the official permission of the federation was obtained to be able to use it during the competition. The main strength has been to be able to use these devices in official competition matches, to verify the real load supported by the players in a specific context, in the field of play and not in the laboratory. Currently we are working on increasing the sample, of different categories and levels for a better definition of women's basketball in general.

This preliminary study was conducted with amateur players, and it is necessary to implement this study with professional players to check if this type of response is similar. It is necessary to carry out specific studies to individualize the results in each competitive level and age of training.

PRACTICAL APPLICATIONS

The results of this study provide the key to adapting the abilities that must be performed during training sessions according to player's positions. Thank these results. physical trainers and coaches will be able to adapt their training to what happens in competition, preparing players to face the same demands as those that are generated by real matches.

As for the internal load, the HRmáx obtained in training equals HRavg in matches. The players must work in higher areas of heart rate during training, mainly in Z4 and Z5. It could be achieved by interval exercises without full recovery, to work at the appropriate threshold. For example, a task of 5 vs. 5 in which each team makes at least three attacks and defenses, without stopping the game (dead ball, stops for fouls, out of bounds, field goal, etc.). As a rest interval, each team will make a free throw.

The eTL supported by the players in the competition is much higher than the one supported during the training. It is necessary for players to experience and train the load they have to endure in matches, mainly to prepare and prevent injuries. for this, the 5 vs. 5 tasks have to keep the players active and intense for a longer time and rest periods must be controlled so that they are not excessive. If necessary, rules can be established for different game positions to perform a minimum number of actions (such as jumps, changes of direction, contacts, etc.). For example:

- That it is not necessary to take off ball after goal to give continuity to the game and that the trainers establish the rest.
- That the ball touches the backboard or the rim to get point. Thus, we managed to increase the number of jumps and impacts to catch the ball by the inside players.
- That outside players have to make a certain number of changes of direction in each attack, with or without the ball.

AUTHOR CONTRIBUTIONS

MR: conceptualization, data collet, formal analysis, investigation, methodology, software, visualization, and writing original draft; JG-R: funding acquisition, supervision, writing original draft, writing review, and editing; SF: supervision, writing review, and editing. SI: supervision, writing review, and editing.

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REFERENCES

Abad, C. C., Pereira, L. A., Kobal, R., Kitamura, K., Cruz, I. F., Loturco, I., et al. (2016). Heart rate and heart rate variability of Yo-Yo IR1 and simulated match in young female basketball athletes: a comparative study. *Int. J. Perfor. Anal. Sport* 16, 776–791. doi: 10.1080/24748668.2016.11868927

Abdelkrim, N. B., Castagna, C., El Fazaa, S., and El Ati, J. (2010). The effect of players' standard and tactical strategy on game demands in men's basketball. *J. Strength Cond. Res.* 24, 2652–2662. doi: 10.1519/JSC.0b013e3181e2e0a3

Abdelkrim, N. B., El Fazaa, S., and El Ati, J. (2007). Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br. J. Sports Med.* 41, 69–75. doi: 10.1136/bjsm.2006.032318

Arruda, A. F., Carling, C., Zanetti, V., Aoki, M. S., Coutts, A. J., and Moreira, A. (2015). Effects of a very congested match schedule on body-load impacts, accelerations, and running measures in youth soccer players. *Int. J. Sports Physiol. Perform.* 10, 248–252. doi: 10.1123/ijspp.2014-0148

Ato, M., López, J. J., and Benavente, A. (2013). Un sistema de clasificación de los diseños de investigación en psicología. *An. Psicol.* 29, 1038–1059. doi: 10.6018/analesps.29.3.178511

Attene, G., Nikolaidis, P. T., Bragazzi, N. L., Dello Iacono, A., Pizzolato, F., Zagatto, A. M., et al. (2016). Repeated sprint ability in young basketball players (Part 2): the chronic effects of multidirection and of one change of direction are comparable in terms of physiological and performance responses. *Front. Physiol.* 7:262. doi: 10.3389/fphys.2016.00262

Barbero, J. C., Granda-Vera, J., Calleja-González, J., and Del Coso, J. (2014). Physical and physiological demands of elite team handball players. *Int. J. Perform. Anal. Sport* 14, 921–933. doi: 10.1080/24748668.2014.11868768

Barreira, P., Robinson, M. A., Drust, B., Nedergaard, N., Raja Azidin, R. M. F., and Vanrenterghem, J. (2017). Mechanical Player Load™ using trunk-mounted accelerometry in football: is it a reliable, task-and player-specific observation? *J. Sports Sci.* 35, 1674–1681. doi: 10.1080/02640414.2016.1229015

Barrett, S., Midgley, A. W., Towlson, C., Garrett, A., Portas, M., and Lovell, R. (2016). Within-match PlayerLoad™ patterns during a simulated soccer match: potential implications for unit positioning and fatigue management. *Int. J. Sports Physiol. Perform.* 11, 135–140. doi: 10.1123/ijspp.2014-0582

Bishop, D., and Wright, C. (2006). A time-motion analysis of professional basketball to determine the relationship between three activity profiles: high, medium and low intensity and the length of the time spent on court. *Int. J. Performance Anal. Sport* 6, 130–139. doi: 10.1080/24748668.2006.11868361

Bompa, T. O., and Haff, G. G. (2009). *Periodization: Theory and Methodology of Training*. Champaign, IL: Human Kinetics Publishers.

Boyle, P., Mahoney, C., and Wallace, W. (1994). The competitive demands of elite male field hockey. *J. Sports Med. Phys. Fitness* 34, 235–241.

Caetano, F. G., de Oliveira, M. J., Marche, A. L., Nakamura, F. Y., Cunha, S. A., and Moura, F. A. (2015). Characterization of the sprint and repeated-sprint sequences performed by professional futsal players, according to playing position, during official matches. *J. Appl. Biomech.* 31, 423–429. doi: 10.1123/jab.2014-0159

Chambers, R., Gabbett, T. J., Cole, M. H., and Beard, A. (2015). The use of wearable microsensors to quantify sport-specific movements. *Sports Med.* 45, 1065–1081. doi: 10.1007/s40279-015-0332-9

Chaouachi, A., Brughelli, M., Levin, G., Boudhina, N. B. B., Cronin, J., and Chamari, K. (2009). Anthropometric, physiological and performance characteristics of elite team-handball players. *J. Sports Sci.* 27, 151–157. doi: 10.1080/02640410802448731

Conte, D., Favero, T. G., Lupo, C., Francioni, F. M., Capranica, L., and Tessitore, A. (2015). Time-motion analysis of italian elite women's basketball games: individual and team analyses. *J. Strength Cond. Res.* 29, 144–150. doi: 10.1519/JSC.0000000000000633

Delextrat, A., Badiella, A., Saavedra, V., Matthew, D., Schelling, X., and Torres-Ronda, L. (2015). Match activity demands of elite Spanish female basketball players by playing position. *Int. J. Performance Anal. Sport* 15, 687–703. doi: 10.1080/24748668.2015.11868824

Drinkwater, E. J., Pyne, D. B., and McKenna, M. J. (2008). Design and interpretation of anthropometric and fitness testing of basketball players. *Sports Med.* 38, 565–578. doi: 10.2165/00007256-200838070-00004

Field, A. (2009). *Discovering Statistics Using SPSS*. London: Sage publications.

Fox, J. L., Scanlan, A. T., and Stanton, R. (2017). A review of player monitoring approaches in basketball. *J. Strength Cond. Res.* 31, 2021–2029. doi: 10.1519/JSC.0000000000001964

Gabbett, T. J. (2016). The training-injury prevention paradox: should athletes be training smarter and harder? *Br. J. Sports Med.* 50, 273–280. doi: 10.1136/bjsports-2015-095788

Howatson, G., and Milak, A. (2009). Exercise-induced muscle damage following a bout of sport specific repeated sprints. *J. Strength Cond. Res.* 23, 2419–2424. doi: 10.1519/JSC.0b013e3181bac52e

Hulka, K., Cuberek, R., and Svoboda, Z. (2014). Time–motion analysis of basketball players: a reliability assessment of Video Manual Motion Tracker 1.0 software. *J. Sports Sci.* 32, 53–59. doi: 10.1080/02640414.2013.805237

Ibáñez, S. J., Feu, S., and Cañadas, M. (2016). *Sistema Integral Para el Análisis de las Tareas de Entrenamiento, SIATE, en Deportes de Invasión*. E-balonmano. com: Revista de Ciencias del Deporte 12.

Impellizzeri, F. M., Rampinini, E., and Marcora, S. M. (2005). Physiological assessment of aerobic training in soccer. *J. Sports Sci.* 23, 583–592. doi: 10.1080/02640410400021278

Makivić, B., Nikić Djordjević, M., and Willis, M. S. (2013). Heart Rate Variability (HRV) as a Tool for diagnostic and monitoring performance in sport and physical activities. *J. Exer. Physiol.* 16, 103–131.

Marcora, S. M., Staiano, W., and Manning, V. (2009). Mental fatigue impairs physical performance in humans. *J. Appl. Physiol.* 106, 857–864. doi: 10.1152/japplphysiol.91324.2008

Matthew, D., and Delextrat, A. (2009). Heart rate, blood lactate concentration, and time–motion analysis of female basketball players during competition. *J. Sports Sci.* 27, 813–821. doi: 10.1080/02640410902926420

McInnes, S., Carlson, J., Jones, C., and McKenna, M. J. (1995). The physiological load imposed on basketball players during competition. *J. Sports Sci.* 13, 387–397. doi: 10.1080/02640419508732254

McLaren, S. J., Macpherson, T. W., Coutts, A. J., Hurst, C., Spears, I. R., and Weston, M. (2017). The relationships between internal and external measures of training load and intensity in team sports: a meta-analysis. *Sports Med.* 48, 641–658. doi: 10.1007/s40279-017-0830-z

Muyor, J. M., Granero-Gil, P., and Pino-Ortega, J. (2017). Reliability and validity of a new accelerometer (Wimu®) system for measuring velocity during resistance exercises. *Proc. Inst. Mech. Eng. Part P J. Sports Eng. Technol.* 232, 218–224. doi: 10.1177/1754337117731700

Narazaki, K., Berg, K., Stergiou, N., and Chen, B. (2009). Physiological demands of competitive basketball. *Scan. J. Med. Sci. Sports* 19, 425–432. doi: 10.1111/j.1600-0838.2008.00789.x

Nikolaidis, P., Calleja-González, J., and Padulo, J. (2014). The effect of age on positional differences in anthropometry, body composition, physique and anaerobic power of elite basketball players. *Sport Sci. Health* 10, 225–233. doi: 10.1007/s11332-014-0198-5

Ostojic, S. M., Mazic, S., and Dikic, N. (2006). Profiling in basketball: physical and physiological characteristics of elite players. *J. Strength Cond. Res.* 20:740. doi: 10.1519/00124278-200611000-00003

Padulo, J., Bragazzi, N. L., Nikolaidis, P. T., Dello Iacono, A., Attene, G., Pizzolato, F., et al. (2016). Repeated sprint ability in young basketball players: multi-direction vs. one-change of direction (Part 1). *Front. Physiol.* 7:133. doi: 10.3389/fphys.2016.00133

Padulo, J., Nikolaidis, P. T., Cular, D., Dello Iacono, A., Vando, S., Galasso, M., et al. (2018). The effect of heart rate on jump-shot accuracy of adolescent basketball players. *Front. Physiol.* 9:1065. doi: 10.3389/fphys.2018.01065

Paul, G., M., David, B., P., and Clare, L., M. (2010). The physical and physiological demands of basketball training and competition. *Int. J. Sports Physiol. Performance* 5, 75–86. doi: 10.1123/ijspp.5.1.75

Petersen, C. J., Pyne, D. B., Dawson, B. T., Kellett, A. D., and Portus, M. R. (2011). Comparison of training and game demands of national level cricketers. *J. Strength Cond. Res.* 25, 1306–1311. doi: 10.1519/JSC.0b013e3181d82cfd

Peterson, K. D., and Quiggle, G. T. (2017). Tensiomyographical responses to accelerometer loads in female collegiate basketball players. *J. Sports Sci.* 35, 2334–2341. doi: 10.1080/02640414.2016.1266378

Pino-Ortega, J., García-Rubio, J., and Ibáñez, S. J. (2018). Validity and reliability of the WIMU inertial device for the assessment of the vertical jump. *PeerJ* 6:e4709. doi: 10.7717/peerj.4709

Puente, C., Abián-Vicén, J., Areces, F., López, R., and Del Coso, J. (2017). Physical and physiological demands of experienced male basketball players during a competitive game. *J. Strength Cond. Res.* 31, 956–962. doi: 10.1519/JSC.0000000000001577

Reilly, T., Morris, T., and Whyte, G. (2009). The specificity of training prescription and physiological assessment: a review. *J. Sports Sci.* 27, 575–589. doi: 10.1080/02640410902729741

Reina, M., Mancha, D., Feu, S., and Ibáñez, S. J. (2017). Se entrena como se compite? Análisis de la carga en baloncesto femenino. *Rev. Psicol. Deporte* 26, 9–13.

Rodriguez-Alonso, M., Fernandez-Garcia, B., Perez-Landaluce, J., and Terrados, N. (2003). Blood lactate and heart rate during national and international women's basketball. *J. Sports Med. Phys. Fitness* 43, 432–436.

Sallet, P., Perrier, D., Ferret, J., Vitelli, V., and Baverel, G. (2005). Physiological differences in professional basketball players as a function of playing position and level of play. *J. Sports Med. Phys. Fitness* 45, 291–294.

Sampaio, J., Ibañez, S. J., Gómez, M. Á., Lorenzo, A., and Ortega, E. (2008). Game location influences basketball players performance across playing positions. *Int. J. Sport Psychol.* 39, 43–50.

Sampaio, J., Leser, R., Baca, A., Calleja-Gonzalez, J., Coutinho, D., Gonçalves, B., et al. (2016). Defensive pressure affects basketball technical actions but not the time-motion variables. *J .Sport Health Sci.* 5, 375–380. doi: 10.1016/j.jshs.2015.01.011

Sampaio, J., McGarry, T., Calleja-González, J., Sáiz, S. J., i del Alcázar, X. S., and Balciunas, M. (2015). Exploring game performance in the National Basketball association using player tracking data. *PLoS ONE* 10:e0132894. doi: 10.1371/journal.pone.0132894

Scanlan, A. T., Dascombe, B. J., Reaburn, P., and Dalbo, V. J. (2012). The physiological and activity demands experienced by Australian female basketball players during competition. *J. Sci. Med. Sport* 15, 341–347. doi: 10.1016/j.jsams.2011.12.008

Stiffler, M. R., Sanfilippo, J. L., Brooks, M. A., and Heiderscheit, B. C. (2015). Star excursion balance test performance varies by sport in healthy division i collegiate athletes. *J. Orthopaedic Sports Physical Therapy* 45, 772–780. doi: 10.2519/jospt.2015.5777

Tee, J. C., Lambert, M. I., and Coopoo, Y. (2016). GPS comparison of training activities and game demands of professional rugby union. *Int. J. Sports Sci. Coaching* 11, 200–211. doi: 10.1177/1747954116637153

Thalheimer, W., and Cook, S. (2002). How to calculate effect sizes from published research: a simplified methodology. *Work Learn. Res.* 1–9. Available online at: http://work-learning.com/effect_sizes.htm

Torres-Ronda, L., Ric, A., Llabres-Torres, I., de Las Heras, B., and i del Alcazar, X. S. (2016). Position-dependent cardiovascular response and time-motion analysis during training drills and friendly matches in elite male basketball players. *J. Strength Cond. Res.* 30, 60–70. doi: 10.1519/JSC.0000000000001043

Vanrenterghem, J., Nedergaard, N.J., Robinson, M.A., and Drust, B., (2017). Training load monitoring in team sports: a novel framework separating physiological and biomechanical load-adaptation pathways. *Sports Med.* 47, 2135–2142. doi: 10.1007/s40279-017-0714-2

Vitale, J. A., Caumo, A., Roveda, E., Montaruli, A., La Torre, A., Battaglini, C. L., et al. (2016). Physical Attributes and NFL combine performance tests between italian national league and american football players. *J. Strength Cond. Res.* 30, 2802–2808. doi: 10.1519/JSC.0000000000001377

Vitale, J. A., Povìa, V., Vitale, N. D., Bassani, T., Lombardi, G., Giacomelli, L., et al. (2018). The effect of two different speed endurance training protocols on a multiple shuttle run performance in young elite male soccer players. *Res. Sports Med.* 26, 436–449. doi: 10.1080/15438627.2018.14 92402

Weaving, D., Marshall, P., Earle, K., Nevill, A., and Abt, G. (2014). A combination of internal and external training load measures explains the greatest proportion of variance in certain training modes in professional rugby league. *Int. J. Sports Physiol Perform.* 9, 905–912. doi: 10.1123/ijspp.2013-0444

White, A. D., and MacFarlane, N. G. (2015). Analysis of international competition and training in men's field hockey by global positioning system and inertial sensor technology. *J. Strength Condit. Res.* 29, 137–143. doi: 10.1519/JSC.0000000000000600

Ziv, G., and Lidor, R. (2009). Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players. *Sports Med.* 39, 547–568. doi: 10.2165/00007256-200939070-00003

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A New Reliable Performance Analysis Template for Quantifying Action Variables in Elite Men's Wheelchair Basketball

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This study aimed to develop a valid and reliable performance analysis template for quantifying team action variables in elite men's wheelchair basketball. First action variables and operational definitions were identified by the authors and verified by an expert panel of wheelchair basketball coaching staff in order to establish expert validity. A total of 109 action variable were then placed into 17 agreed Categorical Predictor Variable categories. The action variables were then used to develop a computerized performance analysis template for post-event analysis. Each possession (*n* = 200) from an international men's wheelchair basketball game was analyzed by the first author on two occasions for assessment of intra-observer reliability and by a coach and a performance analyst for inter-observer reliability. Percentage error and Weighted Kappa coefficients were calculated to compare the levels of error and agreement for each action variable. Intra-observer reliability demonstrated perfect or almost perfect agreement (<K0.980) and low percentage error values (<1.50%) for the 109 action variables within the 17 categories. Inter-observer reliability demonstrated perfect or almost perfect agreement (<K0.974) and low percentage error values (<3.00%) for the 109 action variables within the 17 categories. The template should be used in future for obtaining valid and reliable data in elite men's wheelchair basketball.

Keywords: sport performance analysis, Paralympic, reliability, validity, elite sport

INTRODUCTION

Performance analysis aims to assist the decision making and learning of athletes, coaches and support staff (Sampaio et al., 2013; Hughes and Bartlett, 2015). Objective performance data are collected regarding the key actions and behavioral aspects of an individual's and/or team's performance (Sampaio et al., 2013) through specifically designed performance analysis templates and systems. The data are then utilized to provide feedback. Central to the quality of the feedback is the analyst's ability to design an appropriate data collection template that will permit the collection of valid and reliable performance data.

If a sport performance analysis template can record a sports performance using precise definitions of actions and events and consistently produce similar or identical results each time it is used, it can be deemed both valid and reliable. However, previous performance analysis research has highlighted problems in the processes often undertaken to identify valid action variables and to develop a reliable performance analysis template (Watson et al., 2017; Jayal et al., 2018). Particularly in relation to the validity of defining action variables, performance indicators, operational definitions, and the reliability test procedures themselves (James et al., 2005; Hughes et al., 2012; Thomson et al., 2013; Hughes, 2015).

Hughes (2015) argued the presentation of reliability and validation procedures has increased immensely since Hughes et al. (2002) previously highlighted the need for the reliability of performance analysis templates to be clearly established within all studies. Prior to the 2007 special edition of the International Journal of Performance Analysis in Sport that focused on reliability issues in performance analysis, of the 77 empirical studies published, only 56% of the journal's articles reported reliability procedures and only 42% included details detailing the validation procedures.

Within the special edition's editorial, O'Donoghue (2007, p. i) stated the discipline "takes reliability very seriously because many methods involve human operators where there are many sources of measurement error." Subsequently, the number of articles within the journal presenting information regarding the reliability procedures increased to 68% but the number of studies outlining the validation processes reduced to 40% (312 out of 462 articles that included empirical data between 2007 and 2015). Despite these clear recommendations, the importance of establishing and presenting both the validity and reliability of performance analysis templates is too often still overlooked. More recently, Watson et al. (2017) have reiterated this point and attempted to address the issue regarding validity and reliability of key performance indicators that discriminate between successful and unsuccessful rugby union teams. However, the issue of the collection of valid and reliable performance analysis data in less studied sports, e.g., wheelchair basketball, are no exception to this trend.

Wheelchair basketball is played by people with varying physical disabilities with a primary objective of scoring more baskets than their opponents (Frogley, 2010). To achieve this objective, the offensive team endeavors to progress the ball toward the basket by coordinating actions in an attempt to position themselves close to the basket, whilst the defensive team attempts to coordinate actions to restrict the offensive players' space to shot and regain possession. The two teams consist of players with a range of disabilities, including amputations, birth defects, cerebral palsy, paralysis due to an accident and, spina bifida, and who are unable to play the running form of basketball (Gil-Agudo et al., 2010). The growth in the sport, now being played by over 105 nations (International Wheelchair Basketball Federation, 2016), has led to the performance gap between participation and qualification into a World Championships or Paralympic Games becoming increasingly difficult. Nations have had to become more tactically and technically strategic in the way athletes and teams prepare for competitions through turning to performance analysis (de Bosscher et al., 2008). The discipline, therefore, seems to be an excellent approach for increasing the technical and tactical understanding of wheelchair basketball demands, assisting coaches, athletes, classifiers and analysts with the ability to apply the findings in order to improve training plans and game management.

Each of the seven post-event wheelchair basketball performance analysis articles published, however, that have attempted to explore the technical and tactical demands of the sport using a form of performance analysis template (Vanlandewijck et al., 1995, 2003, 2004; Molik et al., 2009; Skucas et al., 2009; Gómez et al., 2014, 2015), have inherently questionable validity and reliability. These studies have relied on box score data, with no consideration of its validity or reliability and the (modified) comprehensive basketball grading system (CBGS) to provide an "objective" means of evaluating individual player performance. The CBGS was originally developed for use in running basketball and from a very small sample of games at a specific level of competition (Mullens, 1978), making it invalid for use in the wheelchair game. The CBGS records the frequency counts of shots, rebounds, and fouls drawing a game, concluding that the classification system proportionally represents the functional potential of the players. However, these findings offer limited tactical and technical insights into the key determinants of success and thus provide limited contextually rich data that can be used by coaches, players and staff to inform future practice. Furthermore, the post-event analysis completed in these studies and largely in performance analysis research differs from applied practice whereby the immediateness of the obtained results is of priority. Post-event analysis, however, allows for greater in-depth analysis and warrants a higher precision of accuracy due to the possibility that errors can be rectified (Arriaza and Zuniga, 2016).

Researchers have attempted to include wheelchair basketball specific variables in the modified-CBGS (Byrnes and Hedrick, 1994), however, the sport-specific variables were removed due to definitional errors identified as a result of the operators' experience (Vanlandewijck et al., 2003, 2004). The CBGS and modified-CBGS data were also found to be highly correlated with one another. Reliability of these studies was assessed by inter-observer reliability procedures using a Pearson's R Correlation, which has been criticized due to presenting miss-leading results as it is an assessment of relationship, not agreement (Liu et al., 2016). Despite this, researchers have elected to use this "evidence" to determine the quality of players' games and made comparisons between functional classification groups, identifying that higher classified players achieved higher CBGS scores.

Furthermore, researchers have also claimed the findings from individual box score data can be used to provide an insight into team performance. Neither version of the CBGS, however, capture contextual and situational relevant data regarding team performance. Araújo and Davids (2016) argued that it is important to consider the interactive behaviors of players over time and recording these on a continuous or sequential basis. Researchers have identified the performance relationship between game status (e.g., Sampaio et al., 2010), line-up rotations (e.g., Clay and Clay, 2014) and the offensive-defensive dyads involved in sports (García et al., 2013), and thus by capturing this data it may be possible to provide meaningful objective augmented feedback (Araújo, 2017; Jayal et al., 2018). Passos (2008) also argued that the collection of discrete variables, as is the case with the (modified) CBGS, does not provide a true insight into an entire performance. Additionally, the seven studies did not mention how the action variables were established. Therefore, if the process of establishing the action variables is not outlined and the secondary box score data has been shown to be potentially incorrect, the data collected should not be used by coaches, players and support staff to inform decisions regarding team aspects of performance (Ziv et al., 2010). The (modified) CBGS is not suitable for measuring team performance in elite men's wheelchair basketball.

Considering the above concerns within the discipline and specifically in wheelchair basketball regarding reliability, there is a need for a new post-event valid and reliable sports performance analysis template to assess a team's performance in wheelchair basketball. The template is required to correctly identify and record the actions that occur during a game in a consistent manner, thus providing coaches, players and support staff with meaningful performance data to inform future decision making following games. The variables that are analyzed in the study can contribute to the players' learning, thus increasing the likelihood of wheelchair basketball teams achieving performance success. As such, an adequate methodological process for quantifying action variables in elite men's wheelchair basketball was required. Therefore, the aims of this paper were to (i) develop a valid performance analysis template in elite men's wheelchair basketball and (ii) assess its intra-observer and inter-observer reliability by the lead author, a wheelchair basketball coach and a performance analyst intern.

MATERIALS AND METHODS

Following ethical approval from the University of Worcester's Ethics and Research Governance Committee, the methodological approaches used by James et al. (2005) and Thomson et al. (2013) were followed as an initial framework. The framework was adapted and followed nine distinct stages; stages one to six relating to the validation process, stage seven developing the performance analysis template and stages eight and nine referred to establishing reliability (**Figure 1**).

Validation Process

First, a list of 120 action variables was developed from previous wheelchair basketball literature and the knowledge of the authors. The action variables were initially grouped into 16 categories depending on the sub-phases that would occur during a single possession in the game. The action variables within each category were an exhaustive list of all behaviors that could occur which help toward understanding the sequential nature of a possession that would contribute toward scoring a basket.

Second, on receipt of written informed consent, developed in line with The British Association of Sport and Exercise Sciences code of conduct, from four elite wheelchair basketball staff, the list was circulated and the participants were given 1 week to scrutinize the information. The four staff members consisted of three elite wheelchair basketball coaches (Coach one: 20 years' experience; Coach two: 19 years' experience; Coach three: 19 years' experience) and a member of support staff from an elite wheelchair basketball team (3 years' experience). During the week, the staff were asked to review the list and provide their opinions as to whether the variables and categories would allow the collection of objective data regarding the sequential nature of a possession. The staff made notes on the list and returned it.

Third, adaptations were made to the action variables and categories during a focus group with all four staff and the lead researcher. Following the discussion, the adapted list comprised of 109 action variables placed into 17 categories. The Offense – End and Defense – End categories were combined into the End of Possession category, removing 18 action variables, the action variables within the Offense – Shot category were split into three categories (Shot Taken, Shot Point, and Shot Outcome) adding two action variables and the Defensive System category added five action variables to provide additional context to the possession.

Fourth, operational definitions were developed for each of the 109 variables using various resources (Frogley, 2010; Federation International Basketball Association, 2014; International Wheelchair Basketball Federation, 2014). The list of action variables and operational definitions was then re-circulated to each of the wheelchair basketball staff members who were given another week to comment.

Fifth, the staff identified any suggested amendments to the definitions during a second focus group. The definitions for "Zone" and "Highline" Defensive System were discussed and amended to add further clarity.

Sixth, video clips with overlaying text were created illustrating each action variable. The clips were circulated to the wheelchair basketball staff using external hard drives. Each member was given 1 week to watch the clips and ensure the overlaying text represented the operational definitions for each action variable. One staff member requested a further clip to illustrate the different types of Defensive System when a team were playing a "Highline" defense. The clip was circulated to all staff members. After watching the additional clip, the staff members confirmed the second video clip represented the overlaying text more accurately. No additional clips or amendments to the operational definitions were required, resulting in the final list of 109 action variables placed into 17 categories (**Table 1**).

Template Development

Following the validation process (stages one to six above); a performance analysis template was created in SportsCode Elite Version 10 during stage seven by the lead researcher, the four wheelchair basketball staff and the performance analysis intern.

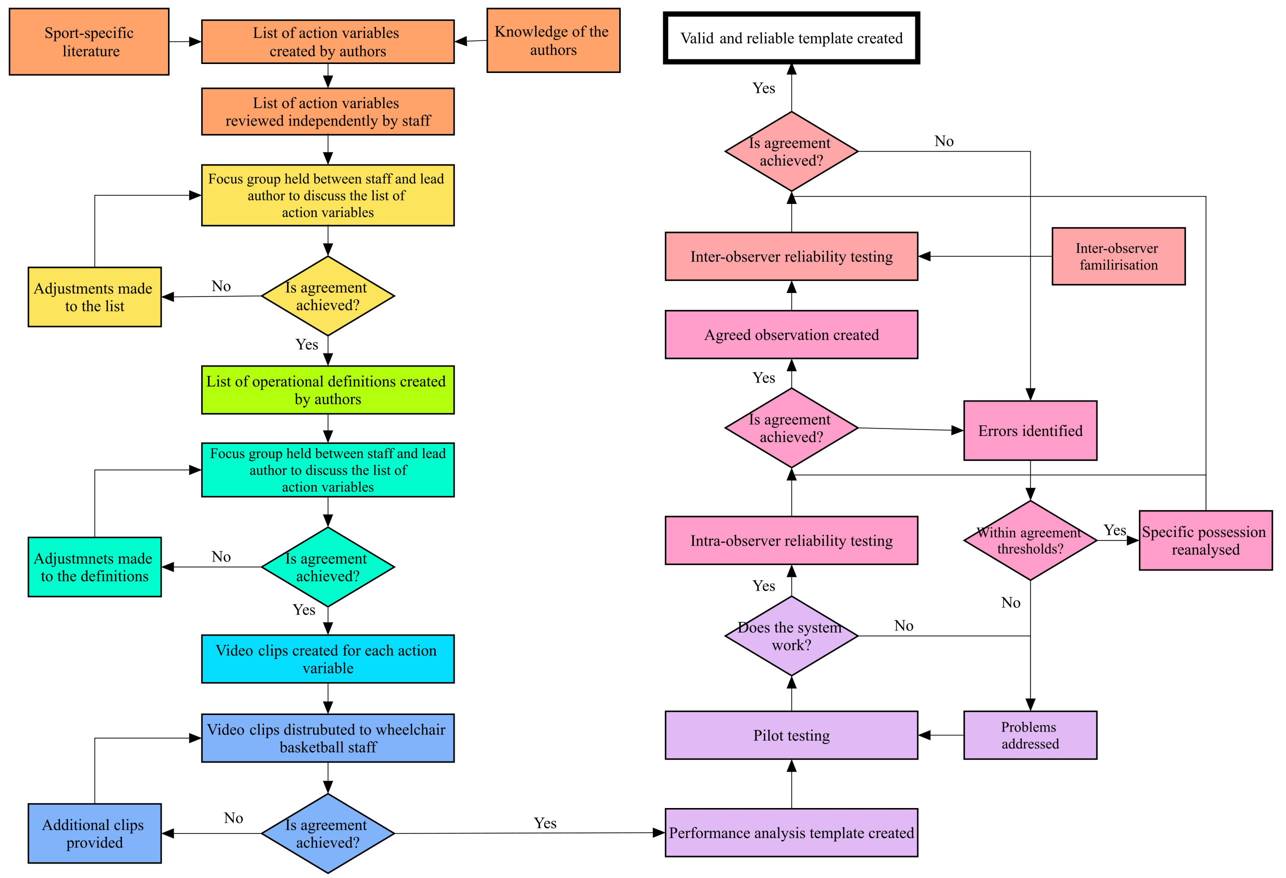


FIGURE 1 | Diagram showing the systematic research process for developing a new performance analysis template [adapted from James et al. (2005) and Thomson et al. (2013)].

The template underwent two pilot tests on a randomly selected elite wheelchair basketball game from a pre-tournament held in 2015. As a result of this pilot, the buttons were resized and positioned in their category group (**Figure 2**).

Reliability Process

Intra-Observer Reliability Assessment

During stage eight, one game of elite male international wheelchair basketball was selected at random from the 2015 European Wheelchair Basketball Championships. The footage was imported into SportsCode Elite Version 10 and converted into a "SportsCode Project" analyzed post-game and viewed at normal playback speed (25 keyframes per second). If necessary, the playback speed was adjusted to ensure events were observed and recorded accurately. Multiple actions within a category could be recorded. For example, if the player was fouled in the act of scoring a successful basket then the End of Possession category would automatically record "Basket Scored" and "Foul For." In addition, the home and away team numbers were checked against the official tournament website and the players' classifications verified on the International Wheelchair Basketball Federation's player database.

Levels of agreement with Weighted Kappa coefficients (Cohen, 1968) and percentage error values (Bland and Altman, 1999) were calculated for each category. The interpretation of Weighted Kappa coefficients within the field of performance analysis has been demonstrated by Lamas et al. (2015); with the following values being utilized: "<0 less than the chance agreement, 0.01–0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, and 0.81–0.99 almost perfect agreement" (Landis and Koch, 1977, p. 165). Whilst, the level of reliability for each category when using the percentage error value was deemed acceptable when less than five per cent error was identified (Hughes et al., 2002).

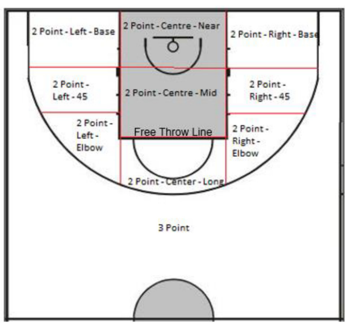
For intra-observer procedures, 100 Home Offense and 100 Away Offense possessions were analyzed on two occasions with a period of 4 weeks between the two observations. The two observations were exported as categorical variables from SportsCode using the "Sorter" function into Microsoft Excel. The 400 rows of data were transferred into a CSV file (**Supplementary Data Sheet S1**) and imported into R (R Core Team, 2015). Weight Kappa coefficients and percentage error values were calculated for each category to determine intra-observer agreement levels between the two observations. Where categories did not demonstrate perfect agreement or establish a

TABLE 1 | Operational definitions for the action variables in each category.

Category	Action variable	Definition
Quarter	Q1 Q2 Q3 Q4	A possession which occurs during the stated quarter of the game. The time in the game is indicated on the scoreboard. Each quarter lasts 10 min, with the clock stopping when the ball is dead (out of bounds, foul or the referee stops play).
	Over time	Once all four quarters have been played, a 5 min period of overtime will be played if the teams are drawing.
Game status	Winning	At the start of a possession, the team with the ball are currently leading on the scoreboard.
	Drawing	At the start of a possession, the team with the ball are currently drawing on the scoreboard.
	Losing	At the start of a possession, the team with the ball are currently losing on the scoreboard.
Home team Away team	The vest numbers of the on-court players, ranging from 0 to 99. For every possession, there will be five "Home Team" numbers and five "Away Team" numbers.	
Home classification Away classification	The classification of the on-court players according to the International Wheelchair Basketball Federation classification system (International Wheelchair Basketball Federation, 2016). For every possession, there will be five "Home Classification" numbers and five "Away Classification" numbers.	
Start of possession	Inbound – baseline	The referee will take the ball to either side of the backboard in the defensive half of the court where the play will begin. One player on the offensive team will push out of bounds behind the baseline and is given 5 s to pass the ball to a teammate.
	Inbound – endline	The referee will take the ball to either side of the backboard in the offensive half of the court where the play will begin. One player on the offensive team will push out of bounds behind the baseline and is given 5 s to pass the ball to a teammate.
	Sideline – front	The referee will take the ball to the location near the half-court line where the play will begin. One player on the offensive team will push out of bounds behind the sideline and is given 5 s to pass the ball to a teammate from within the offensive half of the court.
	Sideline – back	The referee will take the ball to the location near the half-court line where the play will begin. One player on the offensive team will push out of bounds behind the sideline and is given 5 s to pass the ball to a teammate from within the defensive half of the court.
	Defensive rebound	The defensive team gains possession of the ball after a missed shot that is not gathered by an offensive player.
	Offensive rebound	Possession starts when the offensive team retains possession of the ball after a missed shot.
	Free throw	An unopposed shot behind a line 15 feet from the basket, typically awarded to an offensive player who is fouled while in the act of shooting. Each free throw made is worth one point. A free throw is also known as a "foul shot."
	Other start	Any other possession start, e.g., start of the game.
	Turnover	A turnover occurs when the offensive team loses possession of the ball to the opposing team, resulting from a handling error.
Shot taken	Shot	During the possession, the ball is propelled in an upward direction toward the basket in an attempt to score.
	No shot	During the possession, the ball is not propelled toward the basket or if the ball is propelled toward the basket when the shot clock is past 0.1 s resulting in a Violation Against.
Shot point	One	Following the awarding of a free-throw attempt, the ball is propelled toward the basket from the free-throw line.
	Two	The ball is propelled toward the basket from inside the three-point zone and the referee will raise one hand in the arm and holds up two fingers.

(Continued)

TABLE 1 | Continued

Category	Action variable	Definition
	Three	The ball is propelled toward the basket from outside the three-point zone and the referee will raise one hand in the arm and hold up three fingers.
	No shot	During the possession, the ball is not propelled toward the basket or if the ball is propelled toward the basket when the shot clock is past 0.1 s resulting in a Violation Against.
Shot outcome	Successful	A shot that falls through the ring and is awarded the relevant points by the referee, indicated by the number of fingers held up by his/her hand.
	Unsuccessful	A shot that does not fall through the ring and is rebounded by a player or a player is stopped due to a foul/violation or the ball goes out of bounds.
	No shot	During the possession, the ball is not propelled toward the basket or if the ball is propelled toward the basket when the shot clock is past 0.1 s resulting in a Violation Against
Shot clock remaining	6–0.1 S 12–7 s 17–13 s 24–18 s	The time remaining on the shot clock when the offensive player propels the ball toward the basket. The time is recorded when the ball is released from the shooting player's hands and not when the ball hits the ring, backboard or when the basket is scored. 17–13 s is also triggered when a player's free-throw attempt (successful or unsuccessful) would result in the shot clock counting down from 14 s.
	Dead	The time on the shot clock is stopped. This only happens when an unsuccessful free-throw attempt results in an additional attempt.
	No shot	During the possession, the ball is not propelled toward the basket or if the ball is propelled toward the basket when the shot clock is past 0.1 s resulting in a Violation Against.
Shot location		The location on the court where the shot attempt is taken from, this is measured from the position of the wheelchair's front castors. When a Free Throw attempt is taken this is from the Free Throw Line.
	No shot	During the possession, the ball is not propelled toward the basket or if the ball is propelled toward the basket when the shot clock is past 0.1 s resulting in a Violation Against.
Man out offence	Equal numbers	The number of offensive and defensive players in the front-court is equal.
	Numbers advantage	The number of offensive players is different from the number of defensive players in the front-court.
End of possession	Foul against	The referee penalizes the team with the ball for infringing the rules of the game, resulting in a loss of possession.
	Foul for	The referee penalizing a player from the team without possession of the ball for infringing the rules of the game.
	Violation against	The referee awards the defensive team with a throw-in at the place nearest to the infraction of the rules.
	Defensive rebound	The defensive team secure possession from an unsuccessful shot.
	Offensive rebound	The offensive team maintains possession from an unsuccessful shot.

(Continued)

TABLE 1 | Continued

Category	Action variable	Definition
	Basket scored	The referee awards the offensive team with either a one-point, two-point or three-point score dependent on the location and circumstance of the shot.
	Other	The possession ends by another means, e.g., referee stopping play due to a player out of their wheelchair.
	Out of bounds	The ball goes crosses the field of play and results in the offensive team losing possession.
	Free throw	The referee awards a player with an unhindered shot in basketball made from behind a set line due to being fouled by an opponent.
	Handling error	A player from the offensive team loses possession through a backcourt violation, traveling or the opposition stealing the ball.
Defensive system	1 Man press 2 Man press 3 Man press 4 Man press 5 Man press	The stated number of defensive players applying pressure in the backcourt at the point when the ball is inbounded.
	Highline	The defensive players initially set up above the free throw line in a straight line between each sideline and force offensive players toward the sideline.
	Zone	The defensive players initially drop back to around the key before either staying put or pushing out toward the three-point line.
	No defensive system	The defensive players are unable to adopt a system as the offensive team attack the basket too quickly, e.g., from a turnover or the defensive system adopted when a player is taking a free-throw attempt.
Defensive outcome	Successful defense	The defensive team stop the offensive team from scoring and secure possession. If the team stop the offensive team from scoring but fail to secure possession the Defensive Outcome is Unsuccessful.
	Unsuccessful defense	The defensive team are unable to stop the offensive team from scoring or from re-securing possession.
Possession	Maintained	The offensive team re-secure possession.
	Lost	The defensive team are unable to secure possession.
	Basket scored	The offensive team score a basket.

zero per cent error, the source of the discrepancy was identified and the specific possession was re-observed to create an agreed observation.

Inter-Observer Reliability Assessment

Following the establishment of an agreed observation, stage nine involved a wheelchair basketball coach and a performance analysis intern completing an observation of the same game, enabling the completion of an inter-observer reliability test. The wheelchair basketball coach, who had 19 years of sport-specific experience, was involved in the classification of action variables and had a year of experience using a similar performance analysis software program (Dartfish TeamPro, Switzerland). The performance analysis intern had 9 months experience of performance analysis in wheelchair basketball) and 3 years of experience as a performance analyst in rugby union using SportsCode Elite.

The coach and performance analyst intern accessed the action variables, operational definitions and the accompanying video clips 2 weeks prior to conducting the observations to help familiarize themselves with the specific behaviors they were required to record. In addition, the coach and the intern were allowed to code a pre-tournament game between the two competing nations to assist with learning the performance analysis template and the software. Familiarization varied in time for the two operators, with the coach completing four sessions of 2 h over a 5 day period and the intern undertaking an additional 2-h session before both individuals felt they were able to complete the reliability test (O'Donoghue, 2014). The testing was conducted 1 day after they had completed their final familiarization session. The coach and the intern focused on observing the entire game, which equated to 200 possessions. Weighted Kappa coefficients and percentage error values were calculated for each category to determine inter-observer agreement levels with the agreed observation being first compared against the coach's observation and second against the performance analyst intern's observation. Finally, the coach's, performance analyst intern's and the agreed observation were triangulated and

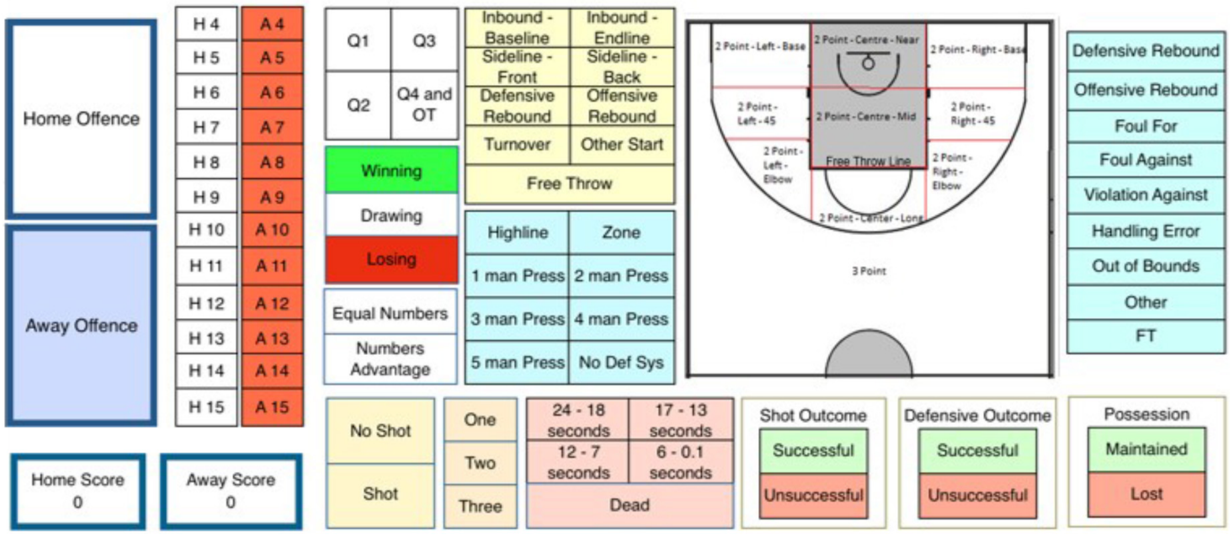


FIGURE 2 | Team performance analysis template for coding wheelchair basketball performance.

expressed as Weighted Kappa coefficients and percentage error values.

RESULTS

Intra-Observer Reliability Test

Cohen's Weighted Kappa demonstrated perfect agreement (K1.000) for 12 categories and almost perfect agreement (K0.987–0.994) for the remaining five categories between the first (Ob1) and second observation (Ob2) (**Table 2**). Percentage error reported zero error for the same 12 categories and below the five per cent acceptable error percentage for the remaining five categories.

Inter-Observer Reliability

Agreed Observation Versus Coach's Observation

The test demonstrated perfect agreement (K1.000) and zero percentage error for ten categories and almost perfect agreement (K0.974–0.993) and within the acceptable percentage error threshold (0.50–1.50%) for the remaining seven categories (**Table 3**). The Man-Out Offense category recorded the lowest Weighted Kappa coefficient (K0.974) but almost a zero percentage error value (0.50%). By comparing the frequency counts for each action variable between the two observations within this category, it was identified that no action was recorded for one possession by the coach resulting in the discrepancy.

Agreed Observation Versus Performance Analyst Intern's Observation

The test demonstrated perfect agreement (K1.00) and zero percentage error with 12 categories and almost perfect agreement (K0.981–0.993) and within the five per cent error limit (0.50–1.50%) with five categories (**Table 3**). The Shot Clock Remaining category recorded the lowest Weighted Kappa coefficient (K0.981) and highest error percentage (1.50%) as a result of three disagreements.

Triangulation of Coach's, Performance Analyst Intern's, and Agreed Observation

Through reporting the Weighted Kappa coefficients and percentage error values of the 17 categories, 9 categories demonstrated perfect agreement and zero percentage error, and 8 categories produced almost perfect agreement (K0.974–0.996) and within the five per cent error threshold (0.50–3.00%). Three categories, Shot Location, Start of Possession and Shot Clock Remaining, reported the largest number of discrepancies amongst the variables within each action variable (**Table 3**). The triangulation results for the Shot Location category highlight the category is the most susceptible to producing errors, however, the Weighted Kappa coefficient and percentage error values are still within the acceptable thresholds for agreement levels.

DISCUSSION

This paper set out to develop a unique valid and reliable performance analysis template for wheelchair basketball. To achieve this aim, the methodological procedures to develop a template completed by James et al. (2005) and Thomson et al. (2013) were adapted. This involved completing a nine-stage methodological process, which included a validation process, template development and reliability assessment. To address the limitations of the (modified) CBGS, it was necessary to employ the knowledge of sport-specific staff to assist in identifying contextually relevant action variables as well as drawing on the existing sport-specific literature. The four members of staff that were used in the paper provided a qualitative contribution through focus groups to further

TABLE 2 | Intra-observer agreement reported using Cohen's Weighted Kappa (K) and percentage error between the first observation (Ob1) and the second observation (Ob2).

	Quarter	Home team	Home classification	Away team	Away classification	Game status	Start of possession	Man out offence	Shot taken	Shot point	Shot outcome	Shot location	Shot clock remaining	End of possession	Defensive system	Defensive outcome	Possession
Ob1 vs.	K1.000	K1.000	K1.000	K1.000	K1.000	K1.000	K0.981	K1.000	K1.000	K1.000	K1.000	K0.988	K0.980	K0.981	K0.980	K1.000	K1.000
Ob2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.50%	0.00%	0.00%	0.00%	0.00%	1.00%	1.50%	1.50%	1.50%	0.00%	0.00%

TABLE 3 | Inter-observer agreement reported using Cohen's Weighted Kappa (K) and percentage error between the agreed observation (Ob3), the coach's observation (Ob4), and the performance analyst intern's observation (Ob5).

	Quarter	Home team	Home classification	Away team	Away classification	Game status	Start of possession	Man out offence	Shot taken	Shot point	Shot outcome	Shot location	Shot clock remaining	End of possession	Defensive system	Defensive outcome	Possession
Ob3	K0.993	K1.000	K1.000	K1.000	K1.000	K1.000	K0.981	K0.974	K1.000	K0.992	K1.000	K0.994	K0.981	K1.000	K0.993	K1.000	K1.000
vs. Ob4	0.50%	0.00%	0.00%	0.00%	0.00%	0.00%	1.50%	0.50%	0.00%	0.50%	0.00%	0.50%	1.50%	0.00%	0.50%	0.00%	0.00%
Ob3	K1.000	K1.000	K1.000	K1.000	K1.000	K1.000	K0.994	K1.000	K1.000	K1.000	K1.000	K0.983	K0.981	K0.987	K0.993	K1.000	K1.000
vs. Ob5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.50%	0.00%	0.00%	0.00%	0.00%	1.50%	1.50%	1.00%	0.50%	0.00%	0.00%
Ob3 vs. Ob4 vs.	K0.996	K1.000	K1.000	K1.000	K1.000	K1.000	K0.987	K0.983	K1.000	K0.995	K1.000	K0.988	K0.974	K0.991	K0.991	K1.000	K1.000
Ob5	0.50%	0.00%	0.00%	0.00%	0.00%	0.00%	1.50%	0.50%	0.00%	0.50%	0.00%	1.50%	3.00%	1.00%	1.00%	0.00%	0.00%

enhance the final list of 109 action variables and operational definitions.

The template was developed to be used post-event, with the ability to extract data as total frequency counts or as successive, discrete possessions. The development of the template built on Cooper et al. (2007) idea of dividing an observation into specific time cells. It also agreed with Thomson et al. (2013) work that this process was a sufficient method for assessing test-retest analysis. However, rather than dividing the observed performance into 2 min or 10-s time cells, each possession, which could last up to 24 s, was used. As outlined above, within each possession, irrelevant of the duration, each observer collected information pertaining to 17 categories.

Intra-observer and inter-observer reliability tests highlighted that the accuracy of all observations was excellent for the notation of all 109 action variables and 17 categories with inter-observer reliability slightly lower than intra-observer reliability. The coach's observation achieved the lowest Weighted Kappa coefficient for the Shot Clock Remaining category whilst the performance analyst intern achieved the lowest Weighted Kappa coefficient for the Man-Out Offense category.

Previous research in boxing and rugby union have identified that it is not unexpected for the level of inter-observer reliability to be inferior to intra-observer reliability (Thomson et al., 2013: intra-observer agreement ranged from 80–100% whereas inter-observer agreement ranging from 33–100%; James et al., 2005: intra-observer agreement ranged from 1.97+3.14% whilst inter-observer agreement ranged from 11.09+8.61%), but all observations in this paper fell within the adequate levels of reliability. It is clear, however, that an adequate period of template piloting, familiarization and training was key to obtaining these excellent levels of reliability. The small disagreements identified between the observations could be due to the dynamic nature of the sport whereby observers are attempting to record action variables quickly and thus may incorrectly click on a closely related button rather than missing an action at all. Examples of this were identified when the coach coded the possession starting as an "Offensive Rebound" whereas the agreed observation coded the possession starting as a "Defensive Rebound." It could also be argued that whilst operational definitions should be clear to distinguish between the two rebound types, they share a number of characteristics and thus may explain the disagreement.

The use of two reliability statistical approaches, Weighted Kappa coefficients (Cohen, 1968) and percentage error values (Bland and Altman, 1999), provided a useful cross-checking method for determining the reliability of the template. The concept of percentage error allowed directed comparisons of agreement to be made irrespective of the scaling between observers (Hopkins, 2000). Thus, it enabled the identification of errors and determined if these were random (McHugh, 2012). Whilst the Weighted Kappa tests acknowledged that in some instances no operator could be sure of the action to record (McHugh, 2012) and provided credit when two observers recorded adjacent values, for example, in the Shot Location category. The use of both percentage error and weighted kappa statistics to assess intra-observer and inter-observer is recommended in the development process of a performance analysis template.

It is important to note, however, that this template was developed for post-event analysis, and thus changes would be required if the goal was to use the template in real-time analysis. The action variables included within the template were carefully considered to ensure meaningful and contextually relevant information was captured. Additional action variables could be added to the template to assist in strengthening the profile of an elite team's performance regarding different tactical approaches, however, this would likely increase the time taken to analyze the wheelchair basketball performance and interpret the data. Subsequently, if additional modifications were made to the action variables, operational definitions, categories, or template, further reliability assessment would be required. Nevertheless, the current template provides the grounding for future attempts to identify the key tactical determinants of team success in elite wheelchair basketball and the processes undertaken to produce the template provide a framework for the development of future templates in all team sports.

CONCLUSION

The paper provides an improved methodological process to establish a valid and reliable performance analysis template, that in this article we have used to produce accurate and reliable observations of key performance behaviors in a sequential nature within elite male wheelchair basketball. Additionally, the template has enabled the collection of most actions that occur in a wheelchair basketball possession whilst also recording the actions of the opposition, allowing for a context-specific insight to be gained. The current template should now be used by wheelchair basketball coaches, analysts and researchers to collect valid and reliable performance data at zonal qualification tournaments, world championships, and Paralympic Games to help identify the key tactical determinants of team success and subsequently to underpin both performance enhancing training and within-game practices.

DATA AVAILABILITY STATEMENT

The datasets generated for this study can be found in the Worcester Research and Publications collection (https://eprints.worc.ac.uk/id/eprint/7334 and https://eprints.worc.ac.uk/id/eprint/7332).

AUTHOR CONTRIBUTIONS

JF devised the structure of the manuscript, collected and analyzed the data, and drafted the manuscript. AO provided the guidance and support for statistical analyses and reporting, and commented on the final draft. DP devised the structure of the manuscript, oversaw the whole research process, commented on drafts and approved the final draft.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00016/full#supplementary-material

DATA SHEET S1 | Raw intra-observer and inter-observer reliability data.

REFERENCES

Araújo, D. (2017). "Variables characterising performance and performance indicators in team sports," in *Performance Analysis in Team Sports*, eds P. Passos, D. Araújo, and A. Volossovitch (Abingdon: Routledge), 38–52.

Araújo, D., and Davids, K. (2016). Team synergies in sport: theory and measures. *Front. Psychol.* 7:1449. doi: 10.3389/fpsyg.2016.01449

Arriaza, E., and Zuniga, M. (2016). Soccer as a study case for analytic trends in collective sports training: a survey. *Int. J. Perform. Anal. Sport* 16, 171–190. doi: 10.1080/24748668.2016.11868879

Bland, M., and Altman, D. (1999). Measuring agreement in method comparison studies. *Stat. Methods Med. Res.* 8, 135–160. doi: 10.1177/096228029900800204

Byrnes, D., and Hedrick, B. (1994). "Comprehensive basketball grading system," in *Wheelchair Basketball*, eds D. Byrnes, B. Hedrick, and L. Shaver (Washington, DC: Paralyzed Veterans of America).

Clay, D. C., and Clay, K. E. (2014). Player rotation, on-court performance and game outcomes in NCAA men's basketball. *Int. J. Perform. Anal. Sport* 14, 606–619. doi: 10.1080/24748668.2014.11868746

Cohen, J. (1968). Weighted kappa: nominal scale agreement provision for scaled disagreement or partial credit. *Psychol. Bull.* 70, 213–220. doi: 10.1037/h0026256

Cooper, S.-M., Hughes, M., O'Donoghue, P., and Nevill, A. (2007). A simple statistical method for assessing the reliability of data entered into sport performance analysis systems. *Int. J. Perform. Anal. Sport* 7, 87–109. doi: 10.1080/24748668.2007.11868390

de Bosscher, V., Bingham, J., Shibli, S., van Bottenburg, M., and de Knop, P. (2008). *The Global Sporting Arms Race: an International Comparative Study on Sports Policy Factors Leading to International Sporting Success*. Oxford: Meyer & Meyer Sport (UK) Ltd.

Federation International Basketball Association (2014). *Official Basketball Rules*. Mies: FIBA Central Board.

Frogley, M. (2010). "Wheelchair basketball," in *Wheelchair Sport: A Complete Guide for Athletes, Coaches, and Teachers*, ed. V. Goosey-Tolfrey (Champaign, IL: Human Kinetics), 119–132.

García, J., Ibañez, S.-J., Cañadas, M., and Antúnez, A. (2013). Complex system theory in team sports. Example in 5 on 5 basketball contest. *Revista de Psicologia Del Deporte* 22, 209–213.

Gil-Agudo, A., Del Ama-Espinosa, A., and Crespo-Ruiz, B. (2010). Wheelchair basketball quantification. *Phys. Med. Rehabil. Clin. North Am.* 21, 141–156. doi: 10.1016/j.pmr.2009.07.002

Gómez, M. -Á, Molik, B., Morgulec-Adamowicz, N., and Szyman, R. (2015). Performance analysis of elite women's wheelchair basketball players according to team-strength, playing-time and players' classification. *Int. J. Perform. Anal. Sport* 15, 268–283. doi: 10.1080/24748668.2015.11868792

Gómez, M. -Á, Pérez, J., Molik, B., Szyman, R., and Sampaio, J. (2014). Performance analysis of elite men's and women's wheelchair basketball teams. *J. Sports Sci.* 32, 1066–1075. doi: 10.1080/02640414.2013.879334

Hopkins, W. (2000). Measures of reliability in sports medicine and science. *Sport Med.* 30, 1–15. doi: 10.2165/00007256-200030010-00001

Hughes, M. (2015). "Analysis of notation data: reliability," in *Essentials of Performance Analysis in Sport*, 2nd Edn, eds M. Hughes and I. Franks (Abingdon: Routledge), 169–179. doi: 10.4324/9781315776743-11

Hughes, M., and Bartlett, R. (2015). "What is performance analysis?," in *Essentials of Performance Analysis in Sport*, 2nd Edn, eds M. Hughes and I. Franks (Abingdon: Routledge), 18–28. doi: 10.4324/9781315776743-3

Hughes, M., Caudrelier, T., James, N., Redwood-Brown, A., Donnelly, I., Kirkbride, A., et al. (2012). Moneyball and soccer: an analysis of key performance indicators of elite male soccer players by position. *J. Hum. Sport Exerc.* 7, 402–412. doi: 10.4100/jhse.2012.72.06

Hughes, M., Cooper, S.-M., and Nevill, A. (2002). Analysis procedures for non-parametric data from performance analysis. *Int. J. Perform. Anal. Sport* 2, 6–20. doi: 10.1080/24748668.2002.11868257

International Wheelchair Basketball Federation (2014). *Official Wheelchair Basketball Rules*. Available at: https://iwbf.org/rules-of-wheelchair-basketball/

International Wheelchair Basketball Federation (2016). *Who We Are*. Available at: https://iwbf.org/the-game/history-wheelchair-basketball/

James, N., Mellalieu, S., and Jones, N. (2005). The development of position-specific performance indicators in professional rugby union. *J. Sports Sci.* 23, 63–72. doi: 10.1080/02640410410001730106

Jayal, A., McRobert, A., Oatley, G., and O'Donoghue, P. (2018). *Sports Analytics Applications in Soccer. In Sports Analytics: Analysis, Visualisation and Decision Making in Sports Performance*. Abingdon: Routledge, 220–244. doi: 10.4324/9781315222783-12

Lamas, L., Santana, F., Heiner, M., Ugrinowitsch, C., and Fellingham, G. (2015). Modeling the offensive-defensive interaction and resulting outcomes in basketball. *PLoS One* 10:e0144435. doi: 10.1371/journal.pone.0144435

Landis, J. R., and Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics* 33, 159–174. doi: 10.2307/2529310

Liu, J., Tang, W., Chen, G., Lu, Y., Feng, C., and Tu, X. M. (2016). Correlation and agreement: overview and clarification of competing concepts and measures. *Shanghai Arch. Psychiatry* 28, 115–120. doi: 10.11919/j.issn.1002-0829.216045

McHugh, M. L. (2012). Interrater reliability: the kappa statistic. *Biochem. Medica* 22, 276–282. doi: 10.11613/BM.2012.031

Molik, B., Kosmol, A., Morgulec-Adamowicz, N., Laskin, J., Jezior, T., and Patrzalek, M. (2009). Game efficiency of elite female wheelchair basketball players during world championships (Gold Cup) 2006. *Eur. J. Adap. Phys. Act.* 2, 26–38. doi: 10.5507/euj.2009.007

Mullens, L. (1978). *European Basketball Championships 1977: Reliability of the Observation Protocol. Attempt to Elaborate a Player Proficiency Protocol*. MSc Thesis, Katholieke Universiteit Leuven, Leuven.

O'Donoghue, P. (2007). Editorial: special issue on reliability. *Int. J. Perform. Anal. Sport* 7, 20–27.

O'Donoghue, P. (2014). *An Introduction to Performance Analysis of Sport*. Abingdon: Routledge.

Passos, P. (2008). *Dynamical Decision Making in Rugby: Identifying Interpersonal Coordination Patterns*. Ph.D. thesis, Universidade de Lisboa, Lisbon.
R Core Team (2015). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.
Sampaio, J., Lago, C., Casais, L., and Leite, N. (2010). Effects of starting score-line, game location, and quality of opposition in basketball quarter score. *Eur. J. Sport Sci.* 10, 391–396. doi: 10.1080/17461391003699104
Sampaio, J., McGarry, T., and O'Donoghue, P. (2013). "Introduction," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (Abingdon: Routledge), 1–2.
Skucas, K., Stonkus, S., Molik, B., and Skucas, V. (2009). Evaluation of wheelchair basketball skill performance of wheelchair basketball players in different game positions. *Sportas* 4, 65–70.
Thomson, E., Lamb, K., and Nicholas, C. (2013). The development of a reliable amateur boxing performance analysis template. *J. Sports Sci.* 31, 516–528. doi: 10.1080/02640414.2012.738922
Vanlandewijck, Y., Evaggelinou, C., Daly, D., Van Houtte, S., Verellen, J., Aspeslagh, V., et al. (2003). Proportionality in wheelchair basketball classification. *Adapt. Phys. Activ. Q.* 20, 369–380. doi: 10.1123/apaq.20.4.369
Vanlandewijck, Y., Evaggelinou, C., Daly, D., Verellen, J., van Houtte, S., Aspeslagh, V., et al. (2004). The relationship between functional potential and field performance in elite female wheelchair basketball players. *J. Sports Sci.* 22, 668–675. doi: 10.1080/02640410310001655750
Vanlandewijck, Y., Spaepen, A. J., and Lysens, R. J. (1995). Relationship between the level of physical impairment and sports performance in elite wheelchair basketball athletes. *Adapt. Phys. Activ. Q.* 12, 139–150. doi: 10.1123/apaq.12.2.139
Watson, N., Durbach, I., Hendricks, S., and Stewart, T. (2017). On the validity of team performance indicators in rugby union. *Int. J. Perform. Anal. Sport* 17, 609–621. doi: 10.1080/24748668.2017.1376998
Ziv, G., Lidor, R., and Arnon, M. (2010). Predicting team rankings in basketball: the questionable use of on-court performance statistics. *Int. J. Perform. Anal. Sport* 10, 103–114. doi: 10.1080/24748668.2010.11868506

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frontiers in Psychology

ORIGINAL RESEARCH
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Design, Validation, and Reliability of an Observation Instrument for Technical and Tactical Actions of the Offense Phase in Soccer

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The use of observational methodology in the sports context provides coaches and other sports professionals with flexible tools that adapt to their needs. In collective sports, the use of these instruments is common for the technical and tactical analysis of the game. Based on the importance of data quality in these instruments, the purpose was to design, validate, and test the reliability of a mixed observational instrument of field formats and category systems to analyze technical and tactical actions in the offense phase in soccer. The instrument collects information regarding the actions with the ball, moment of the play (start, development, and end), and contextual situation for the offensive team and for the goalkeeper. The instrument design, validation, and reliability calculation were done in four stages: (a) review of the literature, (b) design the first draft of the instrument, (c) experts' qualitative and quantitative review of the instrument, and (d) observer training test (reliability calculation). The content validity was established by 12 experts (Ph.D. in sports science or soccer coach with at least of 10 years of coaching experience). The Delphi methodology was used. Experts did a quantitative (scale 0–10) and qualitative evaluation. Experts were asked about: (a) comprehension of the criteria, categorical cores, degree of openness, and their definitions, (b) pertinence of categorical cores and degree of openness, and (c) whether to include other categorical cores or degree of openness in the observation instrument. The lowest Aiken's V index was 0.91 for the categorical core "*numerical situation with opponent goalkeeper.*" The inter- and intra-observer reliability presented good levels of agreement. The lowest Kappa index was 0.96 for the inter-reliability in the categorical core "*defensive pressing lines*" and was 0.98 for the intra-reliability in the categorical core "*ball height (start of ball possession),*" "distance of the defensive player," "*ball height (end of ball possession),*" "*numerical situation,*" and "*defensive pressing lines.*" The coefficients of the generalizability analysis showed a high level of accuracy, validity and reliability of the instrument. The results show that the instrument allows to obtain objective, valid and reliable information about the offensive phase in soccer.

Keywords: performance, evaluation, team sport, match analysis, football, observational methodology

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INTRODUCTION

The study of the actions done by the players and team (i.e., match analysis) is common in soccer (Carling et al., 2006). The goal of team analysis is to give coaches useful information about their players, team, and opponents in order to design training and to prepare their matches (Hughes and Franks, 2004). From a research perspective, the analysis of game has focused on finding patterns in the game or performance indicators (Hughes, 2003; Dufour et al., 2017). For this purpose, the observational methodology is used to collect information in team sports, as it allows for the collection of multiple variables that interact in the sporting context (Anguera, 2003; Anguera and Hernández-Mendo, 2015; Fabra et al., 2018; Maneiro et al., 2018; Nadal et al., 2018). In this sense, observational instruments are used to collect information about the behaviors done by players and teams in order to register indicators to improve sports performance (Anguera et al., 2017, 2018; Maneiro et al., 2017; Moreno and Gómez-Ruano, 2017; Morillo et al., 2017; Serna Bardavío et al., 2017; Chacón-Moscoso et al., 2018). The rules and characteristics of the game of soccer, such other field sports, made that these behaviors are complex in nature, uncertainty, and multifactorial (Vilar et al., 2012). For that reason, most of the observational instruments are created *ad hoc* to solve the needs of the coaches or to answer a specific research problem. However, there is also possible to find in the literature generic and specific observational instruments, such the GAIP-Soccer, TSAP, SOF-5, SOFBAS, FUT-SAT or SoccerEye. These instruments have similarities in the analysis of the players and team behaviors, such technical actions and spatial and temporal analysis. However, most of these instruments are just focused on the field players' actions and they do not integrate the goalkeeper actions and the contextual situations of the players' actions with the ball. The current development of football requires that coaches, researchers and performance analysts use instruments that brings together all aspects of the game. These instruments are required not only to integrate the technical actions of the outfield players, but also to analyze aspects such as the influence of the goalkeeper on the offensive game, the numerical situations that occur and the incidence of the outfield area on the technical–tactical actions that occur.

Match analysis has been part of soccer for a several decades (Hughes and Franks, 2004). The introduction of technology, especially specialized software and video, has increased the used of players' and team analysis by coaches and researchers. The first observation instruments were linked to specific software's [e.g., Noldus or Sportcode (Hughes, 2003)]. The analysis of data quality is one of the bases on which the observational methodology is based. This is critical to collect precise, objective and reliable data about the players' actions. In the 1990s, several generic observation instruments were designed and validated. Examples of these instruments are the Team Sports Assessment Procedure (Gréhaigne et al., 1997) and Game Performance Assessment Instrument (Oslin et al., 1998). These instruments were generic, but they can be adapted easily to the different team sports (Harvey et al., 2010). In the two last decades, several specific observation instruments have developed in soccer. An incomplete list of these instruments is: (a) SOF (currently in its fifth version), initially developed by Anguera et al. (2003); (b) SOFBAS (currently in its second version) initially developed by Castellano (2000), (c) FUT-SAT, developed by Da Costa et al. (2011); and (d) SoccerEye, developed by Barreira et al. (2012). There is also possible to find in the literature a large number of observation instruments generate *ad hoc* to solve specific research problems, such as set-plays, activity profiles and group behavior (Sarmento et al., 2017). The analysis of these instruments and the proposal of categorical cores found in the reviewed literature show similar patterns. They collect information related the start of the offensive phase, the progress of the ball possession (attack and defense player/team), and the end of the offensive phase. The information collected about these phases described the actions done by the players and the situation in which these actions are done (e.g., temporal and spatial patterns). Most of these instruments are focused on the study of the field players. Only studies focus on the specific analysis of the goalkeeper had analyzed the actions of this player (Sainz de Baranda et al., 2005; Sainz de Baranda et al., 2008; Abellán et al., 2017).

Reviewed instruments analyze isolated actions, not integrated in the action in their context or players involved. In the same way, the analysis of the game of soccer requires a valid and reliable instrument. The dynamics of the game needs an instrument that analyzes the continuity of the player's actions with the ball, without isolating the actions of the game. The current tendencies of the game require the integration of the goalkeeper as a critical element that participated on the team's offense and the defense. The dynamics of the game need an instrument that analyses the continuity of the game, without isolating game actions. In addition, the goalkeeper's offensive actions and numerical situations need to be integrated, as his participation in offensive actions in today's football has increased (Florin, 2009; Szwarc et al., 2010). The proposal of observation instrument developed in this paper tries to integrate categorical cores from previous research and instruments and to integrate the goalkeeper in the analysis of the game players' and team patterns. This observational instrument will provide information about how the technical and tactical actions are realized and will help to provide more information related to the dynamic system that involves team sport confrontation (Glazier, 2010; Castellano et al., 2017; González-Espinosa et al., 2017). The purpose of this research was to design, validate, and test the reliability of an observation instrument to analyze the offensive technical and tactical individual ball actions in soccer.

MATERIALS AND METHODS

Design

For the development of the instrument an observational, nomothetic, monitoring and multidimensional design was carried out (Anguera and Hernández-Mendo, 2013). The observation instrument designed was a mixed field format and category system (Anguera and Hernández-Mendo, 2013). The final instrument was composed of 3 criteria and 25 categorical cores. The multifaceted design for the generalizability analysis was composed of three facets: [Observers], [criteria], and [categorical cores]. About these facets three designs were analyzed: [Criteria] [Categorical cores]/[Observers], [Observers]/[Criteria] [Categorical cores] and [Observers] [Criteria]/[Categorical cores].

Participants

The sample studied consisted of 12 matches played by 44 players belonging to four U-12 teams during three tournaments played after the end of the regular season.

Instrument

The dimensions of the criteria collected by the instrument were divided into three groups: the first criterion, start of the ball possession; the second criterion, development (technical–tactical actions done with the ball), and the third criterion, the end of the ball possession. The unit of analysis was the play phase with the ball. The established categories were exhaustive and mutually exclusive (E/ME) (Anguera and Hernández-Mendo, 2013).

Researchers did a pilot study of the observational instrument with under-12 matches to review and complete the categorical cores and degree of openness. The list of categorical cores was grouped into three groups of criteria: (a) start of the ball possession, (b) development (technical–tactical actions done with the ball), and (c) end of the ball possession. Ten categorical cores described the criterion "start of the ball possession" (way of obtaining the ball, ball height, body part, origin zone, zone where the ball was controlled (see **Figures 1**, **2**), numerical situation (offense players vs. defense players), numerical situation with opponent goalkeeper (Offense players vs. Defense players + Goalkeeper), numerical situation with own goalkeeper (Goalkeeper with ball + Offense players vs. Defense players), distance of the defensive player, and teammate support). Five categorical cores described the criterion "development of the ball possession" (tactical collective actions, dribble, ball touches, type of ball contact, and defensive pressing lines). Twelve categorical cores described the criterion "end of the ball possession" [technical action, body part, height, zone where ball possession ends (see **Figures 1**, **2**), goalkeeper zone intervention, zone where the ball ends (see **Figures 1**, **2**), numerical situation (offense players vs. defense players), numerical situation with opponent goalkeeper (Offense players vs. Defense players + Goalkeeper), numerical situation with own goalkeeper (Goalkeeper with ball + Offense players vs. Defense players), and teammate support]. The definition of all the categorical cores and degrees of openness can be found in **Annexes 1–3** of the present paper.

Procedure

The instrument design, validation, and reliability calculation were done in four stages: (a) review of the literature, (b) design the first draft of the observation instrument, (c) experts' qualitative and quantitative review of the instrument, and (d) observer training test (reliability calculation). In the first stage, a review of the following databases was done: Web of Science (WOS) de ISI Thomson Reuters, Latindex, Sports Discus, Scopus, Google Scholar, Scielo, and Dialnet. The keywords of the search were: "soccer" or "football" and "observational instrument." A review of the abstracts was carried out to select the observational instruments used in the literature. After the selection of papers with observational instruments, the researchers reviewed their characteristics, criteria and categorical cores. In the second stage, a draft of a list of categorical cores and degree of openness was created from related scientific literature. The list of criteria included the categories, degree of openness and the behavior's definition.

In the third stage, content validity was established by 12 experts (Ph.D. in sports science or soccer coach with at least of 10 years of coaching experience). The Delphi methodology was used. Experts did a quantitative (scale 0–10) and qualitative evaluation. Experts were asked about: (a) comprehension of the criteria, categorical cores, degree of openness, and their definitions, (b) pertinence of categorical cores and degree of openness, and (c) whether to include other categorical cores or degree of openness in the observation instrument. The content validity was calculated with the Aikens's V coefficient (Aiken, 1985). A Visual Basic app was used to calculate it (Merino and Livia, 2009). The confidence intervals were set out in 90%, 95%, and 99% through score method (Penfield and Giacobbi, 2004). Items with average values <0.70 were eliminated, items ≥ 0.70 and <0.8 were reviewed according to experts' proposals, and items that were ≥ 8.0 were accepted (Bulger and Housner, 2007).

In the fourth stage, the reliability of the instrument was calculated through an observer training and an observation test. Two observers were trained in the use of the observation instrument during three 2-h sessions. The observers had degrees in sports science, had 10 years of experience coaching soccer, and had experience as observers. After the training, a match analysis was carried out by the observers and an expert observer (Master in Sports Science with 5-years of experience in match analysis and soccer). After minimum 15 days, the same analysis was carried out again by the two observers (observer and researcher, Ph.D. in Sports Science with 15-years of experience in match analysis and coaching). The inter- and intra-observer Cohen's kappa, the intra-class correlation coefficient and Kendall's Tau B was utilized to evaluate observer agreement. A generalizability analysis (**Tables 6**, **7**) was performed to test the validity and accuracy of the observation instrument and the reliability of the observers (Blanco-Villaseñor et al., 2000; Morillo et al., 2017). For the statistical analysis the SPSS software version 24.0 was used. For the generalizability analysis, SGAT software was used (Hernández-Mendo et al., 2016).

RESULTS

The list of categorical cores, degree of openness and their definitions after the first and second stages of the observational instrument design is shown in **Tables 1–3**. In the design of the observational instrument, the categorical cores and degree of openness were selected using the categorical cores and degree of openness proposed by Moreno (2005), Sainz de Baranda et al. (2005), Anguera et al. (2011), García-López et al. (2013),

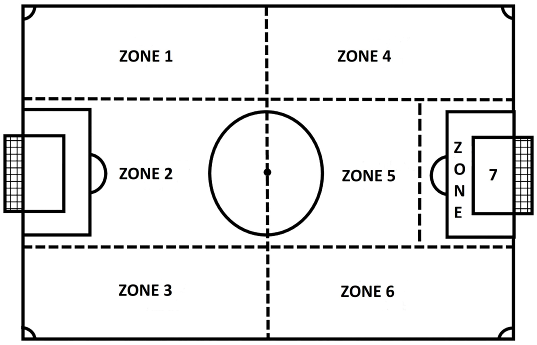

FIGURE 1 | Division of the field used to establish the zone from which the ball was sent.

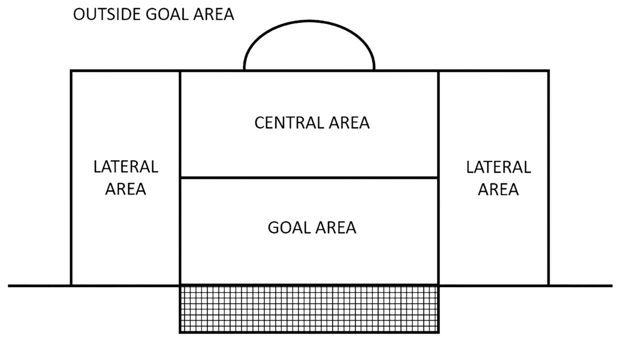

FIGURE 2 | Division of the goal area used to establish the zone where the goalkeeper handled the ball.

Hernández-Mendo et al. (2014), and Anguera and Hernández-Mendo (2015).

In the third stage, the experts reviewed the observation instrument. The experts' qualitative observations were related to the definitions of categorical cores. No categorical cores were eliminated by the experts after the experts' evaluation. In the quantitative evaluation, all categorical cores had an average score >0.70 (**Table 4**). The lower Aiken's V value found was 0.91, concretely in the categorical core "numerical situation with opponent goalkeeper." In the fourth stage (observer training), the lowest intra and inter observer agreement coefficient observers was >0.96 for all the studied categorical cores (Cohen's Kappa

TABLE 1 | Categorical cores, degree of openness, and definitions related to the criterion "start of the ball possession."

Categorical cores	Degree of openness
Way of obtaining the ball	– Field players (tackle, interception, clearance by an opponent, clearance by the opponent goalkeeper, goal rebound, corner flag rebound, deflection by an opponent, deflection by the opponent goalkeeper, throw-in, free-kick, corner kick, penalty kick, pass, throw-in pass, corner kick pass, goal-kick, kick-off, pass by the goalkeeper, and hand pass by the goalkeeper) – Goalkeeper (high save, medium height save, low height save, hand parry, foot parry, fist parry, other parries, deflection, open palm technique with hand, open palm technique with fist, fly and/or dive, screen, 1-on-1 situation, and goal kick)
Ball height	Set piece, flat ball, medium height ball (ankle to waist), and high (above the waist)
Body part	Foot, thigh, hand, head, chest, and fist
Origin zone (**Figure 1**)	Zone 1, zone 2, zone 3, zone 4, zone 5, zone 6, zone 7, kick-off, goal-kick, corner from zone 4, corner from zone 6, throw-in from zone 1, throw-in from zone 4, throw-in from zone 6, throw-in from zone 3, penalty kick and penalty mark
Zone where ball was controlled (**Figures 1**, **2**)	– Field players (zone 1, zone 2, zone 3, zone 4, zone 5, zone 6, zone 7, kick off, goal kick, corner from zone 4, corner from zone 6, throw-in from zone 1, throw-in from zone 3, throw-in from zone 4, throw-in from zone 6, and penalty mark) – Goalkeeper (Goal area, central zone of penalty area, right zone of penalty area, left zone of penalty area, and outside of penalty area)
Numerical situation (offense players vs. defense players)[1]	3v1, 2v1, 3v2, 1v1, 1v0, 1v2, 1v3, 2v2, another equality, another inferiority, and another superiority
Numerical situation with opponent goalkeeper (Offense players vs. Defense players + Goalkeeper)[1]	No goalkeeper, 3v1+G, 2v1+G, 3v2+G, 1v1+G, 1v0+G, 1v2+G, 1v3+G, 2v2+G, another equality, another inferiority, and another superiority
Numerical situation with own goalkeeper (Goalkeeper with ball + Offense players vs. Defense players)[1]	The goalkeeper has not the possession of the ball, G+2v1, G+1v1, Gv1, G, G+2v2, Gv2, Gv3, another equality, another inferiority, and another superiority
Distance of the defensive player	Very close (less than half arm length distance), close (between half arm and an arm length), near (between an arm and two arms length), and long (more than two arms length)
Teammate support[2]	Yes and no

[1]The number of players is counted between the line created by the ball and the goal. [2]Support from teammate: any teammate supports the possessor of the ball in less than 4 m, without a defensive player on, and with a clear pass possibility.

TABLE 2 | Categorical cores, degree of openness, and definitions related to the criterion "development of the ball possession."

Categorical cores	Degree of openness
Tactical collective actions	No collective tactical action, give and go, give and go with third player, overlap, crossover run, block an opposing player to reach the ball, creation of a free space, check away (move away from teammate who has the ball), and check to (player runs toward the ball carrier)
Dribble	Number of dribbles done by the player
Ball touches	No ball contact, short (two contacts), medium (three to four contacts), and large (≥five contacts)
Type of ball contact	No ball contact, delay (player control the ball to organize the offense against a organize defense), quick counterattack (player with ball possession progress with opposition), counterattack (player with ball possession progress against a defensive line), and through ball dribbling (player with ball possession progress toward the goal with a defensive player on and/or a defensive line)
Defensive pressing lines	None, one pressing line, two pressing lines, three pressing lines, and four pressing lines

Organization of defensive lines of players who are between the initial zone of the ball reception and the initial zone of the finishing phase.

TABLE 3 | Categorical cores, degree of openness, and definitions related to the criterion "end of the ball possession."

Categorical cores	Degree of openness
Technical action	Pass, wrong pass, throw-in, hand pass by goalkeeper, low side-volley pass by goalkeeper, high side-volley pass by goalkeeper, dropkick by goalkeeper, shot interception by a field player, shot deflected by a field player, shot off target, goal, goal rebound, shot cleared by goalkeeper, shot caught by goalkeeper, tackle, pass interception by goalkeeper, deflection by a field player, deflection by the goalkeeper, rebound by a teammate, half time/full time, throw-in (ball went out of the side-line), offside, goal kick (ball went out of the goal line), foul of the ball possessor, foul on the ball possessor, foul of a teammate, and foul of a defensive player
Body part	Foot, thigh, hand, head, chest, and fist
Height	Flat ball, medium height ball (ankle to waist), and high (above the waist)
Zone where ball possession end (**Figures 1**, **2**)	Zone 1, zone 2, zone 3, zone 4, zone 5, zone 6, zone 7, ball went out of the opposing goal line, ball went out of the own goal line, player lost the ball possession in a kick-off is performed, corner from zone 1, corner from zone 3, player lost the possession of the ball in a goal kick, player lost the possession of the ball in a throw-in, player lost the possession of the ball in a penalty kick, goal area, central zone of penalty area, right zone of penalty area, left zone of penalty area, and outside of penalty area
Goalkeeper zone intervention (**Figure 2**)	Goal area, central zone of penalty area, right zone of penalty area, left zone of penalty area, and outside of penalty area
Zone where ball ends (**Figure 1**)	Zone 1, zone 2, zone 3, zone 4, zone 5, zone 6, zone 7, kick off, goal kick, corner from zone 1, corner from zone 3, throw-in from zone 1, throw-in from zone 4, throw-in from zone 6, throw-in from zone 3
Numerical situation (offense players vs. defense players)[1]	3v1, 2v1, 3v2, 1v1, 1v0, 1v2, 1v3, 2v2, another equality, another inferiority, and another superiority
Numerical situation with opponent goalkeeper (Offense players vs. Defense players + Goalkeeper)[1]	No goalkeeper, 3v1+G, 2v1+G, 3v2+G, 1v1+G, 1v0+G, 1v2+G, 1v3+G, 2v2+G, another equality, another inferiority, and another superiority
Numerical situation with own goalkeeper (Goalkeeper with ball + Offense players vs. Defense players)[1]	The goalkeeper has not the possession of the ball, G+2v1, G+1v1, Gv1, G, G+2v2, Gv2, Gv3, another equality, another inferiority, and another superiority
Defensive pressing lines overcome [2]	None, one pressing line, two pressing lines, three pressing lines, and four pressing lines
Teammate support [3]	Yes and no

[1]The number of players is counted between the line created by the ball and the goal. [2]Organization of defensive lines of players who are between the initial zone of the ball reception and the initial zone of the finishing phase. [3]Support from teammate: any teammate supports the possessor of the ball in less than 4 m, without a defensive player on, and with a clear pass possibility.

and interclass correlation coefficient); and the lowest intra and inter observer agreement coefficient observers was >0.97 for all the studied categorical cores (Kendall's Tau B) (**Table 5**).

Finally, the analysis of generalizability (**Tables 6**, **7**) shows in the first design a Generalizability coefficient (GC) equal to 1, this result shows a high reliability of the observers. In the second and third design, the results of the GC are equal to or very close to 0, these results indicate a high adjustment of the observation instrument and that its categories were exhaustive and mutually exclusive (E/ME) (Anguera and Hernández-Mendo, 2013). The highest percentage of variance (see **Table 7**) is found in the interaction [Criteria] [Categorical cores], being very low in the rest of the sources of variation.

DISCUSSION

The present paper describes the stages done to design, validate, and test the reliability and generalizability of the observational instrument. Considering the increasing number of observational studies that use "*Ad hoc*" instruments in football, the development of this instrument aims to provide the many observational studies that occur in football with a valid and reliable instrument that allows adequate data collection. In the same way, the developed instrument has the advantage of using open categories, as opposed to other studies that present closed categories, in which only the conducts carried out are registered. In addition, the designed instrument has the advantage that it takes into account the continuity of the game. The instrument registers the actions that happens since the players obtain ball possession until they lose it.

The fact of being able to record the continuity of the offensive game, the procedures by which it is made with the ball, the behaviors it manifests in possession of the ball and finally, the actions developed when it is released from the ball, is an advantage over other instruments that analyze and record actions in an isolated way, for example instruments that analyze goals (Reina-Gómez et al., 2010). In addition this instrument provides, in spite of analyzing the continuity of the offensive action, do not take into account categorical cores of relevance as the actions of the goalkeeper, the corporal zones used in the action, the existence of companions in support or the defensive lines that are surpassed in the offensive action (Sarmento et al., 2010).

The process had different stages, similar to the one followed in the development of observational instruments in other sports (Villarejo et al., 2014; Palao et al., 2015a,b). The first stage involved the review and analysis of the available observation instruments and match analysis literature. The analysis of the available material was focused in the design an instrument that allows obtaining information: (a) about the individual and collective game patterns, (b) about the players evolution in training and competition, (c) about the effect of manipulation of rules in small side-games or in competition, and (d) that guide the training design. After the analysis, the researchers established the categorical cores focus on the following aspects: the sequence of the ball possession (stat, develop, and end), description of the actions done by the player with the ball, description of the temporal, spatial, and context of the actions done with the ball, and inclusion of the goalkeeper in the analysis of the situation. The researchers tried to use in the design of the instrument categorical cores close to the criteria used by coaches with the goal to increase the applicability of the instrument. For that reason, the criteria used for the Spanish Soccer Federation to describe the technical and tactical actions with the ball in the coach training courses was followed (Moreno, 2005). Along with this criterion, it was also used the categorical cores proposed by researchers in other instruments and research studies (Sainz de Baranda et al., 2005; Anguera et al., 2011; García-López et al., 2013; Hernández-Mendo et al., 2014; Anguera and Hernández-Mendo, 2015). The instrument has as unit of analysis the ball possession and differentiates in the ball possession three moments (start, development of end), like other instruments in soccer (e.g., SOFBAS or SoccerEye). The pilot studied carried out by the researchers allowed reviewing the categorical cores and their definitions.

In the third stage of the process, the experts' qualitative and quantitative revision and the use of Aiken's V allowed for measuring the content validity of the items. The values of the quantitative evaluation were high for all the categorical cores (Vo $\geq$ 0.70) and above the minimum values proposed in the literature as a reference (Vo = 0.70) by Penfield and Giacobbi (2004). The qualitative evaluation helped specifically to clarify some of the aspects of the definitions of the different degree of openness of the categorical cores. The use of experts from research and coaching provided a more complete and holistic vision of the sport.

TABLE 4 | Values of content validity (Aiken's V).

Criteria and categorical cores	Aiken's V
Start of the ball possession	
Way of obtaining the ball	1.00
Ball height	0.93
Body part	1.00
Origin zone	1.00
Zone where ball was controlled	1.00
Numerical situation with opponent goalkeeper	0.91
Numerical situation with own goalkeeper	1.00
Distance of the defensive player	0.93
Teammate support	1.00
Development of the ball possession	
Tactical collective actions	1.00
Dribble	1.00
Ball touches	1.00
Type of ball handling	1.00
Defensive pressing lines	0.96
End of the ball possession	
Technical action	1.00
Body part	1.00
Height	0.93
Zone where ball possession ends	1.00
Goalkeeper zone intervention	1.00
Zone where ball ends	1.00
Numerical situation	1.00
Numerical situation with opponent goalkeeper	1.00
Numerical situation with own goalkeeper	1.00
Defensive pressing lines	0.96
Teammate support	1.00

Expert judges (third stage).

The level of intra-reliability, reached between observers after the observer training, showed the instrument is adequate with regard to reliability (Bakeman et al., 1997). The use of categorical cores and degree of openness well established in the area and the qualitative evaluation of the experts contributed to the high level of reliability. Finally, the results shown in the generalizability analysis made it possible to verify the high levels of validity, precision of the instrument and corroborate the high reliability indices of the observers (Blanco-Villaseñor et al., 2000; Hernández-Mendo et al., 2016).

Data obtained by the instrument can provide useful and applicable information to coaches in order to understand game patterns, face the competition and develop the training sessions. The structure of the instrument allows coaches and researchers to

TABLE 5 | Observers' intra and inter agreement after training in the use of the observation instrument (fourth stage).

Criteria and categorical cores	Intra-reliability Kappa/ICC	Inter- reliability Kappa/ICC	Intra-reliability Kendall's Tau B	Inter- reliability Kendall's Tau B
Start of the ball possession				
Way of obtaining the ball	1.00	1.00	1.00	1.00
Ball height	0.98	0.99	0.99	0.99
Body part	1.00	1.00	1.00	1.00
Origin zone	1.00	1.00	1.00	1.00
Zone where ball was controlled	1.00	1.00	1.00	1.00
Numerical situation with opponent goalkeeper	1.00	1.00	1.00	1.00
Numerical situation with own goalkeeper	1.00	1.00	1.00	1.00
Distance of the defensive player	0.98	0.98	0.98	0.98
Teammate support	1.00	1.00	1.00	1.00
Development of the ball possession				
Tactical collective actions	1.00	1.00	1.00	1.00
Dribble	1.00	1.00	1.00	1.00
Ball touches	1.00	1.00	1.00	1.00
Type of ball handling	1.00	1.00	1.00	1.00
Defensive pressing lines	1.00	1.00	1.00	1.00
End of the ball possession				
Technical action	1.00	1.00	1.00	1.00
Body part	1.00	1.00	1.00	1.00
Height	0.98	0.99	0.99	0.99
Zone where ball possession ends	1.00	1.00	1.00	1.00
Goalkeeper zone intervention	1.00	1.00	1.00	1.00
Zone where ball ends	1.00	1.00	1.00	1.00
Numerical situation	0.98	0.97	0.99	0.99
Numerical situation with opponent goalkeeper	1.00	0.98	1.00	0.98
Numerical situation with own goalkeeper	1.00	1.00	1.00	1.00
Defensive pressing lines	0.98	0.96	0.98	0.97
Teammate support	1.00	1.00	1.00	1.00

TABLE 6 | Absolute generalizability coefficient, relative generalizability coefficient, absolute standard deviation, and relative standard deviation in each of the designs.

Design	Absolute generalizability coefficient	Relative generalizability coefficient	Absolute standard deviation	Relative standard deviation
[Criteria] [Categorical cores]/[Observers]	1.000	1.000	0.001	0.001
[Observers]/[Criteria] [Categorical cores]	0.000	0.000	0.069	0.000
[Observers] [Criteria]/[Categorical cores]	0.089	0.089	0.114	0.114

TABLE 7 | Sources of variation, sum of squares, degrees of freedom, mean squares, % and standard error.

Sources of variation	Sum of squares	DF	Mean squares	%	Standard error
Observers	0.000	1	0.000	0.000	0.000
Criteria	1.438	2	0.719	0.391	0.011
[Observers] [Criteria]	0.000	2	0.000	0.000	0.000
Categorical cores	0.003	24	0.000	0.000	0.022
[Observers] [Categorical cores]	0.000	24	0.000	0.000	0.000
[Criteria] [Categorical cores]	31.436	48	0.655	99.608	0.065
[Observers] [Criteria] [Categorical cores]	0.000	48	0.000	0.001	0.000

DF, degrees of freedom.

use it in its entirety or certain parts or criteria can be utilized to solve specific research problems.

CONCLUSION

The results showed that the observational instrument is valid and reliable for measuring the technical and tactical actions done in the offensive phase by the player and team with the ball possession. The instrument has some limitations. Only it was assessed the content validity of the instrument (expert evaluation), and the instrument is focused on the actions of the players and team which the ball possession. However, the instrument can provide coaches and research with information about the type of actions done by the players with the ball, their characteristics and in which context are done (distance, numerical situation) and the level of involvement of the field players and the goalkeeper. This information could allow coaches and research to establish the demands of the game and to create training plans that help players to be prepared for these demands.

ETHICS STATEMENT

This study respected the ethical principles established by the UNESCO Declaration on Bioethics and Human Rights. The parents or guardians of the players were informed of the study and gave their written consent in accordance with the Declaration of Helsinki. The study was approved by the Ethics Committee of University of Murcia (Spain) with ID 1944/2018.

AUTHOR CONTRIBUTIONS

All authors participated in the design, documentation, development, and writing of the manuscript. This paper was reviewed by all authors and all of them are responsible for its contents and providing they are responsible for the final version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00022/full#supplementary-material

REFERENCES

Abellán, J., Sáez-Gallego, N. M., Vila-Maldonado, S., and Contreras, O. (2017). Differences in movement behaviour between successful and less successful goalkeepers in the interception of corner kicks. *J Hum. Sport Excerc.* 12, 307–315. doi: 10.14198/jhse.2017.122.07

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educ. Psychol. Meas.* 45, 131–142. doi: 10.1177/0013164485451012

Anguera, M. T. (2003). "Observational methods," in *Encyclopedia of Psychological Assessment*, ed. R. Fernández-Ballesteros (London: Sage), 632–637.

Anguera, M. T., Blanco-Villaseñor, A., Hernández-Mendo, A., and Losada, L. (2011). Observational designs: their suitability and application in sports psychology. *Cuad. Psicol. Dep.* 11, 63–76.

Anguera, M. T., Blanco-Villaseñor, A., Losada, J. L., Ardá, T., Camerino, O., Castellano, J., et al. (2003). Instrumento de codificación y registro de la acción de juego en fútbol – SOF-1 (Instrument for coding and recording football action - SOF-1). *Rev. Digit. Alto Rendimiento Fútbol* [electronic version].

Anguera, M. T., Camerino, O., Castañer, M., Sánchez-Algarra, P., and Onwuegbuzie, A. J. (2017). The specificity of observational studies in physical activity and sports sciences: moving forward in mixed methods research and proposals for achieving quantitative and qualitative symmetry. *Front. Psychol.* 8:2196. doi: 10.3389/fpsyg.2017.02196

Anguera, M. T., and Hernández-Mendo, A. (2013). Observational methodology in sport science. *EBM. Com. Rev. Cienc. Dep.* 9, 135–160.

Anguera, M. T., and Hernández-Mendo, A. (2015). Data analysis techniques in observational studies in sport sciences. *Cuad. Psicol. Dep.* 15, 13–29. doi: 10.4321/S1578-84232015000100002

Anguera, M. T., Portell, M., Chacón-Moscoso, S., and Sanduvete-Chaves, S. (2018). Indirect observation in everyday contexts: concepts and methodological guidelines within a mixed methods framework. *Front. Psychol.* 9:13. doi: 10.3389/fpsyg.2018.00013

Bakeman, R., Quera, V., McArthur, D., and Robinson, B. F. (1997). Detecting sequential patterns and determining their reliability with fallible observers. *Psychol. Methods* 2, 357–370. doi: 10.1037/1082-989X.2.4.357

Barreira, D., Garganta, J., Prudente, J., and Anguera, M. T. (2012). Desenvolvimento e validação de um sistema de observação aplicado à fase ofensiva em Futebol: Soccer Eye. *Rev. Port. Ciênc. Desporto* 12, 32–57. doi: 10.5628/rpcd.12.03.32

Blanco-Villaseñor, A., Castellano, J., and Hernández-Mendo, A. (2000). Generalizabilidad de las observaciones en la acción del juego en el fútbol. *Psicothema* 12, 81–86.

Bulger, S. M., and Housner, L. D. (2007). Modified Delphi investigation of exercise science in physical education teacher education. *J. Teach. Phys. Educ.* 26, 57–80. doi: 10.1123/jtpe.26.1.57

Carling, C., Williams, A. M., and Reilly, T. (2006). Handbook of soccer match analysis: a systematic approach to improving performance. *J. Sport Sci. Med.* 5:171.

Castellano, J. (2000). *Observación y Análisis de la Acción de Juego en Fútbol.* Ph.D. thesis, University of the Basque Country, Álava.

Castellano, J., Fernández, E., Echeazarra, I., Barreira, D., and Garganta, J. (2017). Influence of pitch length on inter-and intra-team behaviors in youth soccer. *Ann. Psychol.* 33, 486–496. doi: 10.6018/analesps.33.3.271051

Chacón-Moscoso, S., Sanduvete-Chaves, S., Anguera, M. T., Losada, J. L., Portell, M., and Lozano-Lozano, J. A. (2018). Preliminary checklist for reporting observational studies in sports areas: content validity. *Front. Psychol.* 9:291. doi: 10.3389/fpsyg.2018.00291

Da Costa, I. T., Garganta, J., Greco, P. J., Mesquita, I., and Maia, J. (2011). System of tactical assessment in Soccer (FUT-SAT): development and preliminary validation. *Motricidade* 7, 69–84. doi: 10.6063/motricidade.7(1).121

Dufour, M., Phillips, J., and Ernwein, V. (2017). What makes the difference? Analysis of the 2014 World Cup. *J. Hum. Sport Excerc.* 12, 616–629. doi: 10.14198/jhse.2017.123.06

Fabra, P., Balaguer, I., Tomás, I., Smith, N., and Duda, J. L. (2018). Versión española del Sistema de Observación del Clima Motivacional Multidimensional (MMCOS): fiabilidad y evidencias de validez. *Rev. Psicol. Dep.* 27, 11–22.

Florin, T. D. (2009). The identification of the value dimensions of the high performance goalkeeper pattern. *Ovidius Univ. Ann. Ser. Phys. Educ. Sport Sci. Mov. Health* 9, 82–85.

García-López, L. M., González-Víllora, S., Gutiérrez-Díaz, D., and Serra, J. (2013). Development and validation of the game performance evaluation tool (GPET) in soccer. *Sport Rev. Eur. Cienc. Dep.* 1, 89–79.

Glazier, P. S. (2010). Game, set and match? Substantive issues and future directions in performance analysis. *Sports Med.* 40, 625–634. doi: 10.2165/11534970-000000000-00000

González-Espinosa, S., Molina, S. F., García-Rubio, J., Medina, A. A., and García-Santos, D. (2017). Diferencias en el aprendizaje según el método de enseñanza-aprendizaje en el baloncesto. *Rev. Psicol. Dep.* 26, 65–70.

Gréhaigne, J. F., Godbout, P., and Bouthier, D. (1997). Performance assessment in team sports. *J. Teach. Phys. Educ.* 16, 500–516. doi: 10.1123/jtpe.16.4.500

Harvey, S., Cushion, C. J., Wegis, H. M., and Massa-González, A. N. (2010). Teaching games for understanding in American high-school soccer: a quantitative data analysis using the game performance assessment instrument. *Phys. Educ. Sport Pedagogy* 15, 29–54. doi: 10.1080/17408980902729354

Hernández-Mendo, A., Blanco-Villaseñor, A., Pastrana, J. L., Morales-Sánchez, V., and Ramos-Pérez, F. J. (2016). SAGT: aplicación informática para análisis de generalizabilidad [SAGT: new software for generalizability analysis]. *Rev. Iberoam. Psicol. Ejerc. Dep.* 11, 77–89.

Hernández-Mendo, A., Castellano, J., Camerino, O., Jonsson, G., Blanco-Villaseñor, A., Lopes, A., et al. (2014). Observational software, data quality control and data analysis. *Rev. Psicol. Dep.* 23, 111–121.

Hughes, M. (2003). "Notational analysis," in *Science and Socscer*, eds T. Reilly and A. M. Williams (London: Routledge), 245–263.

Hughes, M., and Franks, I. M. (2004). *Notational Analysis of Sport: Systems for Better Coaching and Performance in Sport*. London: Psychology Press.

Maneiro, R., Amatria, M., Moral, J. E., and Lopez, A. (2018). Análisis observacional de las relaciones interlíneas de la Selección Española de Fútbol, mediante coordenadas polares. *Cuad. Psicol. Dep.* 18, 18–32.

Maneiro, R., Losada, J. L., Casal, C. A., and Ardá, A. (2017). Multivariate analysis of indirect free kick in the FIFA World Cup 2014. *Ann. Psychol.* 33, 461–470. doi: 10.6018/analesps.33.3.271031

Merino, C., and Livia, J. (2009). Confidence intervals for the content validity: a visual basic computer program for the Aiken's V. *Ann. Psychol.* 25, 169–171.

Moreno, E., and Gómez-Ruano, M. A. (2017). Validación herramienta observacional para el análisis de rachas de lanzamiento en baloncesto. *Rev. Psicol. Dep.* 26, 87–93.

Moreno, M. (2005). *Technical Education in Youth Soccer. Escuela Nacional de Entrenadores de Fútbol*. Madrid: Gymnos.

Morillo, J. P., Reigal, R. E., Hernández-Mendo, A., Montaña, A., and Morales-Sánchez, V. (2017). Decision-making by handball referees: design of an ad hoc observation instrument and polar coordinate analysis. *Front. Psychol.* 8:1842. doi: 10.3389/psyg.2017.01842

Nadal, G., Serna, J., Nuviala, R., and Falcón, D. (2018). Diseño de un instrumento observacional para la valoración del penalti en fútbol y análisis de los resultados obtenidos. *Rev. Psicol. Dep.* 27, 189–199.

Oslin, J. L., Mitchell, S. A., and Griffin, L. L. (1998). The game performance assessment instrument (GPAI): development and preliminary validation. *J. Teach. Phys. Educ.* 17, 231–243. doi: 10.1123/jtpe.17.2.231

Palao, J. M., Manzanares, P., and Ortega, E. (2015a). Design and validation of an observational instrument for technical and tactical actions in beach volleyball. *Motriz* 21, 137–147. doi: 10.5016/motriz.v21i2.8686

Palao, J. M., Manzanares, P., and Ortega, E. (2015b). Design and validation of an observation instrument for technical and tactical actions in indoor volleyball. *Eur. J. Hum. Mov.* 34, 75–95.

Penfield, R. D., and Giacobbi, P. R. (2004). Applying a score confidence interval to Aiken's item content-relevance index. *Meas. Phys. Educ. Exerc. Sci.* 8, 213–225. doi: 10.1207/s15327841mpee0804_3

Reina-Gómez, A., Hernández-Mendo, A., and Fernández-García, J. C. (2010). Multi-facet design for goal scoring in SOCCER-7. *Qual. Quant.* 44, 1025–1035. doi: 10.1007/s11135-009-9253-8

Sainz de Baranda, P., Ortega, E., Llopis, L., Novo, J. F., and Rodríguez, D. (2005). Analysis of the goalkeeper's defensive actions in football 7. *Apunts* 80, 45–52.

Sainz de Baranda, P., Ortega, E., and Palao, J. M. (2008). Analysis of goalkeepers' defence in the World Cup in Korea and Japan in 2002. *Eur. J. Sport Sci.* 8, 127–134. doi: 10.1080/17461390801919045

Sarmento, H., Anguera, T., Campaniço, J., and Leitão, J. (2010). Development and validation of a notational system to study the offensive process in football. *Medicine* 46, 401–407.

Sarmento, H., Clemente, F. M., Araújo, D., Davids, K., McRobert, A., and Figueiredo, A. (2017). What performance analysts need to know about research trends in Association Football (2012–2016): a systematic review. *Sports Med.* 48, 1–38. doi: 10.1007/s40279-017-0836-6

Serna Bardavío, J., Muñoz Arroyave, V., Hileno González, R., Solsona Leri, E., and Sáez de Ocáriz Granja, U. (2017). Patrones temporales iniciados con bloqueo directo o uno contra uno en baloncesto. *Rev. Psicol. Dep.* 26, 81–86.

Szwarc, A., Lipinska, P., and Chamera, M. (2010). The efficiency model of goalkeeper's actions in soccer. *Balt. J. Health Phys. Act.* 2, 132–138. doi: 10.2478/v10131-0013-x

Vilar, L., Araújo, D., Davids, K., and Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Med.* 42, 1–10. doi: 10.2165/11596520-000000000-00000

Villarejo, D., Ortega, E., Gómez, M. A., and Palao, J. M. (2014). Design, validation, and reliability of an observational instrument for ball possessions in rugby union. *Int. J. Perform. Anal. Sport* 14, 955–967. doi: 10.1080/24748668.2014.11868771

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Are Soccer Players Older Now Than Before? Aging Trends and Market Value in the Last Three Decades of the UEFA Champions League

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The aims of the current study were to analyze the evolution of players' age in the UEFA Champions League since the start of its modern-day format in 1992–1993 up until 2017–2018 and to determine how the players' age relates to their market value. The sample consisted of all players participating in the UEFA Champions League from the 1992–1993 to 2017–2018 seasons (n = 16062). The following variables were used in this study: players' age, number of seasons in the club, number of Champions Leagues won, team performance, and market value of the player in the season. Data were examined using a one-way ANOVA and a linear regression. The main finding of the current study is that an aging trend has occurred in the last three decades in the Champions League. A significant increase in average players' age (>1.6 years) was observed, rising from an age of 24.9 to 26.5 years. Goalkeepers and Center Backs tend to peak later than attackers, and their peak performance can last until an age of about 31 years. Finally, an inverted-U curve defines the association between market value and age, with peak value appearing in the 26–30 age range. These results provide useful information regarding at which age soccer players are likely to perform at the highest level, as well as the age they are likely to have the highest market value.

Keywords: aging trend, peak age, soccer, performance analysis, market value

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INTRODUCTION

Professional soccer teams usually consist of players from a wide age range (Dendir, 2016). In the four major European professional soccer leagues, Fußball-Bundesliga (Germany), Premier League (England), Serie A (Italy), and La Liga (Spain), most players are between 21 and 29 years old, and a substantial drop-off is observed at around the age of 29 years (Dendir, 2016). Moreover, there is a general belief that players usually peak somewhere in their mid to late twenties, with attacking players tending to peak earlier than defenders (Kuper, 2011; Caley, 2013). However, this is based mainly on anecdotal evidence and views of professionals in the game and less on scientific research. In a recent study, Dendir (2016) also found that the average professional soccer player in the major leagues in Europe peaks between the ages of 25 and 27, where the average forward peaks at 25 while defenders at 27. For midfielders, the peak age occurs in the 25–27 age range. Also, several top European soccer clubs have adopted an unofficial contract policy with shorter contracts lengths as players are nearing 30 years, based on a belief that elite players are well past their peak performance after this age (Dendir, 2016). Thus, the age of professional soccer players and at which age professional soccer players peak seems to be an important variable of interest not only to performance analysts and sport scientists, but also managers and coaches. The perception of when players tend to peak can affect the soccer club's personnel decisions, such as the length of contracts offered to players and the acceptable sum of transfer fees when buying or selling players (Dendir, 2016). Knowledge of when players are in their optimal age, therefore, has substantial value for the soccer industry. From a sport perspective, this provide useful information regarding at which age soccer players are likely to perform at the highest level.

However, while the evolution of tactical, technical and physical performance over time have been studied extensively (e.g., Barnes et al., 2014; Wallace and Norton, 2014; Bush et al., 2015), to the best of our knowledge, no studies have examined the aging trend of male elite soccer players in recent decades. Conversely, aging trends in different individual and team sports like baseball (Fair, 2008), tennis (Kovalchik, 2014), or triathlon (Rüst et al., 2012), among others, have been previously investigated, suggesting a marked increase in the age of peak performance of elite athletes during the last two decades, probably due to factors such as advances in sport science and technology (Allen and Hopkins, 2015). In tennis, for example, Kovalchik (2014), p. 8) found that the average age of the top 100 male players has increased over the last decade at a pace of 0.34 years per season since the mid-2000s, rising from the age of 26.2 years to an all-time high of 27.9 years. Given this evidence, there is a clear need to investigate trends in the age of peak performance among top professional soccer players in order to provide important clues about the sport's evolution and may help to create more specific strategies to increase players' performances in the future.

Chronological age of highest performance differs among sports (Smith, 2003) and depends on different biological capabilities involved in each sport and by the specific skills and attributes needed to succeed (Allen and Hopkins, 2015). This argues the evidence that physiological and technical constraint of each sport dictates the window for optimal performance (Dendir, 2016). At this respect, peak window of mid-20s estimated by Dendir (2016) seems to be explained by the combination of endurance and explosive power necessary to cope with physical and physiological demands of modern elite soccer. However, even though the aging process influences the players' physical and mental development and, in turn, their competitive performance (Allen and Hopkins, 2015), there are no scientific studies that have examined the evolution of players' age in elite soccer.

Taking all previous considerations into account, this study aims to analyze the evolution of players' age in the UEFA Champions League since the start of its modern-day format in 1992–1993 up until the 2017–2018 season. It also aims to analyze if the players' age has evolved differently depending on playing position or team level. Lastly, it aims to analyze how the players' age relates to their market value. We hypothesize that the average age of the Champions League players has increased across all positions and team levels. We further hypothesize that an inverted-U curve defines the association between market value and age, with peak value occurring at the mid-20s.

MATERIALS AND METHODS

Sample

The sample consisted of all players participating in the UEFA Champions League from the 1992–1993 to 2017–2018 seasons that played at least in one match (n = 16062). Each participation of a player in a season was recorded as an individual case, i.e., a single player can represent multiple cases. The players were classified into six positions: Goalkeepers (GK, n = 1224), Center Backs (CB, n = 3206), Fullbacks (FB, n = 2383), Center Midfielders (CM, n = 4609), Wingers (W, n = 1980), and Forward (F, n = 2660). This classification was done according to the information provided by the official UEFA website[1].

Variables

The following variables were used in this study: players' age, number of seasons in the club, number of Champions Leagues won, team performance, and market value of the player in the season. Players' age was calculated as the date of competition minus the date of birth according to the information provided by the official UEFA website (see footnote 1). In line with previous studies and for posterior analyses (Botek et al., 2016), soccer players were divided into five age groups: 16–20, 20–25, 26–30, 30–35 and >35 years. The team performance was decided by how far the team reached in the Champions League: Winners, Final, Semifinal, Quarterfinal, Round of 16 and Group Phase. The number of seasons in the club and number of Champions Leagues won by each player was obtained from the UEFA's website (see footnote 1). Finally, according to previous research and due to the difficulty of operationalizing performance in a mixed/skill-based sport like soccer, the market value of the player in the season (Gerhards and Mutz, 2017) was obtained from the Transfermarkt website[2].

Statistical Analysis

Statistical analyses were conducted using IBM® SPSS® Statistics 21 for Macintosh (IBM Co., New York, NY, United States), except for regression analyses that were conducted using STATA (version 15.1, TX, United States). Results are reported as means and standard deviations (mean ± SD). Statistical significance was set at $p < 0.05$. The assumption of normality of the data was checked both graphically and using the Kolmogorov–Smirnov test. All data were normally distributed. The homogeneity of variances was examined using Levene's test. As the samples were normally distributed and displayed homogenous variance, a one-way analysis of variance (ANOVA) was used to evaluate differences in mean ages across different playing positions. Subsequently, one-way independent-measures ANOVA test with sphericity assumed was used to compare mean age from each season. In the event of a difference being present, Bonferroni-adjusted *post hoc* tests were used to identify specific effects.

Moreover, the effects of the age of the players (AGE), the playing position (PP), the number of seasons in the club (NS) and the number of Champions Leagues won (NCL) on the

[1] www.uefa.com

[2] www.transfermarkt.com

market values of the players were also examined through a linear regression model. Positive or negative coefficients indicate a greater or lesser market value of the players, respectively. β_1 is the intercept; β_2, β_3, β_4, and β_5 are the impacts of each of the independent variables; and ε_1 is the error term. The model is as follows:

$$\text{Market Value} = \beta_1 + \beta_2\ \text{AGE} + \beta_3\ \text{PP} + \beta_4\ \text{NS} + \beta_5\ \text{NCL} + \varepsilon_1$$

RESULTS

The histogram of the age distribution for players included in the study is presented in **Figure 1**. The age of the players ranges from 16 to 43, with an average of 25.75 ± 4.14 years. A large number of players were observed between 21 and 29 years (>80%). From 29 years an onward, there is a substantial yearly decrease in the number of players. Between the 1992–1993 and 2017–2018 seasons, a significant increase in the players' average age (>1.6 years) was observed ($p < 0.001$). However, this increase was not uniform, and two break-points were identified along these seasons, the first one in season 2003–2004 and the second one in season 2013–2014, which can be observed in **Figure 2**.

With all seasons pooled, the one-way ANOVA showed significant differences between positional roles on mean age ($p < 0.001$). GK (28.19 ± 4.66 years) and CB (26.31 ± 4.13 years) showed significantly higher mean ages than F (25.32 ± 3.92 years), W (24.70 ± 3.90 years) and CM (25.44 ± 3.99 years). Although an aging tendency was apparent for all playing positions between the 1992–1993 and 2017–2018 seasons, a more stable trend was observed in F, CM, and GK compared to CB, W, and FB (**Figure 3**).

As can be seen in **Figure 4**, although an aging trend was found for all categories of team performance considered, no significant differences were found between winners, finalists or semifinalists and the other categories.

Effects of independent variables on the market values of the players are displayed in **Table 1**. Players 21–25 and 26–30 years old have a higher market value ($p < 0.01$) compared to players 16–20 years old (reference category in the regression model). However, players 31–35 and more than 35 years old have a lower market value than players 16–20 years old ($p < 0.01$). Concerning the playing position, F, W, and CM are more expensive than GK (reference category in the regression model), while no differences were found between CB, FB and GK.

The more seasons a player stays in a club, the higher their market value is. For each season in the club, the value of the player increases by €435,123 ($p < 0.01$). Finally, the number of Champions Leagues won by the players has a significant effect on their market value; each Champions League won increases their market value by more than €8 million.

DISCUSSION

This study provides new information about the evolution of professional soccer players' age of peak performance. The principal finding of the present study is that an aging trend has occurred in the last three decades in the UEFA Champions League. Previous studies (Kuper, 2011; Caley, 2013; Dendir, 2016) have demonstrated that professional soccer players peak around their mid-20s. However, none of these studies have analyzed the aging pattern in elite soccer. It seems that the evolution of contemporary soccer is probably associated with increasing age of athletes. Several factors may have contributed to recent "aging" of the top players. One of the factors is likely the increased investments of football clubs on support functions to monitor, increase and sustain the players' performance;

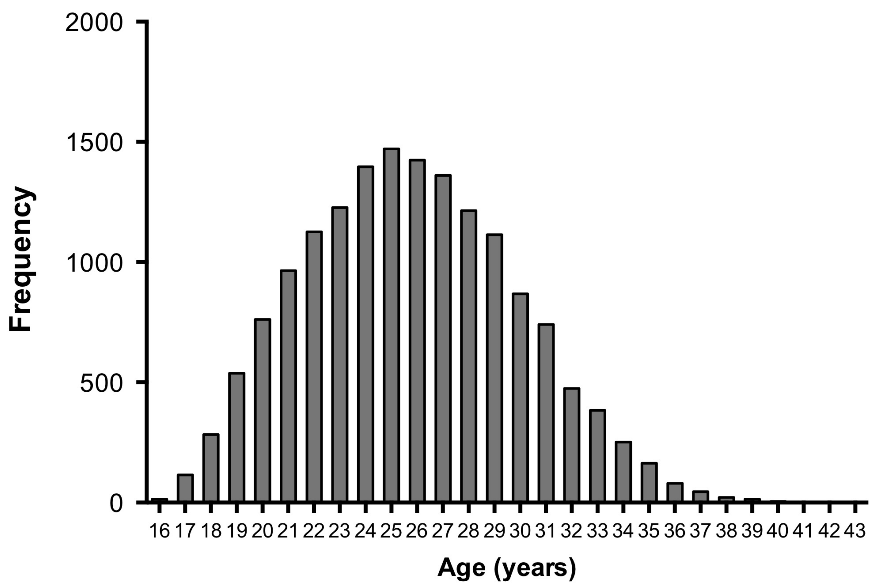

FIGURE 1 | Age distribution of UEFA Champions League players from 1992–1993 to 2017–2018.

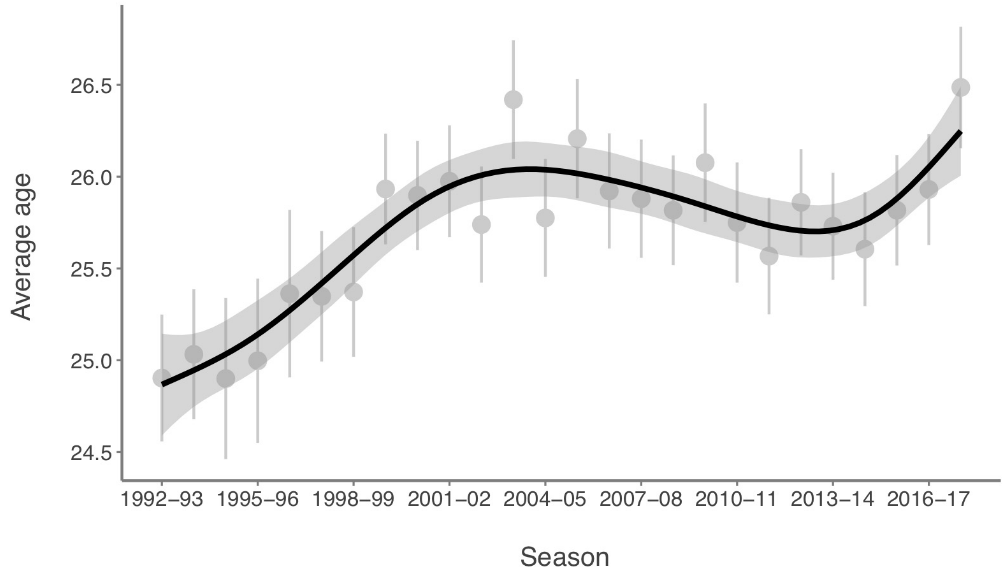

FIGURE 2 | Age trend of UEFA Champions League players.

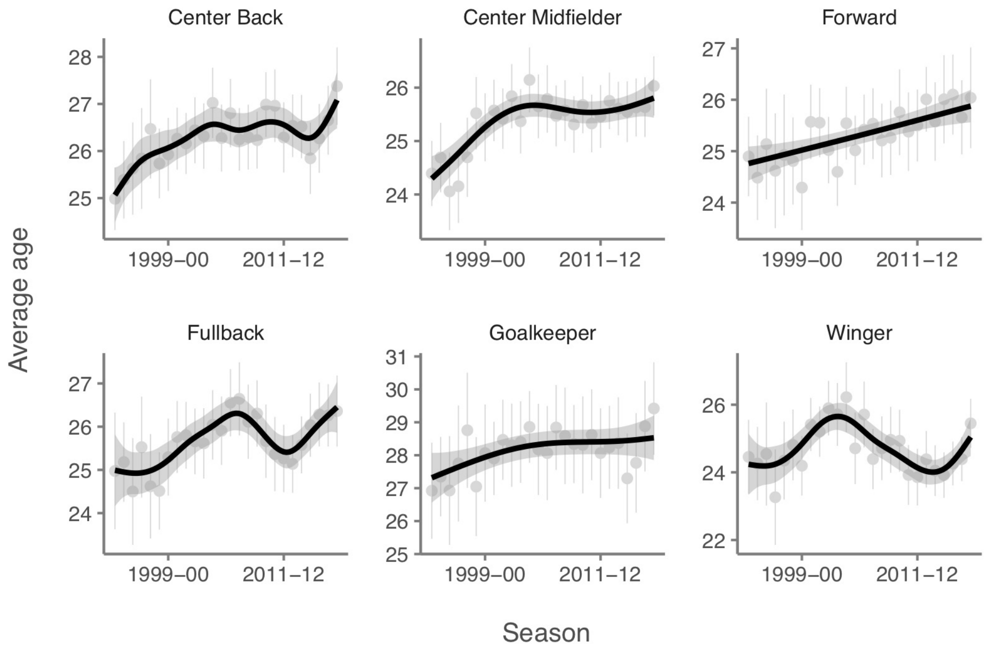

FIGURE 3 | Age trend by playing position.

including modern training facilities, strength and conditioning departments and dietists (Anderson and Sally, 2013; Williams, 2013; Dendir, 2016).

Although an aging tendency has occurred for all playing positions between the 1992–1993 and 2017–2018 seasons, GK and CB tend to peak later than F. Recently, Dendir (2016) found that the average forward and defender peaks at 25 and 27, respectively. For midfielders, the peak age occurs in the 25–27 age range. These findings can be largely explained by differences in the physical demands of playing each position, which has previously been heavily studied (Bangsbo et al., 1991; Rienzi et al., 2000; Mohr et al., 2003, 2008; Bradley et al., 2009, 2010, 2011; Di Salvo et al., 2009). Using time-motion analysis, these studies have shown that forward performs both higher number of (and longer) maximal sprints, higher number of shuffles, more contact at high intensity and higher amount of high and very high intensity activities; defenders the spend the least time running and sprinting, while midfielders

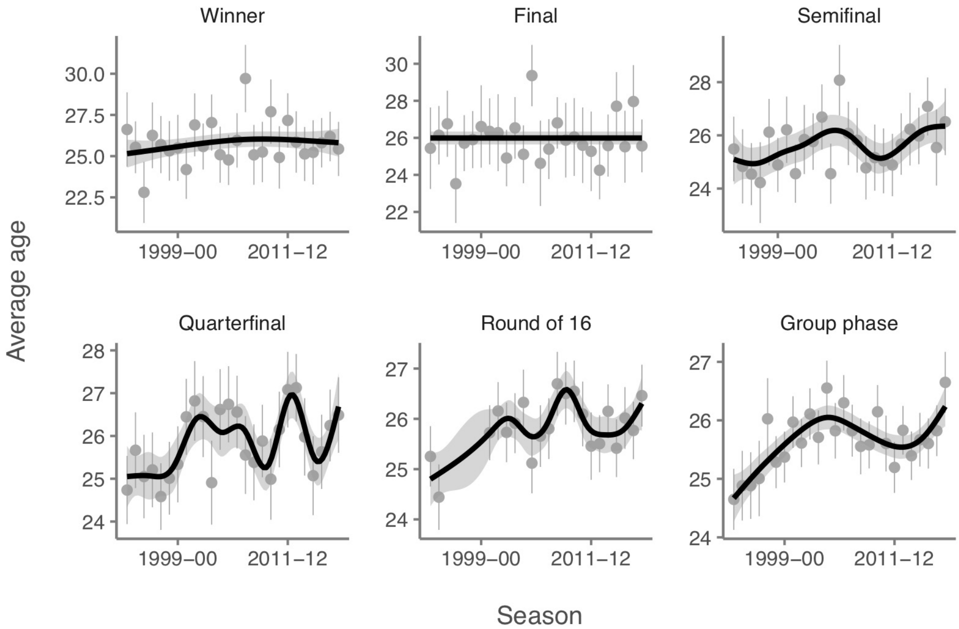

FIGURE 4 | Age trend by team performance.

the most (Bangsbo et al., 1991; Mohr et al., 2003, 2008; Bradley et al., 2009, 2010, 2011; Di Salvo et al., 2009). The lower physical demand for defenders is likely one of the reasons they tend to peak at a later age, as well as maintaining a high performance higher up in age. In similar fashion, the higher amount of high-intensity activity is probably one of the causes of the earlier peak of forward.

Conventional wisdom suggests that there is a perfect age to be a successful player. The average age of the 32 teams that participated in the last two World Cups was 27.5 and 27.37. It has been found that a one-year increase in average team age results in a performance drop of four positions in the World Cup (Dendir, 2016). According to our results, although an aging trend was found for all team performance categories considered, no significant differences were found between winners, finalists or semifinalists and the other classifications. These results may be due to the fact that players from all over the world participate in the Champions League, and the differences between the participating teams probably are smaller than in the World Cup. Future studies should provide more information about the relationship between aging trend and success in elite soccer.

The results confirm the hypothesis that an inverted-U curve characterizes the relationship between market valuation and the age, with peak value occurring in the 26–30 age range. These results are similar to those provided in other studies. For example, Anderson and Sally (2013) found that the peak value in the Premier League occurs at age 26. There is a substantial drop-off in the market value at the 31–35 age range. Finally, players over 35 have the lowest market value. In regard to playing position, attackers have a higher market value than defenders. That is, the closer the opponent penalty area, the higher the market value of the players, with forward having the highest market value.

A limitation in the current study is that extraneous variables that might have some effects the results where not included (Gómez et al., 2013). For example, the own and opponent team's formation might affect the amount of players the teams contract for each position. The fact that anonymized data was used in the study mean that some observation might correspond to the same player. Finally, it has not been controlled that the players occupied the same playing position or that

TABLE 1 | The influence of the age of the players, playing position, number of seasons in the club and number of Champions Leagues won on the market values of soccer players.

Variables	Coefficients
Age	
21–25 years	4,361,629 (442,206)*
26–30 years	5,024,691 (449,663)*
31–35 years	–2,300,026 (550,657)*
>35 years	–8,790,432 (1,263,247)*
Playing Position	
Center Back	524,204 (543,055)
Fullback	–703,459 (562,786)
Central Midfielder	2,238,671 (521,619)*
Winger	3,979,548 (580,273)*
Forward	4,931,916 (567,981)*
Seasons in the Club	435,123 (47,849)*
Champions Leagues won	8,238,528 (620,846)*
Intercept	1,808,392*
R^2	0.18
Number of observations	8665

*$p < 0.01$

they have played in more than one team during the analyzed seasons.

In conclusion, the results in the paper confirm that (i) an aging trend has occurred in the last three decades in the Champions League, and that (ii) GK and CB tend to peak later than attackers, and their peak performance can be maintained longer, until an age of about 31 years. The current results provide useful information in terms of informing our expectations about when soccer players are likely to perform at the maximum level. They also inform us about when they are likely to be the most valuable in the market. From a player's recruitment or renovation perspective, the current findings can provide valuable information to assist in decisions regarding recruitment and player list management within professional soccer clubs. When a new contract will be signed, the duration of the contract or the salary of the players can now be decided more objectively. Similarly, post-match assessment of the technical, tactical and physical aspects of performance can be made more objectively by factoring in the effect of the age of the players and can help managers and coaches to guide decisions regarding individualizing training strategies or design training load periods.

AUTHOR CONTRIBUTIONS

CL-P and ER conceptualized the study. AR-G performed the data curation. CL-P, ER, and AK involved the formal analysis. CL-P, ER, AK, and AR-G designed the methodology. CL-P administrated the project. CL-P supervised the study. AK visualized the study. CL-P, ER, and AK wrote the manuscript.

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REFERENCES

Allen, S. V., and Hopkins, W. G. (2015). Age of peak competitive performance of elite athletes: a systematic review. *Sports Med.* 45, 1431–1441. doi: 10.1007/s40279-015-0354-3

Anderson, C., and Sally, D. (2013). *The Numbers Game: Why Everything You Know About Football is Wrong*. London: Viking.

Bangsbo, J., Nørregaard, L., and Thorsoe, F. (1991). Activity profile of competition soccer. *Can. J. Sports Sci.* 16, 110–116.

Barnes, C., Archer, D. T., Hogg, B., Bush, M., and Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English premier league. *Int. J. Sports Med.* 35, 1095–1100. doi: 10.1055/s-0034-1375695

Botek, M., Krejčí, J., McKune, A. J., and Klimešová, I. (2016). Somatic, endurance performance and heart rate variability profiles of professional soccer players grouped according to age. *J. Hum. Kinet.* 54, 65–74. doi: 10.1515/hukin-2016-0035

Bradley, P. S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., et al. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA premier league soccer matches. *J. Sports Sci.* 29, 821–830. doi: 10.1080/02640414.2011.561868

Bradley, P. S., Di Mascio, M., Peart, D., Olsen, P., and Sheldon, B. (2010). High-intensity activity profiles of elite soccer players at different performance levels. *J. Strength Cond. Res.* 24, 2343–2351. doi: 10.1519/JSC.0b013e3181aeb1b3

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., and Krustrup, P. (2009). High-intensity running in English FA premier league soccer matches. *J. Sports Sci.* 27, 159–168. doi: 10.1080/02640410802512775

Bush, M., Barnes, C., Archer, D. T., Hogg, B., and Bradley, P. S. (2015). Evolution of match performance parameters for various playing positions in the English premier league. *Hum. Mov. Sci.* 39, 1–11. doi: 10.1016/j.humov.2014.10.003

Caley, M. (2013). *The Football Aging Curve. Sb Nation Cartilage Free Captain*. Available at: http://cartilagefreecaptain.sbnation.com/2013/12/9/5191634/the-football-aging-curve [accessed October 1, 2018].

Dendir, S. (2016). When do soccer players peak? A note. *J. Sports Anal.* 2, 89–105. doi: 10.3233/JSA-160021

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., and Drust, B. (2009). Analysis of high intensity activity in premier league soccer. *Int. J. Sports Med.* 30, 205–212. doi: 10.1055/s-0028-1105950

Fair, R. C. (2008). Estimated age effects in baseball. *J. Quant. Anal. Sports* 4:1. doi: 10.2202/1559-0410.1074

Gerhards, J., and Mutz, M. (2017). Who wins the championship? Market value and team composition as predictors of success in the top European football leagues. *Eur. Soc.* 19, 223–242. doi: 10.1080/14616696.2016.1268704

Gómez, M. Á, Lago-Peñas, C., and Pollard, R. (2013). "Situational variables," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (London: Routledge).

Kovalchik, S. A. (2014). The older they rise the younger they fall: age and performance trends in men's professional tennis from 1991 to 2012. *J. Quant. Anal. Sports* 10, 99–107.

Kuper, S. (2011). *The Optimal Age to be an Athlete. Askmen.Com*. Available at: https://uk.askmen.com/sports/fanatic_300/325_the-best-age-for-athletes.html [accessed October 2, 2018].

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., and Bangsbo, J. (2008). Match activities of elite women soccer players at different performance levels. *J. Strength Cond. Res.* 22, 341–349. doi: 10.1519/JSC.0b013e318165fef6

Mohr, M., Krustrup, P., and Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *J. Sports Sci.* 21, 519–528. doi: 10.1080/0264041031000071182

Rienzi, E., Drust, B., Reilly, T., Carter, J. E., and Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *J. Sports Med. Phys. Fitness* 40, 162–169.

Rüst, C. A., Knechtle, B., Rosemann, T., and Lepers, R. (2012). Sex difference in race performance and age of peak performance in the ironman triathlon world championship from 1983 to 2012. *Extrem. Physiol. Med.* 1:15. doi: 10.1186/2046-7648-1-15

Smith, D. J. (2003). A framework for understanding the training process leading to elite performance. *Sports Med.* 33, 1103–1126. doi: 10.2165/00007256-200333150-00003

Wallace, J. L., and Norton, K. I. (2014). Evolution of world cup soccer final games 1966–2010: game structure, speed and play patterns. *J. Sci. Med. Sport* 17, 223–228. doi: 10.1016/j.jsams.2013.03.016

Williams, A.M. (Ed.) (2013). *Science and Soccer: Developing Elite Performers*. Milton Park: Routledge. doi: 10.4324/9780203131862

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A Systems Approach to Performance Analysis in Women's Netball: Using Work Domain Analysis to Model Elite Netball Performance

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Netball is a newly professional women's sport, as such there has been little research conducted investigating performance analysis (PA) in elite netball. The aim of this study was to develop a model of the elite netball performance system to identify the complex relationships among key performance indicators. Eleven elite subject matter experts (SMEs) participated in workshops to produce a systems model of the netball match performance. The model was developed using the work domain analysis (WDA) method. A model of the netball match performance system was produced showing the interrelated objects, processes, functions, values, and purposes involved in elite level netball matches. The model identified the components of elite level netball performance and the interactions and relationships between them. The output of this research has identified novel PA measures including passing and possession measures, measures of cognitive performance, and measures related to physical activity. Netball is a complex sport, involving multiple dynamic and interrelated components. Consequently, there is an opportunity to develop holistic PA measures that focus on interacting components, as opposed to components in isolation.

Keywords: netball, performance analysis, work domain analysis, coaching, women's sport

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INTRODUCTION

Netball is one of the most popular women's sports, and is played by more than 20 million people across more than 80 countries (Netball Australia, 2018). Since 1963 a netball World Championship tournament has been played every 4 years. In 1990 netball first featured in the Commonwealth Games as a demonstration sport, and has since been played competitively for medals since 1998 (Netball Australia, 2018). Despite substantial international popularity, netball remained an amateur sport for several decades. However, netball now has 61 countries recognized by the International Netball Federation, which includes several professional netball leagues. This recently obtained professional status of netball will no doubt generate new pressures and demands common within professional sport, one of which will be the increased demand for successful on-court match performance. To optimize match performance, it is necessary to assess performance variables in order to provide practical feedback to players and coaches, which will guide coaches decision making and subsequently the coaching process (Bishop, 2008).

Performance analysis (PA) in sport involves analysing and evaluating the technical, tactical, physical, and cognitive aspects of performance in training and competition to better understand the components of successful performance (Hughes and Franks, 2004; Bishop, 2008). There is a substantial body of PA research associated with long standing professional sports such as football (Sarmento et al., 2014, 2017), basketball (Bourbousson et al., 2010; Gómez et al., 2013; Sampaio et al., 2015), handball (Meletakos et al., 2011; Oliveira et al., 2012; Lago-Peñas et al., 2013), rugby (Vaz et al., 2010; Bishop and Barnes, 2013; Higham et al., 2014), water polo (Gómez et al., 2014; Lupo et al., 2014; Ruano et al., 2016), and Australian rules football (Robertson et al., 2015, 2016). In netball, research has focused on understanding the players' physical (Davidson and Trewartha, 2008; Cormack et al., 2014; Bailey et al., 2017; Thomas et al., 2017), biomechanical (Fish and Greig, 2014; Sinclair et al., 2015), and anthropometric (Hopper et al., 1995) characteristics in isolation, rates of injury occurrence, and injury prevention strategies (Hume and Steele, 2000; McManus et al., 2006; Mason-Mackay et al., 2016). Although these studies have been important for understanding the physical demands of netball and have demonstrated the differences in variables between different levels of competition, they do little to describe on-court performance. As such, there is a paucity of PA research in netball that has attempted to integrate multiple components of match performance, or to understand team functioning. However, recent research has demonstrated that a complex system approach is necessary to understand sports performance, which requires a more holistic approach than isolated measurement of performance variables (McLean et al., 2017b; Salmon et al., 2017a; Hulme et al., 2018).

Previous research on the technical and tactical components of PA in netball has typically used descriptive notational analysis (frequencies and percentages) of isolated performance variables for individual players such as passing, turnovers, and shooting to determine successful netball performance (O'Donoghue et al., 2008; Pulling et al., 2016). This suggests that the current understanding of the composition of successful netball performance, and the appropriate methods to measure them is limited (Croft et al., 2017). A limitation of this approach in netball, and generally for team sports, is that components of performance are often investigated in isolation without consideration of the interactions between other components of performance (Rein and Memmert, 2016; McLean et al., 2017b). This represents a deterministic and reductionist approach to PA and does not consider interdependencies or the relational perspectives within and between teams that is required to understand and describe complex team performance (Mackenzie and Cushion, 2013; McLean et al., 2017b).

In sports PA research, it is becoming increasingly accepted that measuring isolated PA variables without considering the interactions between them, and the influence of match context, is limited and cannot appropriately explain team sports performance (McLean et al., 2017b; Sarmento et al., 2017). In addition, such analyses contribute to a research-practice gap, whereby the reductionist analyses are of limited use to coaches for the design of training practices (Bishop, 2008; McLean et al., 2017b). Invasion sports such as netball represent complex systems, where multiple human and non-human components are operating within a dynamic and constantly changing match environment (Duarte et al., 2012, 2013; McLean et al., 2017b). Investigating sporting performance as complex systems allows an understanding of the cooperative behaviors of team members in space and time, as well as emergent behaviors based on the opposition actions (Balague et al., 2013; Travassos et al., 2013). Traditional sport science research applications that measure individual performance variables cannot provide a complete understanding of the complexity of performance or the factors influencing it, nor do they allow the detection of new emergent behaviors that could improve performance, or how performance can be measured (Carling et al., 2014). Recent studies have demonstrated the benefit of analysing and understanding sporting performance using methods specifically designed for analysing complex systems (McLean et al., 2017b; Salmon et al., 2017a; Hulme et al., 2018). Systems ergonomics methods are specifically designed to understand complex system behavior, for example, one study used cognitive work analysis (CWA), a systems ergonomics method, to model the football performance system to identify the components of football performance, and the interactions between them (McLean et al., 2017b). Importantly, the use of subject matter experts (SMEs) in the development of the football performance model helped to provide practical insights for coaches that are both important to measure that are representative of the state of the system, and those that have a limited use for coaches (McLean et al., 2017b). In addition, over the past 5 years, there has been a progressive increase in team analysis measures based on positional data (Bartlett et al., 2012; Frencken et al., 2012; Moura et al., 2012), and teamwork interactions based on network analysis, in football and basketball (Clemente et al., 2015a; Gonçalves et al., 2017; McLean et al., 2017c). Moreover, at an elite level, coaches prefer emergent team PA measures compared to individual player analyses (McLean et al., 2017b). As such, the use of analysis methods to investigate group behaviors have improved our understanding of the complex and dynamic nature of team sports, and have provided usable information for coaches regarding team functioning (Sarmento et al., 2017).

The infancy of professional netball, and the subsequent lack of integrated PA research in elite level netball provides a unique opportunity to obtain a more complete understanding of the composition of performance in elite netball, to understand the interactions between components, emergent properties (Croft et al., 2017), and to develop a conceptual base for future research and PA in netball. By building on established PA research in other areas, it will be possible to optimize PA in netball, potentially skipping decades of research describing isolated and independent performance components, as has been the case in other sports (Mackenzie and Cushion, 2013). Therefore, the primary aim of the current study is to describe and model the netball performance system via the application of CWA, a systems ergonomic method that has been used to understand complex systems, and in the design and re-design of complex systems across multiple domains (see "Materials and Methods" section). This first-of-its-kind analysis will allow the identification of the different components of performance and how they interact to influence performance in netball. In turn, the model will support identification of appropriate PA measures for netball.

MATERIALS AND METHODS

Participants

Ethical approval for this study was granted by the Human Research Ethics Committee at the University of the Sunshine Coast (A/17/1043). Eleven elite level SMEs participated in structured workshops to develop a systems analysis model of the netball match performance system. The SMEs were experienced elite level netball coaches (C), professional netball players (PL), netball performance analysts (PA), an exercise physiologist (EP), a sports psychologist (SP), a skill acquisition specialist (SA), a high-performance manager of a professional netball team (HPM), and a strength and conditioning coach (S&C) (**Table 1**).

Study Design

In the current study, WDA, the first phase of a systems ergonomics method, CWA, was used to develop a model of the netball match performance system to describe in detail the composition of netball performance (Naikar et al., 1999). CWA (Vicente, 1999) is a systems analysis and design framework that has previously been used in sport to analyze the football match performance system (McLean et al., 2017b) and other complex sociotechnical systems (Read et al., 2016; Salmon et al., 2016, 2017b), and to inform system design or redesign activities (Cornelissen et al., 2014; Stanton and Bessell, 2014). The framework comprises five phases; however, the phases applied is dependent on the purpose of the analysis. This study uses the first phase of CWA (Vicente, 1999), WDA. WDA is used to provide an event and actor independent model of the system under analysis: in this case the elite netball match performance system. The aim is to understand the constraints imposed on the actions of any player performing activities within a netball match environment. This is achieved by describing systems at five conceptual levels using the abstraction hierarchy (AH) method (McLean et al., 2017b) (**Table 2**).

Within the WDA model the specific functional purposes, measures, functions, processes and physical objects are displayed as nodes. The nodes are linked across the AH levels via means-ends relationships (indicated by connecting lines in **Figure 1**). This indicates that linked nodes above a node in the hierarchy relate to why the content of the node is required, and the linked nodes below a node relate to how the node is achieved (Salmon et al., 2017b). For example, in the netball model the function 'Attack' might have links to values and priorities such as 'Number of goals scored' and 'Scoring streak' above, and links from object-related processes such as 'Target for scoring' and 'Physical performance' below.

Procedure

The procedure for conducting a WDA requires an accepted nine step methodology (Naikar, 2013). The following section outlines the steps followed during the development of the current WDA.

Step 1: Establish Aims and Purpose

The purpose of the analysis was to develop a systems model of netball match performance, including a description of on-court

TABLE 1 | Subject matter expert (SME) characteristics.

SME	Professional experience (years)	Professional games played	Professional games coached	International games played	International tournaments	Number of other sports worked in	National sport academy (years)	Accreditation
C	18	~350	~250	42	–	–	–	–
C	12	~50	76	–	–	–	8	HPC
PL	7	32	–	63	2	–	–	–
PL	3	35	–	10*	1*	–	–	–
PA	15	–	–	–	3	4	–	Ph.D.; ISPAS (L5)
PA	10	–	–	–	5	4	5	Ph.D.; AspS2; ISPAS (L5)
SP	22	–	–	–	–	7	–	AHPRA
EP	23	–	–	–	–	–	–	Ph.D.
S&C	2	–	–	–	2	3	–	ASCA (L2)
HPM	20	–	–	–	2	17	20	ASCA (L3)
SA	14	–	–	–	–	12	10	Ph.D.
Total	146	67	250	115	15	36	43	
Mean	13.3	33.5		38.3	2.5	9	10.8	

World youth cup, ~self-reported estimates. 'Professional games coached' includes assistant coach. ISPAS, International Society of Performance Analysis of Sport; ASCA, Australian Strength and Conditioning Association; AHPRA, Australian Health Practitioners Registration Agency; Ph.D., Doctor of Philosophy; HPC, High Performance Coach; ASpS2, Accredited Sports Scientist Level 2 – Exercise and Sports Science Australia. International tournaments include: Olympic Games, World Championships, Commonwealth Games, South Asian Games, World Youth Cups, Asian Champions Trophy.

TABLE 2 | Abstraction hierarchy descriptions.

Abstraction hierarchy level	Question
1. Functional purposes	What is the reason for playing?
2. Values and priority measures	How can players, coaches assess whether the functional purposes are being achieved?
3. Purpose-related functions	What functions must be performed to achieve the purposes of the netball match system?
4. Object-related processes	What processes or affordances are provided by the physical objects in the netball match system?
5. Physical objects	What physical objects are in the netball match system?

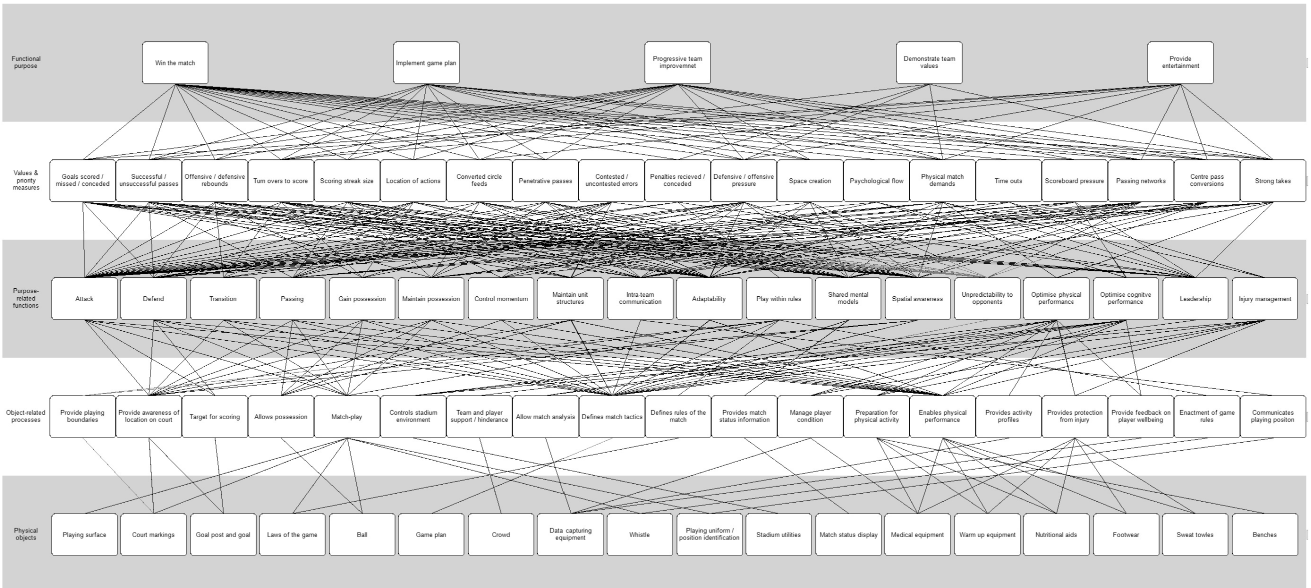

FIGURE 1 | The work domain analysis of the netball performance system.

performance, current measures used to assess performance, and to identify novel measures of performance.

Step 2: Anticipate Project Constraints

The main constraint considered was limited access to elite level SMEs due to the high demands placed on their time during training and competition. To manage this, we used multiple SMEs, including players, coaches, match analysts, and strength and conditioning coaches and held three separate workshops to provide as much opportunity for participation as possible.

Step 3: Define the System Boundary

To develop the WDA, it was necessary to set analysis boundaries. The boundary for the current analysis was confined to professional women's netball match-play. Factors related to performance that occur outside of the match, such as training, nutrition, sleep, etc., were not considered in the analysis. A second aspect of the analysis boundary was a specific focus on elite level women's netball.

Step 4: Classify System Constraints

For the purpose of this study, the WDA constraints represent the specific types of relationships that are to be modeled between the different components of netball match performance. For example, the physical context in which netball players operate imposes constraints on the actions of individual and group behaviors, whether this be via a need to adapt to the opposing team or the pressure to perform under stressful passages of play. Given that the relationships among performance-based components are largely non-deterministic (i.e., players continuously exhibit large degrees of freedom and latitude for behavior), the type of data sources and development of the analysis needed to include the firsthand experience of 'real' people who could reflect on why certain actions and behaviors occur during on court performances.

Step 5: Locate Data Sources

Existing scientific research in elite-level netball and wider sports performance peer-reviewed academic literature, as well as the identified SMEs were considered appropriate data sources to develop an initial WDA. In addition, the first author attended multiple training sessions of a professional netball team prior to the analysis to assist in understanding what comprises netball performance. The knowledge gained enabled recommendations of PA measures from other sports that could be modified and used in netball to assess performance.

Step 6: Construct the WDA

An initial model of the netball match system was developed by the research team based on the data collected in step five. The research team comprised four researchers experienced in applying systems ergonomics methods to sporting domains (Hulme et al., 2017; McLean et al., 2017b; Salmon et al., 2017a), two of which are human factors (HFs) practitioners with extensive experience in applying CWA in systems analysis and design across a range of safety critical domains (Read et al., 2015; Salmon et al., 2016), and two experienced netball performance analysts. Due to the scarcity of netball specific PA measures, several of the nodes within the initial WDA were derived from the PA literature on well-established professional sports. The research team applied the means-ends-links to the final model, to show the connections between the nodes across the levels of the AH using the how-what-why prompts.

Step 7: Refine the Analysis

The draft WDA model was reviewed and refined by the SMEs in three separate workshops. The SMEs were questioned on the appropriateness of the nodes in the draft model, including whether each node should be included or excluded from the model, and if the terms used were applicable to netball practitioners and coaches. Where required nodes and relationships were either removed, modified, or added.

Steps 8 and 9: Review and Validate the WDA

The completed WDA was presented to the two expert netball performance analysts for review. They were asked to review each node within the model, starting at the functional purposes level and proceeding downward to the physical objects level. The analysts agreed with the nodes at each level and provided no further modifications to the WDA model. To determine the novelty of included PA measures, the first author reviewed the existing literature on PA in netball, and items that have not previously been assessed in netball literature were considered to be novel to netball PA.

RESULTS

Modifications to the WDA

Based on the feedback from the SMEs during the workshops, there were modifications to the original WDA model of the netball performance system that was developed by the research team. See **Appendix 1** for a summary of the SME modifications to the WDA model.

Work Domain Analysis

The 'netball match performance model' is presented in **Figure 1**.

Functional Purposes

Five functional purposes identified highlighting the importance of winning the match, continual team improvement, adherence to the game plans, the demonstration of team values, and a need to entertain audiences.

Values and Priority Measures

Nineteen values and priority measures were identified. These included measures of goal scoring and passing, defense, cognitive measures of psychological flow and scoreboard pressure, team structure measures of space creation, and the strategic use of time outs.

Purpose Related Functions

Eighteen general functions were deemed necessary for achieving the functional purposes. These included match phase measures such as such as attack, defend, and transition. Functions of cognitive and physical performance, and tactical measures including controlling momentum, maintenance of structures, and adaptability.

Object Related Processes and Physical Objects

The two lower levels of the WDA show the physical objects in the system and the processes that each object supports in order to achieve the purpose-related functions. For example, the 'Goal post and goal' provides a 'Target for scoring,' and 'Footwear' provides 'Protection from injury.'

Means-End-Links

The means-end links in the WDA provide an indication of the relationships between the nodes across the five levels in terms of a how-what-why triad (**Figure 2**). The many-to-many means-end-links demonstrate the numerous possibilities for action available to the actors within the system (**Figure 1**).

DISCUSSION

The primary aim of this study was to develop, using WDA, a first-of-its-kind model of the netball performance system to determine the composition and interactions between the components of netball performance. Furthermore, the study aimed to identify components of performance that are not currently measured that have potential to advance PA in netball.

Issues Identified With Current PA in Netball

The discussions with SMEs in the workshops, and information from the relevant netball PA literature, indicates that PA in elite level netball primarily uses isolated notational analysis measures of individual players to describe performance. For example, commonly used measures identified included successful and unsuccessful passes, offensive and defensive rebounds, and number of penalties received. This reductionist approach is further problematic as the SMEs identified a lack of integration of these measures. It is our contention that PA in netball can be enhanced by addressing these issues by incorporating measures to analyze team behaviors. These measures can be extracted from the WDA. The following sections will discuss the results from across the levels of the WDA, with a specific focus on the functions and measures novel to PA in netball. The discussed functions and measures will highlight potential analysis methods aimed at increasing the quality of feedback

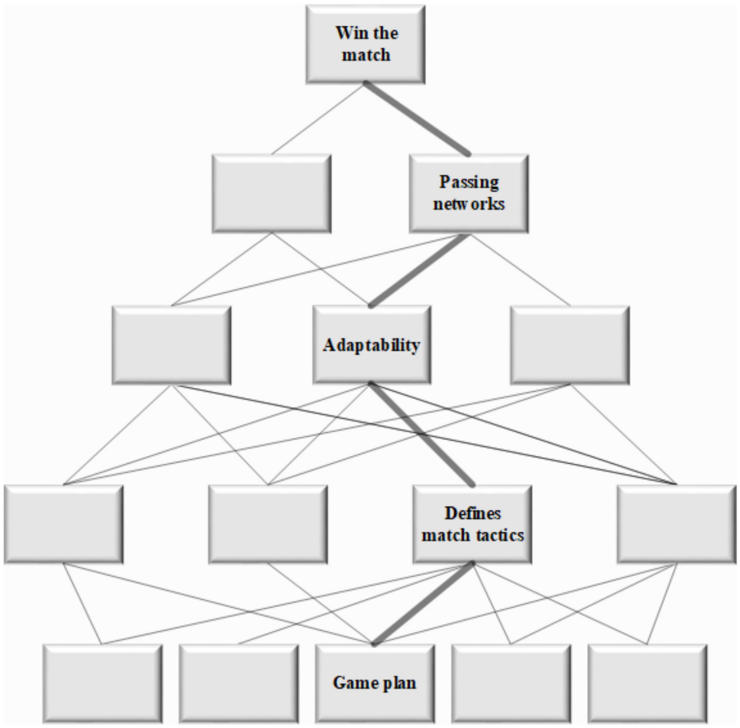

FIGURE 2 | Example means-end-links pathway. The relationship between levels of the abstraction hierarchy are indicated by the means-end-links using a how-what-why triad. Working from bottom to top, the physical object 'Game plan,' enables the object related process of 'Define match tactics,' which includes the purpose related function of 'Adaptability' of which can be assessed by the 'Passing networks' which can be measured to determine its influence on the functional purpose 'Win the match.' This approach is completed for all components in the developed netball performance system model.

to coaches, and subsequently improve coach's decision making to improve the coaching process. The measures and functions presented in the following sections are those that are deemed to be novel to netball, based on the current literature and from the workshop discussions with the SMEs. The two lower levels; object related processes and the physical objects from the WDA are not discussed further as they do not represent specific measures and functions of performance, which is the main focus of the study. They do, however, influence the behavior of the system which is indicated by the means-end-links (**Figure 2**).

Functional Purposes

Five functional purposes were identified in the WDA (**Figure 1**). Although winning the match would logically be considered as the most important functional purpose, other functional purposes were identified, which were seen as changing in priority depending upon contextual factors. For example, the coaching staff and players may still be satisfied when losing if the team has implemented the game plan, progressively improved from previous performances, and demonstrated team values. The means-end links in the WDA demonstrate the interactions between the measures and functions, and the core functional purposes. However, it is questionable as to how appropriately the functional purposes within the system are currently measured, due to the reductionist tendencies of the notational analysis measures typically used for PA in netball. Using performance measures that cannot comprehensively measure the functional purposes identified in the WDA indicates that at present coaches may be required to subjectively assess the functional purposes of a match. This is potentially problematic as coaches use match performance statistics to reinforce their opinions of match events for decisions relating to future matches (Hughes and Bartlett, 2002). As such, basing decisions on variables that cannot fully capture the interactions of the components of performance, may lead to incorrect or misinformed decision making by coaches. In other words, "Most of us only see what we expect to see, and what we expect to see is what we are conditioned to see when we have learned the definitions and classifications of our culture" (Turner et al., 1967). Therefore, to optimize PA in netball, more sophisticated measures used in other more established professional sports (that are presented in the WDA) could be modified and used to objectively describe if the functional purposes are being achieved. In addition, the SMEs emphasized that as a relatively new professional women's sport, it is important that netball matches provide entertainment in order to develop a strong supporter base, to gain sponsors, and to compete with other women's sports to ensure long-term sustainability.

Values and Priority Measures

Several of the values and priority measures from the WDA, including passing and goal scoring variables, turnovers, and rebounds have previously been measured to assess netball

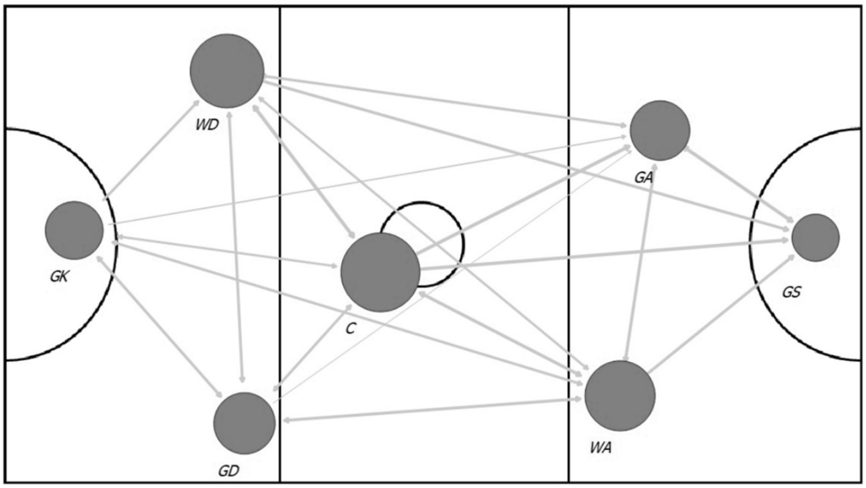

FIGURE 3 | Network analysis diagram of passing in a netball match. The direction of attack is from left to right. In this conceptual example, the node (player) size is based on degree centrality (number of outward passes in the match). The larger nodes represent more passes made, and the edges (passes) are weighted by frequency of passes completed between players, e.g., thicker lines indicate a greater frequency of passes. GK (goalkeeper), GD (goal defense), WD (wing defense), C (center), WA (wing attack), GA (goal attack), GS (goal shooter).

performance (O'Donoghue et al., 2008; Pulling et al., 2016; Croft et al., 2017). Although these match actions are important for successful performance in netball, they are often measured in isolation and without context, which limits their use for coaches (McLean et al., 2017b). Therefore, the model was used to identify novel measures of performances including group behaviors, measures from other sports that could be modified and applied to netball, outcome measures related to physical performance, and measures to optimize cognitive performance.

Passing, Possession, and Shooting

Research on passing in netball has previously used descriptive notational analysis methods to determine performance (Pulling et al., 2016). Using isolated passing success or frequency to assess performance has decreased in many other sports and been replaced with more sophisticated methods (Gonçalves et al., 2017; McLean et al., 2017c, 2018b; Ribeiro et al., 2017; Mclean and Salmon, 2019). Therefore, to enhance PA in netball, the WDA included passing metrics used in other team sports to assess performance which have potential to be used for PA in netball. One of the aims of invasion team sports is to score points by overcoming the opposition through intra team coordination and passing (Eccles and Tenenbaum, 2004). Therefore, for the passing analyses to be effective, the methods applied need to explain this team connectivity and coordination. Network analysis is a commonly used method to assess passing interactions in other sports (Ribeiro et al., 2017). Network analysis is used to analyze passing networks and provides quantifiable metrics of the connectivity of the team, and identifies the influential players within the team (Clemente et al., 2015a,b; McLean et al., 2017a,c, 2018a). The advantage of measuring passing networks over traditional approaches is the consideration of interdependencies and relational perspectives relative to the entire team, compared to individual assessment of passing (**Figure 3**) (Wäsche et al., 2017). This provides information to coaches regarding team functioning, and potentially assesses whether match tactics are being achieved, or require changing. Therefore, the use of passing networks rather than isolated passing metrics (e.g., successful and unsuccessful passes) will provide additional information on team functioning in netball. In addition, the passing network analyses could be further enhanced when integrated with the location on the court where the passing networks commence, progress through the court, and break down (McLean et al., 2017c). This allows the identification of the areas of the court where passing networks were successful, the vectors of the passing network, or potentially where the opposition focuses their passing networks and their vectors (McLean et al., 2017c).

Passing metrics that identify and describe the penetration through opposition defenses, and spatial dominance are beginning to be used in other sports as a measure to assess the quality of passes (McLean et al., 2017b; Rein et al., 2017; Tenga et al., 2017). These metrics consider the number of opposition players bypassed by a single pass, which is an effective pass compared to a sideways or backward pass that enables the defenders to still be involved in that specific moment of the game. Given the use of these measure in other team sports, penetrative passes would be a useful measure in netball, which prompted its inclusion in the WDA. Although this approach represents a somewhat isolated passing metric, it is a good example of how isolated passing analysis can be used alongside contextual details to provide a detailed analysis of the effectiveness of a pass.

The analysis indicated that isolated types of passing that are currently measured, such as center passes, and goal circle edge feeds, should be reported with a shooting outcome. For example, instead of simply counting the center passes, and goal circle edge feeds, measuring the center passes that were converted, or the goal circle edge feeds that were converted would provide a more detailed analysis, and could be incorporated into the passing network analysis.

Physical Performance Measures

Measuring physical performance in isolation, such as distance covered or the number of accelerations performed, also has limitations in relation to PA in sport, as physical outputs alone are not good indicators of overall performance (McLean et al., 2017b). Netball performance requires repeat explosive actions (Cormack et al., 2014), however, simply measuring the accelerations does not provide any information for how the accelerations benefit performance. In the model, strong takes were identified as a potential measure that has a performance outcome related to physical performance. Strong takes was defined as a received pass preceded by a rapid acceleration. Furthermore, acceleration data derived from motion tracking micro-technology could be a useful measure to determine effective defensive pressure, as it has been shown that percentage of passing occurrences is less in high compared to low defensive pressure for expert netball players (Bruce et al., 2009). Therefore, a measurement that describes the speed to apply defensive pressure, based on accelerations of the players may be a potential future measure when analysing performance in netball. Understanding physical match demands is important, especially from a load and injury prevention perspective (Bailey et al., 2017), however, more work is needed to integrate physical measures to performance outcome measures. Furthermore, the PA measures incorporating physical demands proposed here are somewhat subjective, suggesting that more sophisticated and objective methods are required.

Optimizing Cognitive Performance

The SMEs indicated that based on previous experience psychological flow was identified as a key component of performance in elite level netball. Psychological flow in sport is explained as the optimal psychological state for performance (Csikszentmihalyi, 1990). Experiencing flow for an athlete is characterized by an intense focus and absorption in an activity, at the exclusion of all other thoughts and emotions (Swann et al., 2012). As a result, players acquire a sense of ‘everything coming together’ even in the most demanding situations (Swann et al., 2012). Interestingly, psychological flow in netball is not represented in the literature and the SMEs indicated that flow is not routinely assessed in professional netball. The absence of such measures are despite the existence of flow state scales developed to measure flow (Jackson and Marsh, 1996). Understanding the mechanisms of flow, and the behaviors and actions of players and teams demonstrated during flow states could enhance performance in netball. Importantly, as players share common experiences such as the same opponent, the same coach, and the same conditions of play, flow can be experienced at a team level (Bakker et al., 2011).

Minimizing scoreboard pressure errors was included in the WDA as an area where players’ cognitive performance could be enhanced. The effect of scoreboard pressure on the players, which typically occurs toward the end of quarters, was described by the SMEs as a critical phase in the match that can have a direct influence on netball performance and match outcome. For example, toward the end of matches and in overtime of close matches, basketball players may be overstimulated (anxiety and self-doubt) and therefore vulnerable to distractions (Hill et al., 2009, 2010; Gómez et al., 2015). This results in poorer decision making and subsequently turnovers of possession, compared to an optimally stimulated state (Hill et al., 2009, 2010; Bradley et al., 2011). Although, no research exits on scoreboard pressure in netball, coaches could improve this component of performance in training using time and match status constraints to replicate these periods of a match.

Purpose Related Functions

The functions identified at this level included the high-level functions of attack, defend, gain and maintain possession, and components of these functions have been previously measured using a variety of methods (O’Donoghue et al., 2008; Pulling et al., 2016). However, several novel functions of netball performance were identified in the current model and require further investigation to optimize netball performance. These include controlling momentum, spatial awareness, unpredictability to opponents, and maintaining unit structures. Importantly, these functions consider the relational perspective of team members, and reduce the isolated type of analysis used so far in PA in netball research.

Unpredictability to Opponents

Unpredictability to opponents in attack was identified and included as a function of performance in the WDA. Commonly termed entropy in sport science, unpredictability has been measured in other sports to determine the predictability of ball movements during play (Hobbs et al., 2018). In basketball, there is a relationship between teams who display entropy in offensive phases and the probability of a shot for an undefended player (D’Amour et al., 2015). A separate study investigating entropy of ball movements in basketball showed that in matches won, the team displayed increased entropy in the front court (scoring zone) compared to matches lost (Hobbs et al., 2018). This result not only shows the importance of being unpredictable in and around the scoring areas, but also the importance of analysing unpredictability in relation to elements of match context such as the location of actions. Given the use of entropy as measure of performance in basketball, it is logical that entropy could be a useful measure in netball to assess performance due to the similarities of the sports. In addition, this could be optimized in netball to include the entropy of the players spatial movements (Sampaio and Maçãs, 2012) in combination with the ball trajectories (Hobbs et al., 2018). An interesting future direction would be to investigate entropy as a function of match status, to assess differences in entropy whilst winning and losing netball matches.

Maintenance of Unit Structures

The maintenance of team structures in sport is an integral component of successful performance (McLean et al., 2017b). As such, maintaining unit structure in netball is a critical strategy to (a) be compact defensively, and (b) destabilize the opposing teams' defensive structures by increasing the distance between the opposition defenders when attacking (Moura et al., 2012). In football, during attacking phases of a match the players are more dispersed across the length and width of the pitch compared to defending situations where they are more compact (Moura et al., 2012). As an attacking team, an aim is to increase the dispersion of the defenders to attempt to create space for a shot at goal. For example, when the distance between defensive players in football is increased, more attempts at goal are conceded compared to when the distance between defenders is decreased (Moura et al., 2012). Although there is no research of this type in netball, research into team structures in other sports has shown the value of such information to understand the necessary components of creating attempts at goal. A difference between netball and other sports is that the match constraints in netball allow players of only certain positions to attack or defend. For example, only four players from each team can occupy the defensive zone, and only four players from each team can occupy the attacking zone of the court. For this reason, maintaining attacking or defensive units was included in the WDA rather than maintaining the entire team structure. There are various existing methods of assessing the maintenance of team structure, including stretch index, measurements of surface area, playing area, effective playing area, and centroid measures (Sarmento et al., 2017), all of which have potential to determine the maintenance of unit structures in elite netball.

Controlling Momentum

The ability to control momentum in netball was supported in this analysis. The SMEs described controlling momentum in netball as the ability to slow down or speed up play as the match situation demands. Synonymous with controlling momentum is match tempo, which has not been clearly defined in sport science research (McLean et al., 2017b). There are conflicting definitions of tempo, and attempts to define it have included time in possession, speed of the ball, and speed of the players (Tenga et al., 2009; Buchheit et al., 2010; Wallace and Norton, 2014). However, a comprehensive definition of tempo, and the relationship between tempo and performance in sport is yet to be established (McLean et al., 2017b). The SMEs indicated that understanding the mechanisms of controlling momentum in netball would be beneficial to performance. Firstly, an appropriate method to determine how to measure tempo in netball is required, followed by methods to understand the player behaviors required to control it. This represents an opportunity for future research, and such results that would be informative and useable for coaches.

This first-of-its-kind WDA of the elite women's netball performance system has demonstrated that netball is a complex system, which consists of multiple interacting and competing components of performance. The purpose of the WDA is not to determine the relative importance of individual nodes, but to capture all of the possibilities that influence performance. One of the strengths of WDA is that it does not attempt to describe or predict the behavior of the individuals within the analysis, but instead describes the constraints in the system that can influence and effect behavior (McLean et al., 2017b). This is important because coaches each have their own philosophies and preferred coaching styles. In the current study, it was important to model the existing measures of PA in netball, as well as to include novel functions of performance and potential measures that would exist in the optimal netball performance system. It is noted that the necessary resources required for measuring some of the proposed performance variables from the current study may not be readily available for many netball performance analysts at this early point in professional netball. This should represent a challenge to researchers to develop methods that are sophisticated and inexpensive, yet useable in practice. For instance, valid and reliable observational instruments for the technical and tactical analysis of rugby performance have been designed and could be extended to many of the novel netball performance measures proposed in this study (Villarejo et al., 2014). It has been shown here that by understanding the PA variables of other sports more advanced in terms of PA than netball, there are possibilities to modify variables to be appropriate for netball. By enhancing the PA methods in netball, a more detailed analysis is achieved which will subsequently improve the feedback to coaches and players, and improves coach's knowledge of PA. By using elite level netball SMEs to develop the model ensures that the novel methods identified here will be usable in practice.

A final point of consideration relates to the lack of sports science research that has applied systems thinking approaches in women's sports contexts. Thus, this research addresses two important needs. First, netball is an under-researched area relative to other team-based sports contexts, and the use of a systems-based PA framework has been beneficial at identifying non-traditional aspects of on-court performances that require the attention of coaches and players. Secondly, this research should encourage sports scientists to apply other systems thinking approaches to optimize performance in women's sports contexts – whether this be netball or otherwise. For example, the next step following this research may be to explore how best to measure, test and validate the novel performance components identified and question the feasibility of doing so from a practical and coaching standpoint. This way, the growth of women's sport can parallel scientific advancement and innovation in the sports sciences, bringing with it the formalization of systems thinking approaches in a underrepresented athletic group.

Limitations

A potential limitation of the current study is the small number of SMEs used to develop the WDA model of elite level netball. However, the SMEs who participated in the current study have extensive experience in elite level netball including participation in national and international competitions as coaches, analysts, and players. Furthermore, a similar model of football performance used eight SMEs in their analysis (McLean et al., 2017b), and other research using this method has ranged from three to eleven SMEs to develop similar models (Jenkins et al., 2011; Salmon et al., 2016). In addition, the demographics of the SMEs spanned three of the top nations in world netball (Australia, New Zealand, and South Africa). A limitation of the WDA method is that is does not weight the relationships between the nodes to determine nodal importance. However, the purpose of the WDA phase of the CWA framework is to model the entire netball performance system, and in doing so identify all the components within the system that influence the functions and measures of performance. Future research could attempt to weight the relationships between nodes to determine nodal importance.

CONCLUSION

The current study provided a first-of-its-kind complex systems model of the elite women's netball match performance system. The model depicts the key components of netball match performance along with the means-ends relationships between them. It is concluded that, whilst netball performance is complex in nature, there are various opportunities to understand this complexity through the introduction of new PA measures. Further investigation is recommended, particularly the development, testing and validation of the new measures discussed. It is hoped that researchers and practitioners use the model presented in this article to facilitate this, and that netball PA is optimized as a result.

AUTHOR CONTRIBUTIONS

SM, AH, GR, and PS conceived the study. SM, AH, GR, AB, and PS performed the study. SM, AH, MM, GR, AB, and PS analyzed the data, wrote and revised the manuscript.

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REFERENCES

Bailey, J. A., Gastin, P. B., Mackey, L., and Dwyer, D. B. (2017). The player load associated with typical activities in elite netball. *Int. J. Sports Physiol. Perform.* 12, 1218–1223. doi: 10.1123/ijspp.2016-0378

Bakker, A. B., Oerlemans, W., Demerouti, E., Slot, B. B., and Ali, D. K. (2011). Flow and performance: a study among talented Dutch soccer players. *Psychol. Sport Exer.* 12, 442–450. doi: 10.1016/j.psychsport.2011.02.003

Balague, N., Torrents, C., Hristovski, R., Davids, K., and Araújo, D. (2013). Overview of complex systems in sport. *J. Syst. Sci. Complex.* 26, 4–13. doi: 10.1007/s11424-013-2285-0

Bartlett, R., Button, C., Robins, M., Dutt-Mazumder, A., and Kennedy, G. (2012). Analysing team coordination patterns from player movement trajectories in soccer: methodological considerations. *Int. J. Perform. Anal. Sport* 12, 398–424. doi: 10.1080/24748668.2012.11868607

Bishop, D. (2008). An applied research model for the sport sciences. *Sports Med.* 38, 253–263. doi: 10.2165/00007256-200838030-00005

Bishop, L., and Barnes, A. (2013). Performance indicators that discriminate winning and losing in the knockout stages of the 2011 Rugby World Cup. *Int. J. Perform. Anal. Sport* 13, 149–159. doi: 10.1080/24748668.2013.11868638

Bourbousson, J., Sève, C., and McGarry, T. (2010). Space–time coordination dynamics in basketball: part 1. Intra-and inter-couplings among player dyads. *J. Sports Sci.* 28, 339–347. doi: 10.1080/02640410903503632

Bradley, P. S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., et al. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *J. Sports Sci.* 29, 821–830. doi: 10.1080/02640414.2011.561868

Bruce, L., Farrow, D., Raynor, A., and May, E. (2009). Notation analysis of skill expertise differences in netball. *Int. J. Perform. Anal. Sport* 9, 245–254. doi: 10.1080/24748668.2009.11868481

Buchheit, M., Mendez-Villanueva, A., Simpson, B., and Bourdon, P. (2010). Repeated-sprint sequences during youth soccer matches. *Int. J. Sports Med.* 31, 709–716. doi: 10.1055/s-0030-1261897

Carling, C., Wright, C., Nelson, L. J., and Bradley, P. S. (2014). Comment on 'Performance analysis in football: a critical review and implications for future research'. *J. Sports Sci.* 32, 2–7. doi: 10.1080/02640414.2013.807352

Clemente, F. M., Martins, F. M. L., Kalamaras, D., Wong, D. P., and Mendes, R. S. (2015a). General network analysis of national soccer teams in FIFA World Cup 2014. *Int. J. Perform. Anal. Sport* 15, 80–96. doi: 10.1080/24748668.2015.11868778

Clemente, F. M., Martins, F. M. L., Wong, D. P., Kalamaras, D., and Mendes, R. S. (2015b). Midfielder as the prominent participant in the building attack: a network analysis of national teams in FIFA World Cup 2014. *Int. J. Perform. Anal. Sport* 15, 704–722. doi: 10.1080/24748668.2015.11868825

Cormack, S. J., Smith, R. L., Mooney, M. M., Young, W. B., and O'Brien, B. J. (2014). Accelerometer load as a measure of activity profile in different standards of netball match play. *Int. J. Sports Physiol. Perform.* 9, 283–291. doi: 10.1123/ijspp.2012-0216

Cornelissen, M., McClure, R., Salmon, P. M., and Stanton, N. A. (2014). Validating the strategies analysis diagram: assessing the reliability and validity of a formative method. *Appl. Ergon.* 45, 1484–1494. doi: 10.1016/j.apergo.2014.04.010

Croft, H., Willcox, B., and Lamb, P. (2017). Using performance data to identify styles of play in netball: an alternative to performance indicators. *Int. J. Perform. Anal. Sport* 17, 1034–1043. doi: 10.1080/24748668.2017.1419408

Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Performance*. New York, NY: Cambridge UniversityPress.

D'Amour, A., Cervone, D., Bornn, L., and Goldsberry, K. (2015). *Move or Die: How Ball Movement Creates Open Shots in the NBA*. Boston, MA: MIT Sloan Sports Analytics Conference.

Davidson, A., and Trewartha, G. (2008). Understanding the physiological demands of netball: a time-motion investigation. *Int. J. Perform. Anal. Sport* 8, 1–17. doi: 10.1080/24748668.2008.11868443

Duarte, R., Araújo, D., Correia, V., and Davids, K. (2012). Sports teams as superorganisms. *Sports Med.* 42, 633–642. doi: 10.2165/11632450-000000000-00000

Duarte, R., Araújo, D., Folgado, H., Esteves, P., Marques, P., and Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *J. Syst. Sci. Complex.* 26, 62–72. doi: 10.1007/s11424-013-2290-3

Eccles, D. W., and Tenenbaum, G. (2004). Why an expert team is more than a team of experts: a social-cognitive conceptualization of team coordination and communication in sport. *J. Sport Exerc. Psychol.* 26, 542–560. doi: 10.1123/jsep.26.4.542

Fish, K., and Greig, M. (2014). The influence of playing position on the biomechanical demands of netball match-play. *J. Athl. Enhanc.* 3, 1–5.

Frencken, W., Poel, H. D., Visscher, C., and Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *J. Sports Sci.* 30, 1207–1213. doi: 10.1080/02640414.2012.703783

Gómez, M.-A., Lorenzo, A., Ibañez, S.-J., and Sampaio, J. (2013). Ball possession effectiveness in men's and women's elite basketball according to situational variables in different game periods. *J. Sports Sci.* 31, 1578–1587. doi: 10.1080/02640414.2013.792942

Gómez, M. -Á, DelaSerna, A., Lupo, C., and Sampaio, J. (2014). Effects of situational variables and starting quarter score in the outcome of elite women's water polo game quarters. *Int. J. Perform. Anal. Sport* 14, 73–83. doi: 10.1097/JSC.0000000000000234

Gómez, M. Á, Lorenzo, A., Jiménez, S., Navarro, R. M., and Sampaio, J. (2015). Examining choking in basketball: effects of game outcome and situational variables during last 5 minutes and overtimes. *Percept. Mot. Skills* 120, 111–124. doi: 10.2466/25.29.PMS.120v11x0

Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jiménez, S., and Sampaio, J. (2017). Exploring team passing networks and player movement dynamics in youth association football. *PLoS One* 12:e0171156. doi: 10.1371/journal.pone.0171156

Higham, D. G., Hopkins, W. G., Pyne, D. B., and Anson, J. M. (2014). Performance indicators related to points scoring and winning in international rugby sevens. *J. Sports Sci. Med.* 13, 358–364.

Hill, D. M., Hanton, S., Fleming, S., and Matthews, N. (2009). A re-examination of choking in sport. *Eur. J. Sport Sci.* 9, 203–212. doi: 10.1080/17461390902818278

Hill, D. M., Hanton, S., Matthews, N., and Fleming, S. (2010). Choking in sport: a review. *Int. Rev. Sport Exerc. Psychol.* 3, 24–39. doi: 10.1080/17509840903301199

Hobbs, W., Morgan, S., Gorman, A. D., Mooney, M., and Freeston, J. (2018). Playing unpredictably: measuring the entropy of ball trajectories in international women's basketball. *Int. J. Perform. Anal. Sport* 18, 1–12. doi: 10.1080/24748668.2018.1453639

Hopper, D. M., Hopper, J. L., and Elliott, B. C. (1995). Do selected kinanthropometric and performance variables predict injuries in female netball players? *J. Sports Sci.* 13, 213–222. doi: 10.1080/02640419508732230

Hughes, M., and Franks, I. M. (2004). *Notational Analysis of Sport: Systems for Better Coaching and Performance in Sport*. London: Psychology Press.

Hughes, M. D., and Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *J. Sports Sci.* 20, 739–754. doi: 10.1080/026404102320675602

Hulme, A., Salmon, P., Nielsen, R., Read, G. J., and Finch, C. (2017). Closing Pandora's box: adapting a systems ergonomics methodology for better understanding the ecological complexity underpinning the development and prevention of running-related injury. *Theor. Issues Ergon. Sci.* 18, 338–359. doi: 10.1080/1463922X.2016.1274455

Hulme, A., Thompson, J., Plant, K. L., Read, G. J., Mclean, S., Clacy, A., et al. (2018). Applying systems ergonomics methods in sport: a systematic review. *Appl. Ergon.* doi: 10.1016/j.apergo.2018.03.019 [Epub ahead of print].

Hume, P. A., and Steele, J. R. (2000). A preliminary investigation of injury prevention strategies in Netball: are players heeding the advice? *Journal of Science and Medicine in Sport* 3, 406–413.

Jackson, S. A., and Marsh, H. W. (1996). Development and validation of a scale to measure optimal experience: the flow state scale. *J. Sport Exerc. Psychol.* 18, 17–35. doi: 10.1123/jsep.18.1.17

Jenkins, D. P., Stanton, N. A., Salmon, P. M., and Walker, G. H. (2011). Using work domain analysis to evaluate the impact of technological change on the performance of complex socio-technical systems. *Theor. Issues Ergon. Sci.* 12, 1–14. doi: 10.1080/14639220903353401

Lago-Peñas, C., Gómez, A. M., Viaño, J., González-García, I., and Fernández-Villarino, M. d. L. á (2013). Home advantage in elite handball: the impact of the quality of opposition on team performance. *Int. J. Perform. Anal. Sport* 13, 724–733. doi: 10.1080/24748668.2013.11868684

Lupo, C., Condello, G., Capranica, L., and Tessitore, A. (2014). Women's water polo World Championships: technical and tactical aspects of winning and losing teams in close and unbalanced games. *J. Strength Cond. Res.* 28, 210–222. doi: 10.1519/JSC.0b013e3182955d90

Mackenzie, R., and Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *J. Sports Sci.* 31, 639–676. doi: 10.1080/02640414.2012.746720

Mason-Mackay, A. R., Whatman, C., Reid, D., and Lorimer, A. (2016). The effect of ankle bracing on landing biomechanics in female netballers. *Phys. Ther. Sport* 20, 13–18. doi: 10.1016/j.ptsp.2015.11.002

Mclean, S., and Salmon, P. (2019). The weakest link: a novel use of network analysis for the broken passing links in football. *Sci. Med. Football* 1–4. doi: 10.1080/24733938.2018.1562277

McLean, S., Salmon, P., Gorman, A., Dodd, K., and Solomon, C. (2018a). Integrating communication and passing networks in football using social network analysis. *Sci. Med. Football.* doi: 10.1080/24733938.2018.1478122

McLean, S., Salmon, P., Gorman, A., Wickham, J., Berber, E., and Solomon, C. (2018b). The effect of playing formation the passing network characteristics of a professional football team. *Hum. Mov.* 19. 14–22. doi: 10.5114/hm.2018.79416

McLean, S., Salmon, P. M., Gorman, A. D., Naughton, M., and Solomon, C. (2017a). Do inter-continental playing styles exist? Using social network analysis to compare goals from the 2016 EURO and COPA football tournaments knock-out stages. *Theor. Issues Ergon. Sci.* 18, 370–383. doi: 10.1080/1463922X.2017.1290158

McLean, S., Salmon, P. M., Gorman, A. D., Read, G. J., and Solomon, C. (2017b). What's in a game? A systems approach to enhancing performance analysis in football. *PLoS One* 12:e0172565. doi: 10.1371/journal.pone.0172565

McLean, S., Salmon, P. M., Gorman, A. D., Stevens, N. J., and Solomon, C. (2017c). A social network analysis of the goal scoring passing networks of the 2016 European Football Championships. *Hum. Mov. Sci.* 57, 400–408. doi: 10.1016/j.humov.2017.10.001

McManus, A., Stevenson, M. R., and Finch, C. F. (2006). Incidence and risk factors for injury in non-elite netball. *J. Sci. Med. Sport* 9, 119–124. doi: 10.1016/j.jsams.2006.03.005

Meletakos, P., Vagenas, G., and Bayios, I. (2011). A multivariate assessment of offensive performance indicators in men's handball: trends and differences in the World Championships. *Int. J. Perform. Anal. Sport* 11, 284–294. doi: 10.1080/24748668.2011.11868548

Moura, F. A., Martins, L. E. B., Anido, R. D. O., De Barros, R. M. L., and Cunha, S. A. (2012). Quantitative analysis of Brazilian football players' organisation on the pitch. *Sports Biomech.* 11, 85–96. doi: 10.1080/14763141.2011.637123

Naikar, N. (2013). *Work Domain Analysis: Concepts, Guidelines, and Cases*. Boca Raton, FL: CRC Press. doi: 10.1201/b14774

Naikar, N., Sanderson, P. M., and Lintern, G. (1999). Work domain analysis for identification of training needs and training-system design. *Paper Presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Washington, DC. doi: 10.1177/154193129904302103

Netball Australia (2018). *History of Netball*. Available at: http://netball.com.au/about-netball-australia/history-of-netball/ [acessed October 19, 2018].

O'Donoghue, P., Mayes, A., Edwards, K. M., and Garland, J. (2008). Performance norms for British national super league netball. *Int. J. Sports Sci. Coach.* 3, 501–511. doi: 10.1260/174795408787186486

Oliveira, T., Gómez, M., and Sampaio, J. (2012). Effects of game location, period, and quality of opposition in elite handball performances. *Percept. Mot. Skills* 114, 783–794. doi: 10.2466/30.06.PMS.114.3.783-794

Pulling, C., Eldridge, D., and Lomax, J. (2016). Centre passes in the UK netball super league. *Int. J. Perform. Anal. Sport* 16, 389–400. doi: 10.1080/24748668.2016.11868894

Read, G. J., Salmon, P. M., Lenné, M. G., and Stanton, N. A. (2015). Designing sociotechnical systems with cognitive work analysis: putting theory back into practice. *Ergonomics* 58, 822–851. doi: 10.1080/00140139.2014.980335

Read, G. J., Salmon, P. M., Lenné, M. G., and Stanton, N. A. (2016). Walking the line: understanding pedestrian behaviour and risk at rail level crossings with cognitive work analysis. *Appl. Ergon.* 53, 209–227. doi: 10.1016/j.apergo.2015.10.004

Rein, R., and Memmert, D. (2016). Big data and tactical analysis in elite soccer: future challenges and opportunities for sports science. *Springerplus* 5:1410. doi: 10.1186/s40064-016-3108-2

Rein, R., Raabe, D., and Memmert, D. (2017). Which pass is better?" Novel approaches to assess passing effectiveness in elite soccer. *Hum. Mov. Sci.* 55, 172–181. doi: 10.1016/j.humov.2017.07.010

Ribeiro, J., Silva, P., Duarte, R., Davids, K., and Garganta, J. (2017). Team sports performance analysed through the lens of social network theory: implications for research and practice. *Sports Med.* 47, 1689–1696. doi: 10.1007/s40279-017-0695-1

Robertson, S., Back, N., and Bartlett, J. D. (2016). Explaining match outcome in elite Australian rules football using team performance indicators. *J. Sports Sci.* 34, 637–644. doi: 10.1080/02640414.2015.1066026

Robertson, S., Woods, C., and Gastin, P. (2015). Predicting higher selection in elite junior Australian rules football: the influence of physical performance and anthropometric attributes. *J. Sci. Med. Sport* 18, 601–606. doi: 10.1016/j.jsams.2014.07.019

Ruano, M. Á, Serna, A. D., Lupo, C., and Sampaio, J. E. (2016). Effects of game location, quality of opposition, and starting quarter score in the outcome of elite water polo quarters. *J. Strength Cond. Res.* 30, 1014–1020. doi: 10.1097/JSC.0000000000000234

Salmon, P. M., Clacy, A., and Dallat, C. (2017a). It's not all about the bike: distributed situation awareness and teamwork in elite women's cycling teams. *Contemp. Ergon.* 2017, 240–248.

Salmon, P. M., Walker, G. H., Stanton, N. A., and Jenkins, D. P. (2017b). *Cognitive Work Analysis: Applications, Extensions and Future Directions*. Boca Raton, FL: CRC Press.

Salmon, P. M., Lenné, M. G., Read, G. J., Mulvihill, C. M., Cornelissen, M., Walker, G., et al. (2016). More than meets the eye: using cognitive work analysis to identify design requirements for future rail level crossing systems. *Appl. Ergon.* 53, 312–322. doi: 10.1016/j.apergo.2015.06.021

Sampaio, J., and Maçãs, V. (2012). Measuring tactical behaviour in football. *Int. J. Sports Med.* 33, 395–401. doi: 10.1055/s-0031-1301320

Sampaio, J., McGarry, T., Calleja-González, J., Sáiz, S. J., del Alcázar, X. S., and Balciunas, M. (2015). Exploring game performance in the National basketball association using player tracking data. *PLoS One* 10:e0132894. doi: 10.1371/journal.pone.0132894

Sarmento, H., Clemente, F. M., Araújo, D., Davids, K., McRobert, A., and Figueiredo, A. (2017). What performance analysts need to know about research trends in Association football (2012–2016): a systematic review. *Sports Med.* 48, 799–836. doi: 10.1007/s40279-017-0836-6

Sarmento, H., Marcelino, R., Anguera, M. T., CampaniÇo, J., Matos, N., and LeitÃo, J. C. (2014). Match analysis in football: a systematic review. *J. Sports Sci.* 32, 1831–1843. doi: 10.1080/02640414.2014.898852

Sinclair, J., Chockalingam, N., Naemi, R., and Vincent, H. (2015). The effects of sport-specific and minimalist footwear on the kinetics and kinematics of three netball-specific movements. *Footwear Sci.* 7, 31–36. doi: 10.1080/19424280.2014.983445

Stanton, N. A., and Bessell, K. (2014). How a submarine returns to periscope depth: analysing complex socio-technical systems using cognitive work analysis. *Appl. Ergon.* 45, 110–125. doi: 10.1016/j.apergo.2013.04.022

Swann, C., Keegan, R. J., Piggott, D., and Crust, L. (2012). A systematic review of the experience, occurrence, and controllability of flow states in elite sport. *Psychol. Sport Exerc.* 13, 807–819. doi: 10.1016/j.psychsport.2012.05.006

Tenga, A., Kanstad, D., Ronglan, L., and Bahr, R. (2009). Developing a new method for team match performance analysis in professional soccer and testing its reliability. *Int. J. Perform. Anal. Sport* 9, 8–25. doi: 10.1080/24748668.2009.11868461

Tenga, A., Mortensholm, A., and O'Donoghue, P. (2017). Opposition interaction in creating penetration during match play in elite soccer: evidence from UEFA champions league matches. *Int. J. Perform. Anal. Sport* 17, 802–812. doi: 10.1080/24748668.2017.1399326

Thomas, C., Ismail, K. T., Simpson, R., Comfort, P., Jones, P. A., and Dos'Santos, T. (2017). Physical profiles of female academy netball players by position. *J. Strength Cond. Res.* doi: 10.1519/JSC.0000000000001949 [Epub ahead of print].

Travassos, B., Davids, K., Araújo, D., and Esteves, P. T. (2013). Performance analysis in team sports: advances from an ecological dynamics approach. *Int. J. Perform. Anal. Sport* 13, 83–95. doi: 10.1080/24748668.2013.11868633

Turner, V., Turner, V. W., and Victor, T. (1967). *The Forest of Symbols: Aspects of Ndembu Ritual*, Vol. 101. New York, NY: Cornell University Press.

Vaz, L., Van Rooyen, M., and Sampaio, J. (2010). Rugby game-related statistics that discriminate between winning and losing teams in IRB and Super twelve close games. *J. Sports Sci. Med.* 9:51.

Vicente, K. J. (1999). *Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-Based Work*. Boca Raton, FL: CRC Press.

Villarejo, D., Ortega, E., Gómez, M. -Á, and Palao, J.-M. (2014). Design, validation, and reliability of an observational instrument for ball possessions in rugby union. *Int. J. Perform. Anal. Sport* 14, 955–967. doi: 10.1080/24748668.2014.11868771

Wallace, J. L., and Norton, K. I. (2014). Evolution of World cup soccer final games 1966–2010: game structure, speed and play patterns. *J. Sci. Med. Sport* 17, 223–228. doi: 10.1016/j.jsams.2013.03.016

Wäsche, H., Dickson, G., Woll, A., and Brandes, U. (2017). Social network analysis in sport research: an emerging paradigm. *Eur. J. Sport Soc.* 14, 138–165. doi: 10.1080/16138171.2017.1318198

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APPENDIX 1 | SME MODIFICATIONS TO THE INITIAL WDA.

Level of abstraction	Action taken
Functional purposes	***Minor rewording:*** ‘Play in line with club values’ > ‘demonstrate team values’ ***Added nodes:*** ‘Provide entertainment’
Values and priority measures	***Minor rewording:*** ‘Goals scored/conceded’ > ‘goals scored/missed/conceded’; ‘center restarts’ > ‘center pass conversions’ ***Removed nodes:*** ‘Distance covered’; ‘center restarts’; ‘goal assists’; ‘goal attempt blocks’; ‘number of possessions’ ***Added nodes:*** ‘Psychological flow’; ‘player workload’; ‘penetrative passes’; ‘converted edge feeds’; ‘contested errors/uncontested errors’; ‘time outs’; ‘scoreboard pressure’; ‘passing chains’; ‘defensive/offensive pressure’ ***Nodes incorporated elsewhere:*** ’Handling errors’; ‘intercepts’; ‘loose ball wins’ incorporated into ‘turnovers to score’ ‘Discipline’ incorporated into ‘penalties received/conceded’ ‘Defensive block’; ‘goal attempt blocks’ incorporated into ‘defensive pressure’
Purpose related functions	***Minor rewording:*** ‘Mange tempo’ > ‘control momentum’ ‘Maintain structures’ > ‘maintain unit structures’ ‘Adhere to team culture’ > ‘value team culture’ ***Removed node:*** ‘Gain and maintain possession’ ***Added nodes:*** ‘Spatial awareness’; ‘gain possession’; ‘maintain possession’; ‘optimize cognitive performance’; ‘optimize physical performance’; ‘unpredictability to opponents’
Object related processes	***Minor rewording:*** ‘Team support/hinderance’ > ‘team and player support/hinderance’ ‘Visual communication’ > ‘communicates playing position’ ‘Implement rules’ > ‘enactment of game rules’ ‘Stadium atmosphere’ > ‘controls stadium environment’
Physical objects	***Minor rewording:*** ‘Game plan and tactics’ > ‘game plan’ ***Removed node:*** ‘Air conditioning’ ***Added nodes:*** ‘Benches’; ‘stadium utilities’ ***Nodes incorporated elsewhere:*** ‘GPS’ incorporated into ‘data capturing equipment’

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Differences in the Offensive and Defensive Actions of the Goalkeepers at Women's FIFA World Cup 2011

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The aim of this study was to analyze the technical and tactical offensive and defensive actions of the goalkeepers and to determine the relationship between these actions and the qualifying results of their respective teams. The sample studied is made up of the goalkeepers (n = 20) of the senior national teams that participated in the FIFA Women's World Cup in Germany 2011. A descriptive analysis was developed comparing the offensive and defensive actions in competition carried out by the goalkeepers on qualified teams (pass the group stage) with the goalkeepers on unclassified teams (not pass the group stage). For the inter-group comparison, the value of the coefficient of variation was incorporated and the effect size calculated. All data were treated with a statistical significance level of $p < 0.05$. The results show that the goalkeepers on qualified teams have higher offensive registers, as well as a higher number of passes successfully completed in different areas of the field. The goalkeepers on unclassified teams show higher defensive records such as saves inside the area, foot stops and wrong clearances among others.

Keywords: women's football, match statistics, notational analysis, performance indicators, soccer

INTRODUCTION

The number of scientific investigations on women's football specific to the topics of player characteristics and demands of the game has considerably increased in recent years due to the increased popularity of the women's game worldwide, although they are not yet as numerous as in the case of men's football (Martínez-Lagunas et al., 2014). However, most of the published studies have been focused on the physiological and physical attributes of female footballers, which appear to condition the way the team plays and performs during games and competition (Gabbett and Mulvey, 2008; Mohr et al., 2008).

The analysis of competition is currently a key process for improving the performance of football teams in matches and training (Carling et al., 2005; Sarmento et al., 2014). This analysis of the competition pretends to identify the strengths of the own or rival team and to have information more adequate to the complexity of collective sports (Carling et al., 2008; Agras et al., 2016). To this end, a variety of performance indicators are proposed, which are a combination of variables that help to achieve sporting success (Hughes and Bartlett, 2002; Mackenzie and Cushion, 2013). These indicators constitute an ideal profile that can be used to predict future behavior in a sporting activity (O'Donoghue, 2005). The comparative analysis over time of the performance profiles of the winning teams reveals how the styles of play evolve and identifies those variables (such as possession of the ball or blank shots) that are considered the most important in today's football (Castellano et al., 2012; Sarmento et al., 2014).

In football, the characteristics of the players, the tactics, the rhythm of the game and play at home or abroad are the most important factors in the performance (Yamanaka et al., 1993; Bangsbo et al., 2006; Taylor et al., 2010). Hughes and Franks (2005) compared the performance of successful and unsuccessful teams at the 1990 FIFA World Cup, finding greater possession and more shots on goal from successful teams. Several studies have found differences in the individual and collective technical and tactical patterns of the teams with the highest sports performance (Yang et al., 2018). In this line, Folgado et al. (2015) point to the level of tactical development, the pace of play and player fatigue as determining factors in performance. In this way, the specific position of the player affects the technical, tactical and physiological performance of the players in competition (Reilly, 1997; Di Salvo et al., 2008). Studies have found large differences in the physiological efforts and play actions of different specific positions in football (Rienzi et al., 2000; Di Salvo et al., 2008).

A few studies have focused on match analysis of women's football. Soroka and Bergier (2010) studied the characteristics of attack and defense actions to win or lose in women's football. Hewitt et al. (2014) reported a different game activity between higher and lower ranked teams in women's football. Pollard and Gómez (2014) analyzed the advantage of playing at home in the European women's leagues, comparing them to the men's leagues, concluding that the advantage is greater in the men's leagues. On the other hand, Ibañez et al. (2018) reported a different game activity between higher and lower ranked teams in women's football. However, the studies have not specifically analyzed the characteristics of the goalkeeper's actions and their impact on the team performance.

The goalkeeper is the most specialized position in football. The goalkeeper's primary role in soccer is to protect his/her team's goal, whilst a secondary purpose lies in ball distribution during the initiation of an attack. As the objective of football is to out-score the opposition, it stands to reason that the demands placed upon goalkeepers have the potential to directly influence the outcome of a match (Seaton and Campos, 2011). Indeed, as the only players permitted to legally handle the ball (when inside the penalty area) whilst the game is "live," their positional role is not akin to that of other outfield playing positions (Van Der Kamp, 2006; Di Salvo et al., 2008; Fariña et al., 2013; Almeida et al., 2016).

White et al. (2018) made a review of current literature about match-play and performance test responses of football goalkeepers. This review summarized the available literature pertaining to the performance responses of football goalkeepers and concluded that football goalkeepers demonstrate different physiological profiles from outfield players (i.e., superior jump performance, reduce VO2max values, slower sprint times). Similarly, there are differences in physiological, anthropometric and technical parameters between high-performance and amateur goalkeepers (Rebelo et al., 2013).

In relation with the technical and tactical analysis of the goalkeeper's actions some studies have used observational techniques to identify the type of activities performed by goalkeepers during match play. In youth players Sainz de Baranda et al. (2005c), analyzed the goalkeeper's defensive actions in the 7-a-side football format. At this same age, Ortega-Toro et al. (2018) found differences in the goalkeeper's offensive and defensive actions between the formats of Fútbol-5 and Fútbol-8. In high-performance football, Sainz de Baranda et al. (2008), during the 2002 World Cup, reported that international goalkeepers performed 23 defensive technical actions over 90 min, of which the most frequent actions were saves. Other studies of Spanish professional goalkeepers reported a lower incidence of saves, however, these studies reinforce the defensive role of football goalkeepers (Liu et al., 2015). Liu et al. (2015) examined the performance of goalkeepers by considering three situational variables (opposition, result, and location). Along the same lines, Villemain and Hauw (2014) identified the game actions that generate the most uncertainty for goalkeepers.

Peráček et al. (2017), during the European Championship U17, found that demands on the goalkeeper's game performance are high. However, they found out that at present there has been a change in the ratio between defensive and offensive game activities in favor of offensive.

Then, goalkeepers need to participate/contribute effectively to the implementation of the team's game model and not only stay on goalpost to defend/stop the shots. Goalkeepers need to be able to play with their feet, actively participating in the offensive phase, mainly in the distribution of the ball (participates in build up play and involved as much as possible in shaping the play when team is in possession). Therefore, Sainz de Baranda et al. (2005b) point out the importance of analyzing the participation of the goalkeeper both in the defensive phase and in the offensive phase.

The aim of the current study was to analyze technical and tactical offensive and defensive performance of goalkeepers from the national teams participating in the 2011 FIFA Women's World Cup in Germany, comparing the actions of the goalkeepers on qualified teams (pass the group stage) with the goalkeepers on unclassified teams (do not pass the group stage).

MATERIALS AND METHODS

The sample included 20 goalkeepers from the 16 national teams that participated in 32 matches of the 2011 FIFA Women's World Cup in Germany (age: 28.9 ± 4.2 years; height: 172.5+6.5 cm; weight: 62.3 ± 6.3 kg; years of experience: 11.23 ± 4.23 years). Teams were divided in two groups in relation to advanced (classified teams) or not advanced (unclassified teams) from the group stage of the tournament. The first round, or group stage, sees the sixteen teams divided into four groups of four teams. The knockout stage comprises the eight teams that advanced from the group stage of the tournament. The teams who passed the first round were: Germany, Japan, Sweden, Australia,

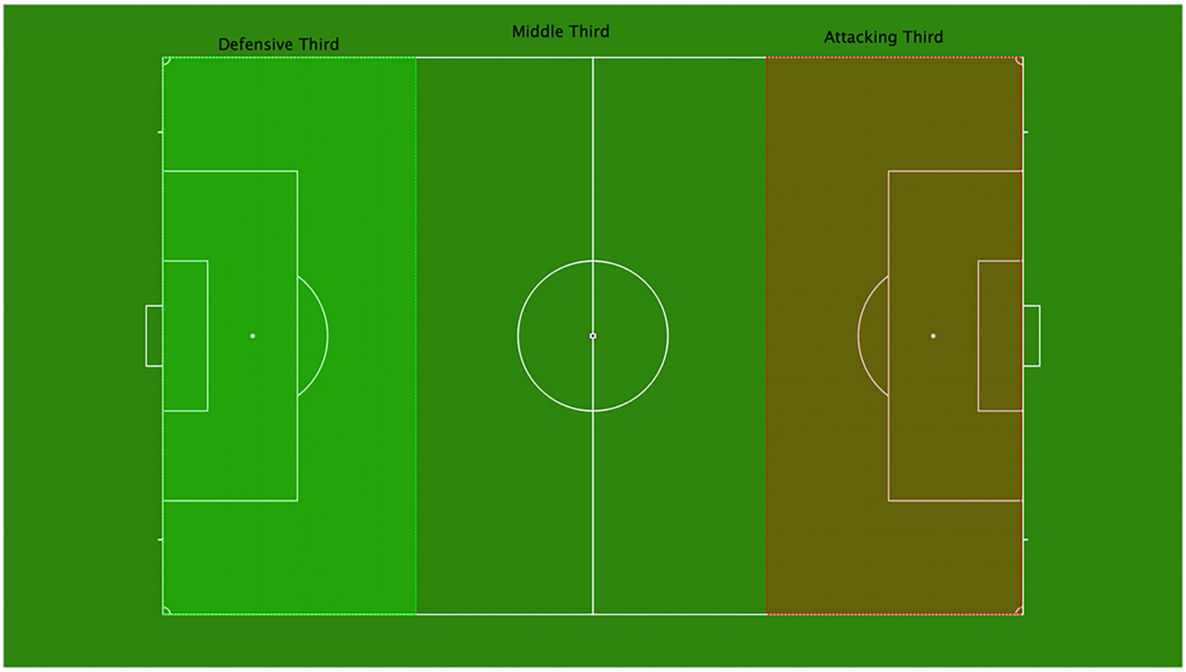

FIGURE 1 | Field zones used for establishing the pass length in the offensive actions of the goalkeeper.

England, France, Brazil and United States (these teams were the classified teams). The unclassified teams were: Equatorial Guinea, Nigeria, Korea DPR, Norway, Canada, Mexico, New Zealand, and Colombia.

Statistics used in the study were made available by OPTA Sportsdata Spain Company (Madrid). The reliability of tracking system (OPTA Client System) has been verified by Liu et al. (2013) which showed a high level of inter-operator reliability using the system to track goalkeeper's match actions (weighted kappa for two tested goalkeepers: 0.86 and 0.92). The Company maintained the anonymity of players and teams following European Data Protection Law. The study was approved by the Ethics Committee of University of Murcia (ID 1944/2018).

Based on the review and analysis of available literature in the performance analysis of football, the following match performance indicators were chosen for analyses the goalkeepers' intervention. The variables were divided into two main categories (offensive and defensive actions) (see **Figure 1**). The offensive actions were divided in pass zones and types of passes (see **Table 1**) and the defensive actions were divided in goals and shots received, types of saves and basic goalkeeper's actions (see **Table 2**).

Statistical Analysis

First, a descriptive analysis based on goalkeeper actions (mean and standard deviation) was performed. In addition, the value of the coefficient of variation (CV) for each of the variables was incorporated in order to know the variability or stability of each action of the goalkeeper. After that, the mean difference test (T student for independent samples) was carried out, analyzing the variables and using as grouping variables the classified teams (teams that had passed the first round; $n = 8$) against the non-classified teams (teams that had not passed the first round; $n = 8$). To know the magnitude of the differences found, the size of the effect (ES) was calculated using the Cohen's d (1988) considering the values as small effect ($d < 0.2$), medium effect ($0.2 \leq d < 0.6$), high effect ($0.6 \leq d < 1.2$) and strong effect ($d > 1.2$). Statistical analyses were performed using the IBM SPSS Statistics 21.0 statistical package (IBM Corp., Armonk, NY, United States) and the statistical significance was established at $p < 0.05$.

RESULTS

Table 3, shows the differences between classified and unclassified teams, and total values of the variables of the pass areas.

The results in **Table 3** show that the mean number of passes attempted made by the goalkeeper and their success is always higher in the qualified teams (teams that have passed the group stage). Conversely, the coefficient of variation, for the majority of unclassified teams is higher, except for the variables: attempted passes in the offensive third and the successful passes in the offensive third field. It is also noteworthy that none of the variables show any significant differences between classified and unclassified teams; There exists a trend toward statistical significance in the successful passes in the middle third field ($p = 0.06$; ES = 0.93; high effect) and in the successful passes in the offensive third field ($p = 0.05$; ES = 1.04; high effect).

The results shown in **Table 4** show the type of passes that goalkeepers make. In all the variables the mean is higher in the classified teams. In addition, the actions that are most performed

TABLE 1 | List of goalkeeper offensive actions and definitions.

Variables	Technical/tactical action	Definition
Pass zones	Attempted passes in own half (APOH)	Any intentional played ball from one player to another in own half of field
	Successful passes in own half (SPOH)	Any intentional played ball from one player to another in own half of field
	Attempted passes in opponent's half (APOP)	Any intentional played ball from one player to another in the attacking half of the pitch (opposite field)
	Successful passes in opponent's half (SPOP)	Accurate passes in the attacking half of the pitch (opposite field)
	Attempted passes in defensive third field (APDT)	Any intentional played ball from one player to another in defensive third field
	Successful passes in defensive third field (SPDT)	Accurate passes in defensive third field
	Attempted passes in middle third field (APMT)	Any intentional played ball from one player to another in middle third field
	Successful passes in middle third field (SPMT)	Accurate passes in middle third field
	Attempted passes in offensive third field (APOT)	Any intentional played ball from one player to another in offensive third field
	Successful passes in offensive third field (SPOT)	Accurate passes in offensive third field
Types of passes	Short passes (SP)	Passes over a distance less than 35 yards or 32 meters
	Success in short passes (SSP)	Accurate passes over a distance less than 35 yards or 32 meters
	Long passes (LP)	Accurate passes that have a distance greater than 35 yards or 32 meters
	Success in long passes (SLP)	Accurate passes that have a distance greater than 35 yards or 32 meters
	Passes received (PR)	Sending and receiving the ball between two players of the same team
	Passes to the opponent (POP)	Passes to the opponent
	Team's own forward passes (TOFP)	Team's own forward passes
	Team's own diagonal passes (TODP)	Team's own diagonal passes
	Passes forward to the opponent (PFO)	Passes forward to the opponent
	Passes with a fast moving ball (PMB)	Style of play in which the ball is passed on or distributed after only one or two touches
	Successful passing with a fast moving ball (SPMB)	Accurate Passes with a fast moving ball
	Long ball goal kick (LBGK)	Kick that is used to return into play from inside the goal area (greater than 35 yards or 32 meters); awarded to the defending team when a ball that crossed the goal line was last touched by a player on the attacking team.
	Successful long ball goal kick (SLBGK)	Accurate long ball goal kick (greater than 35 yards or 32 meters)
	Short goal kicks (SGK)	Kick that is used to return into play from inside the goal area (less than 35 yards or 32 meters); awarded to the defending team when a ball that crossed the goal line was last touched by a player on the attacking team.
	Successful short goal kick (SSGK)	Accurate short goal kick (less than 35 yards or 32 meters)

by both the classified and unclassified teams are long passes with a mean of 19.38+6.40 for classified and 15.85+6.79 for unclassified teams and passes on the contrary with a mean of 13.30+6.36 for classified and 10.78+6.28 for unclassified teams. The coefficient of variation is higher in most unclassified teams. Finally, it is observed that there are statistically significant differences in passes with a fast moving ball ($p = 0.027$; ES = 1.16; high effect) and in the successful passing with a fast moving ball ($p = 0.028$; ES = 1.16; high effect).

The results in **Table 5** show the goals and shots conceded by the goalkeepers. In almost all variables, the mean number of goals and shots allowed is higher in unclassified teams, especially in shots allowed (SA – 5.51 ± 0.97) and shots allowed inside the area (SAIA – 3.57 ± 0.89). The exceptions lie in goals from outside the area (GAOA) (0.21 ± 0.31 vs. 0.24 ± 0.20) and the number of times they do not concede a goal (NG) (0.16 ± 0.17 vs. 0.32 ± 0.21) which is higher in classified teams. In addition, there are statistically significant differences in the variable shots allowed ($p = 0.001$; ES = 1.92; strong effect) and in the variable shots allowed inside the area ($p = 0.001$; ES = 1.86; strong effect).

The results included in **Table 6** show the types of saves made by the goalkeepers. In almost all the variables the mean number of actions is higher in the goalkeepers of the unclassified teams, with the exception of the variables set-piece saves (SPS) (0.08 ± 0.15 vs. 0.10 ± 0.18) and body saves (BS) (0.10 ± 0.20 vs. 0.14 ± 0.20), which are higher in classified teams. The CV is higher in almost all classified teams. In addition, statistically significant differences are observed in more than one variable: saves inside the area (SIA) ($p = 0.010$; ES = 1.41; strong effect), standing saves (SS) ($p = 0.009$; SE = 1.42; strong effect); palm hand saves (PHS) ($p = 0.009$; ES = 1.43; strong effect); and badly oriented clears ($p = 0.010$; ES = 1.39; strong effect).

Table 7 shows the basic defensive goalkeeper's actions. In all actions the mean obtained in the variables is higher in the unclassified teams with the exception of the variable of recoveries (RE) (11.38 ± 1.30 vs. 12.17 ± 3.35) that is higher in the teams classified. It is also observed that the coefficient of variation (CV) is higher in classified teams, except for the variable total clearance (TC) (60.75% for unclassified teams) and punches (PU) (86.71% for unclassified teams). The variable recoveries is the most performed variable by both classified and unclassified goalkeepers, followed by the action of hand-blocks balls (HBB). In addition, there are statistically significant differences in the variable drops (DRP) ($p = 0.006$; ES = 1.49; strong effect).

TABLE 2 | List of goalkeeper defensive actions and definitions.

Variables	Technical/tactical action	Definition
Goals and shots received	Goals allowed (GA)	Total goals scored by the opposition
	Goals allowed inside the area (GAIA)	Total goals conceded from a shot inside the area
	Goals allowed outside the area (GAOA)	Total goals conceded from a shot outside the area
	Shots allowed (SA)	Total shots made by the opposition
	Shots allowed inside the area (SAIA)	Total shots made inside the area
	Shots allowed outside the area (SAOA)	Total shots made outside the area
	Goals allowed in fast play (GAFP)	Total goals scored by the opposition in fast play. Counter attack.
	Goals allowed in clear play (GACP)	Total goals scored by the opposition in clear play. Open play attack.
	No goals are conceded (NG)	No goals conceded to the rival team
Types of saves	Saves inside the area (SIA)	Saves inside de area
Saves: A goalkeeper preventing the ball from entering the goal with any part of his body when facing an intentional attempt from an opposition player	Saves outside the area (SOA)	Saves outside de area
	Set-piece saves (SPS)	Goalkeeper saves a shot from set-piece (corner kick, free kick, or throw-in)
	Air saves (AS)	Total goalkeeper air saves
	Standing saves (SS)	Goalkeeper saves a shot by standing and deflecting/parrying to safety saves away from starting position
	Saves on site (SOS)	Total goalkeeper saves on site
	Fingertip saves (FS)	Goalkeeper save using his/her fingertips
	Palm hand saves (PHS)	Goalkeeper save using his/her palm hand
	Foot saves (FOS)	Goalkeeper save using his/her feet
	Body saves (BS)	Goalkeeper save using his/her body
	Oriented clear (OC)	Attempt made by the goalkeeper to get the ball out of the danger zone
	Badly oriented clear (BOC)	Clearing the ball from danger by kicking it up field or out of bounds. The kick has no intended receiver and is usually done to relieve pressure in the goal area.
	Block saves (BLOS)	Block a shot that would have resulted in a goal
	Two-step saves (2STS)	Ball secured but not on first attempt
Basic Goalkeeper's actions	Total clearance (TC)	Total number of times the ball is clearances defensively. The goalkeeper clears the ball in difficult situations when he is not sure he can catch it
	Blocks (BLK)	A goalkeeper blocks the ball from reaching its target
	Punches (PU)	A high ball that is punched clear by the goalkeeper. The keeper must have a clenched fist and attempting to clear the high ball rather than claim it.
	Drops (DRP)	A high ball where the goalkeeper tries to catch the ball, she gets her hands on the ball but drops it from grasp.
	Hand-blocks balls (HBB)	A goalkeeper blocks a shot with her hand.
	Recoveries (RE)	When the goalkeeper takes possession of a loose ball and successfully keeps possession for at least two passes or an attacking play

DISCUSSION

The aim of this study was to examine the technical and tactical performance of goalkeepers of the senior teams participating in the Women's World Cup Germany 2011, differentiating between the teams who passed the group stage and the others.

The analysis of performance indicators in sports has direct practical implications. As Higham et al. (2014) note, reference values can assist in understanding variability in team performance, can aid coaches in establishing quantifiable objectives for training and performance, and can help when evaluating the efficacy of training interventions and tactical changes (Daza et al., 2017). Knowledge of performance indicators can also be used to create performance profiles to predict team behaviors and performance outcomes (Wagner et al., 2014).

One of the first works carried out with the objective of analyzing the technical-tactical performance of the football goalkeepers was that of Sainz de Baranda et al. (2008). The purpose of this study was to examine the characteristics of goalkeepers' defense interventions in parallel with the type of opponent attack. Results related to goalkeepers' defense showed that the penalty area was the zone most often used, and the defensive actions most frequently used were the save (9.96±3.8), followed by foot control (6.5±4.2), and the clear out (2.9±1.8). In total, Sainz de Baranda et al. (2008) observed a mean of 23.4 defensive technical actions per match. This results are similar to that reported by Sainz de Baranda and Serrato (2000) for the 1998 World Cup (22.1 actions per match) but lower than that reported by Sainz de Baranda (2002) for the 2000 European Championship (28.31 actions per match).

In the current study (FIFA, 2011), we observed a mean of 24.06 defensive technical actions per match, with 12.29 saves and 11.77 recoveries. The results of the current study and the others studies reinforce that the main defensive role of soccer goalkeepers is preventing scoring opportunities and confirm that these events

TABLE 3 | Offensive actions of the goalkeepers.

	Unclassified			Classified			Total			*P*	ES	E**	CI (90%)	
	Mean	*SD*	CV	Mean	*SD*	CV	Mean	*SD*	CV				Lw	Upp
APOH	13.23	6.04	45.60	14.78	4.65	31.46	14.01	5.27	37.61	0.57	0.27	M	−0.54	1.11
SPOH	6.33	3.87	61.13	9.53	2.95	30.95	7.93	3.71	46.78	0.08	0.88	H	0.04	1.79
APOP	10.78	6.28	58.25	13.26	6.31	47.58	12.02	6.21	51.66	0.44	0.37	M	−0.44	1.22
SPOP	2.86	1.90	66.43	4.72	2.48	52.54	3.79	2.34	61.74	0.11	0.80	H	−0.03	1.69
APDT	8.55	4.46	52.16	8.91	2.62	29.40	8.73	3.53	40.43	0.84	0.09	S	−0.73	0.92
SPDT	8.03	4.23	52.67	8.38	2.47	29.47	8.20	3.35	40.85	0.84	0.10	S	−0.72	0.92
APMT	11.81	5.25	44.45	14.70	4.80	32.65	13.26	5.08	38.31	0.27	0.54	M	−0.28	1.41
SPMT	4.53	2.16	47.68	6.55	1.95	29.77	5.54	2.24	40.43	0.06	0.93	H	0.09	1.84
APOT	3.65	2.19	60	4.44	3.21	72.29	4.04	2.69	66.58	0.57	0.27	M	−0.54	1.11
SPOT	0.35	0.31	88.57	1.25	1.11	88.80	0.80	0.91	113.75	0.05	1.04	H	0.20	1.98

*Differences between classified and unclassified, and total values of the pass areas. *Differences statistically significant. APOH, attempted passes in own half; SPOH, successful passes in own half; APOP, attempted passes in opponent's half; SPOP, successful passes in opponent's half; APDT, attempted passes in defensive third field; SPDT, successful passes in defensive third field; APMT, attempted passes in middle third field; SPMT, successful passes in middle third field; APOT, attempted passes in offensive third field; SPOT, successful passes in offensive third field. ** E = effect [small effect ($d < 0.2$) = S; medium effect ($0.2 \leq d < 0.6$) = M; high effect ($0.6 \leq d < 1.2$) = H; strong effect ($d > 1.2$) = ST].*

TABLE 4 | Offensive actions of the goalkeepers.

	Unclassified			Classified			Total			*P*	ES	E**	CI (90%)	
	Mean	*SD*	CV	Mean	*SD*	CV	Mean	*SD*	CV				Lw	Upp
SP	8.18	4.05	49.51	8.67	3.03	34.94	8.42	3.46	41.09	0.78	0.13	S	−0.69	0.96
SSP	7.24	3.77	52.07	7.77	2.55	32.81	7.51	3.12	41.54	0.74	0.16	S	−0.66	0.99
LP	15.83	6.79	42.89	19.38	6.40	33.02	17.60	6.63	37.67	0.30	0.51	M	−0.31	1.37
SLP	5.68	2.59	45.59	8.41	2.24	26.63	7.04	2.73	38.77	0.40	1.07	H	0.22	2.00
PR	4.47	3.70	82.77	8.49	4.15	48.88	6.48	4.33	66.82	0.06	0.97	H	0.13	1.89
POP	10.78	6.28	58.25	13.30	6.36	47.81	12.04	6.24	51.82	0.43	0.38	M	−0.44	1.22
TOFP	8.94	3.65	40.82	9.11	4.15	45.55	9.03	3.78	41.86	0.92	0.04	S	−0.78	0.87
TODP	9.01	5.57	61.82	9.94	2.58	25.95	9.47	4.22	44.56	0.67	0.20	M	−0.61	1.04
PFO	10.78	6.28	58.25	13.30	6.36	47.81	12.04	6.24	51.82	0.43	0.39	M	−0.44	1.22
PMB	6.85	4.72	68.90	12.77	4.90	38.37	9.81	5.56	56.67	0.02*	1.16	H	0.31	2.12
SPMB	4.83	3.36	69.56	8.59	2.77	32.24	6.71	3.55	52.90	0.02*	1.16	H	0.30	2.11
LBGK	7.15	3.35	46.85	8.81	2.32	26.33	7.98	2.92	36.59	0.26	0.54	M	−0.28	1.41
SLBGK	3.50	2.05	58.57	4.49	0.69	15.36	3.99	1.57	39.34	0.23	0.61	H	−0.21	1.48
SGK	8.19	3.61	44.07	5.29	2.21	41.77	6.74	3.26	48.36	0.07	0.92	H	0.08	1.83
SSGK	7.51	3.51	46.73	4.95	2.12	42.82	6.23	3.10	49.75	0.09	0.83	H	0.002	1.73

*Differences between classified and unclassified, and total values of pass categories. *Differences statistically significant. SP, short passes; SSP, success in short passes; LP, long passes; SLP, success in long passes; PR, passes received; POP, passes to the opponent; TOFP, team's own forward passes; TODP, team's own diagonal passes; PFO, passes forward to the opponent; PMB, passes with a fast moving ball; SPMB, successful passing with a fast moving ball; LBGK, long ball goal kick; SLBGK, successful long ball goal kick; SGK, short goal kicks; SSGK, successful short goal kick. ** E = effect [small effect ($d < 0.2$) = S; medium effect ($0.2 \leq d < 0.6$) = M; high effect ($0.6 \leq d < 1.2$) = H; strong effect ($d > 1.2$) = ST].*

occur relatively infrequently during a match, although they may be modulated by various contextual factors (Liu et al., 2015).

In the current study, results showed that there were differences in some of the match performance indicators for goalkeepers. Goalkeepers on classified teams allowed fewer goals, shots and made fewer defensive actions, saves inside the area, standing saves, palm hand saves and badly oriented clears. This is possibly due to the fact that high level teams were subjected to less attacking play from the opponents, whereas the opposite happened to goalkeepers of low level teams.

Similar findings were found by Liu et al. (2015) when league standing was used to group Spanish La Liga clubs into high-, intermediate-, and low-standard teams. The analysis of the results showed the goalkeepers on high-standard teams (i.e., top six league positions) made fewer saves than those on low-standard teams and also performed fewer touches of the ball, passes, interceptions, clearances and catches. With regard to the influence of opposition, goalkeepers on low-and intermediate-standard teams made more saves when facing a high-standard opposition than when facing other low-standard

TABLE 5 | Defensive actions of the goalkeepers.

	Unclassified			Classified			Total			P	ES	E**	CI (90%)	
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV				Lw	Upp
GA	1.66	0.67	40.36	1.10	0.42	38.18	1.38	0.61	44.20	0.07	0.95	H	0.11	1.86
GAIA	1.45	0.69	47.58	0.86	0.51	59.30	1.16	0.66	56.89	0.07	0.92	H	0.08	1.83
GAOA	0.21	0.31	147.61	0.24	0.20	83.33	0.22	0.25	113.63	0.81	0.11	S	−0.71	0.94
SA	5.51	0.97	17.60	3.53	0.98	27.76	4.52	1.39	30.75	0.001*	1.92	ST	0.97	3.04
SAIA	3.57	0.89	24.92	2.00	0.69	34.50	2.79	1.12	40.14	0.001*	1.86	ST	0.92	2.97
SAOA	1.94	0.63	32.47	1.53	0.70	45.75	1.73	0.68	39.30	0.242	0.58	M	−0.24	1.45
GAFP	0.19	0.21	110.52	0.07	0.14	200.00	0.13	0.18	138.46	0.21	0.64	H	−0.19	1.51
GACP	1.08	0.53	49.07	0.67	0.51	76.11	0.88	0.55	62.50	0.13	0.75	H	−0.08	1.63
NG	0.16	0.17	106.25	0.32	0.21	65.62	0.24	0.20	83.3	0.99	0.79	H	−0.04	1.69

*Differences between classified and unclassified with respect to goals and shots received. *Differences statistically significant. GA, goals allowed; GAIA, goals allowed inside the area; GAOA, goals allowed outside the area; SA, shots allowed; SAIA, shots allowed inside the area; SAOA, shots allowed outside the area; GAFP, goals allowed in fast play; GACP, goals allowed in clear play; NG, no goals conceded. ** E = effect [small effect ($d < 0.2$) = S; medium effect ($0.2 \leq d < 0.6$) = M; high effect ($0.6 \leq d < 1.2$) = H; strong effect ($d > 1.2$) = ST].*

TABLE 6 | Defensive actions of the goalkeepers.

	Unclassified			Classified			Total			P	ES	E**	CI (90%)	
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV				Lw	Upp
SIA	2.08	0.73	35.09	1.08	0.61	56.48	1.58	0.83	52.53	0.01*	1.41	ST	0.52	2.41
SOA	1.73	0.70	40.46	1.29	0.61	47.28	1.51	0.68	45.03	0.20	0.63	H	−0.19	1.51
SPS	0.08	0.15	187.5	0.10	0.18	180.00	0.09	0.16	177.77	0.80	0.11	S	−0.70	0.94
AS	0.90	0.32	35.55	0.52	0.38	73.07	0.71	0.39	54.92	0.05	1.02	H	0.18	1.95
SS	1.95	0.32	16.41	1.18	0.65	55.08	1.56	0.63	40.38	0.009*	1.42	ST	0.54	2.42
SASP	0.28	0.38	135.71	0.17	0.15	88.23	0.22	0.28	127.27	0.43	0.36	M	−0.46	1.20
SOS	0.69	0.73	105.79	0.51	0.36	70.58	0.60	0.56	93.33	0.54	0.30	M	−0.52	1.14
FS	0.17	0.36	211.76	0.03	0.09	300.00	0.10	0.26	260.00	0.32	0.50	M	−0.31	1.36
PHS	3.58	1.04	29.05	2.18	0.79	36.23	2.88	1.15	39.93	0.009*	1.43	ST	0.55	2.44
FOS	0.13	0.17	130.76	0.04	0.08	200.00	0.08	0.14	175.00	0.24	0.64	H	−0.18	1.51
BS	0.10	0.20	200	0.14	0.20	142.85	0.12	0.19	158.33	0.75	0.19	S	−0.63	1.02
OC	0.95	0.65	68.42	0.66	0.57	86.36	0.80	0.61	76.25	0.35	0.45	M	−0.37	1.30
BOC	0.86	0.37	43.02	0.39	0.26	66.66	0.63	0.40	63.79	0.01*	1.39	ST	0.51	2.39
BLOS	0.90	0.65	72.22	0.71	0.46	64.78	0.80	0.55	68.75	0.50	0.32	M	−0.50	1.16
2STS	0.94	0.84	89.36	0.57	0.64	112.28	0.76	0.75	98.68	0.34	0.47	M	−0.35	1.32

*Differences between classified and unclassified and types of saves. *Differences statistically significant. SIA, saves inside the area; SOA, saves outside the area; SPS, set-piece saves; AS, air saves; SS, standing saves; SASP, saves away from starting position; SOS, saves on site; FS, fingertip saves; PHS, palm hand saves; FOS, foot saves; BS, body saves; OC, oriented clear; BOC, badly oriented clear; BLOS, block saves; 2STS, two-step saves. ** E = effect [small effect ($d < 0.2$) = S; medium effect ($0.2 \leq d < 0.6$) = M; high effect ($0.6 \leq d < 1.2$) = H; strong effect ($d > 1.2$) = ST].*

teams. Conversely, goalkeepers on high-standard teams made more saves when facing a low-standard opposition than when facing intermediate-or other high-standard teams. Such counterintuitive findings may be attributable to differences in playing style/formation when high-standard teams face a lesser opposition, whereby adopting a more expansive approach may create opportunities for the opposition to counter-attack.

It is interesting to take account that the goalkeepers on unqualified teams allowed more shots, more shots inside the area, and more goals inside the area, with statistically significant differences. Some studies show that the percentage of shots fired in a match is similar both inside and outside the area (Sainz de Baranda et al., 2008). But, with relation to the number of goals allowed, other authors claim that the most goals are scored in the area (Yagüe and Paz, 1995; Romero et al., 1997). Gómez (1999) found that 66.9% of the goals scored in the Spanish First Division in 1998–1999 were scored from inside the penalty area. In this same line, Park et al. (2016) report that 89% of goals are scored from inside the penalty area.

To develop a defensive game, the goalkeeper should coordinate his or her actions with the defensive players on the team and adapt the defensive strategy to counter the opposition. In the FIFA Women's World Cup Germany 2011, the most successful teams were capable of moving their defensive block around 30 meters up and down the pitch without losing their balance or increasing the distances between players. Within their defensive block, they hunted for the ball and supported

TABLE 7 | Defensive actions of the goalkeepers.

	Unclassified			Classified			Total			*P*	ES	E**	CI (90%)	
	Mean	*SD*	CV	Mean	*SD*	CV	Mean	*SD*	CV				Lw	Upp
TC	1.86	1.13	60.75	1.43	0.83	58.04	1.65	0.98	59.39	0.39	0.41	M	−0.41	1.26
BLK	1.35	0.82	60.74	1.17	0.74	63.24	1.26	0.76	60.31	0.06	0.22	M	−0.60	1.05
PU	1.43	1.24	86.71	1.14	0.78	68.42	1.28	1.01	78.90	0.58	0.26	M	−0.55	1.10
DRP	0.61	0.29	47.54	0.21	0.21	100	0.41	0.32	78.04	0.006*	1.49	ST	0.60	2.51
HBB	7.98	0.78	9.77	7.40	2.22	30.00	7.69	1.64	21.32	0.50	0.33	M	−0.49	1.17
RE	11.38	1.30	11.42	12.17	3.35	27.52	11.77	2.49	21.15	0.54	0.29	M	−0.52	1.13

*Differences in the basic goalkeeper's actions between classified and unclassified. *Differences statistically significant. TC, total clearance; BLK, blocks; PU, punches; DRP, drops; HBB, hand-blocks balls; RE, recoveries. ** E = effect [small effect ($d < 0.2$) = S; medium effect ($0.2 \leq d < 0.6$) = M; high effect ($0.6 \leq d < 1.2$) = H; strong effect ($d > 1.2$) = ST].*

each other to win the ball back. Another important aspect of the successful teams (all four semi-finalists) was the fact that they had the goalkeeper playing as a libero behind the defense when the defensive block was positioned high up the pitch (FIFA, 2011). This may be one reason why the goalkeepers on classified teams made more recoveries than the goalkeepers on unclassified teams.

Another difference between the goalkeepers on classified and unclassified teams were the number of badly oriented clears and the number of drops. The higher number of oriented clears and badly oriented clears made by the goalkeepers on unclassified teams could be related with the playing style of the opponent. For example, Tenga et al. (2010) showed that the goalkeeper's recovery is associated with counterattack. In the same way, the number of drops can be conditioned to the playing style of the opponent (crosses, corners, aerial success, etc,). The variables related to the opposing team's attacks, related to passing and organizing, ball possession, pass, successful pass and cross were variables that had been found to discriminate winning and losing teams in UEFA Championship League (Lago-Peñas et al., 2011) and Spanish Professional Football League (Lago-Peñas and Dellal, 2010).

On the other hand, with relation to the offensive actions of the goalkeepers, it is important to know that some research has shown decreasing frequency of defensive game activities in favor of offensive game activities (Sainz de Baranda et al., 2005b). Currently, the goalkeeper not only has a defensive role, but also possesses an offensive role very important in the implementation of the team's game model.

Sainz de Baranda et al. (2005b) examined the characteristics of goalkeepers' offensive interventions in 56 matches of the 2002 World Cup in Korea and Japan. Sainz de Baranda et al. (2005b) observed a mean of 30.3 ± 7.9 actions per goalkeeper in a match, and the offensive actions most frequently used were the kick pass (11.31 ± 5.3) and the goal kick (9.56±2.2). In relation to length, Sainz de Baranda et al. (2008) observed a predominance of the long actions (62.19%), with an average number of 19 ± 8.9, while the short actions have an average 11.53 ± 6.84. With respect to orientation, the central zone was the most used (41.5%), followed by the right zone (29.3%) and the left zone (29.2%). When it comes to precision, 48.3% of the actions obtained direct precision, 13.9% obtained possession after rejection and 37.7% of the time ball possession was lost. Therefore, a total of 63% of the attacks started by the goalkeeper allow for continuation of ball possession.

The results of the Sainz de Baranda et al. (2005b) study indicated that the interventions in the attack have increased as the years pass. Higher data in this study (30.3 actions) than in previous studies was observed. Sainz de Baranda (2002) in the European Championship in Holland and Belgium in 2000 and Sainz de Baranda and Serrato (2000) in the World Cup in France in 1998 registered an average of 28.48 and 25.96 actions, and Yagüe and Martin (1995) in the World Cup in the United States in 1994 registered an average of 25.3 actions, respectively.

In the current study (FIFA, 2011), we observed a mean of 26.03 offensive actions per match, with 14.01 passes attempted in the own half of the field (short pass) and 12.02 passes attempted in the opposite field (long pass). Furthermore, results showed that there were differences in some of the match performance indicators for goalkeepers. Goalkeepers on classified teams attempted more long passes, more passes in the opponent's half of field, more passes in the middle third field and more passes in the offensive third field. Overall the differences are in the success of ball distribution. The results showed that in all the variables the goalkeepers on classified teams have more precision with a high magnitude of the effect. Furthermore, there are statistically significant differences in the variables related with passes with a fast moving ball in motion. The results showed that goalkeepers on classified teams made more passes with a fast moving ball in motion than the goalkeepers on unclassified teams and there were differences between goalkeepers in terms of success too, with higher rates of successful passing with a fast moving ball.

Similar findings were found by Szwarc et al. (2010) and Seaton and Campos (2011) that suggested that there were differences between goalkeepers from different levels in terms of ball distribution and success of performance indicators.

As indicated by the FIFA in the technical report and statistics of the Women's World Cup Germany 2011, the most-complete goalkeepers in this tournament became the team's first point of attack after gaining possession of the ball. They were skilful in distributing the ball with their hands or their feet quickly and effectively to the area where their teammates were positioned. When bringing the ball back into play, almost all of the goalkeepers in this tournament were able to punt the ball deep into the attacking part of the pitch, but only a few goalkeepers were able to effectively reach their attackers.

This paper is a first step toward a more in-depth study of the technical and tactical actions of specific positions in women's football in general and of goalkeepers in particular. It is necessary to mention the limitations of this study, due to the scarcity of studies that examine the role of the goalkeeper from a technical and tactical point of view (Di Salvo et al., 2008; García-Angulo and Ortega, 2015).

Information provided by the current research can enable a more thorough understanding of goalkeeper performance characteristics. Our consideration is in full compliance with Sainz de Baranda et al. (2005a) and Jara et al. (2018) who claim that the player should be trained to meet the requirements on the game. Currently, the goalkeeper progressively has a larger role in the collective game, so for a complete learning process, planning of goalkeeper practice should consider both attacking and defensive actions.

CONCLUSION

This study allows us to identify, characterize and differentiate different attack and defense patterns of the goalkeeper between successful and unsuccessful teams. Results show that significant differences between the two groups. Data establishes that successful teams are characterized by an offensive game pattern with greater number of actions and more precision. On the other hand, goalkeepers on unsuccessful teams have shown a defensive game pattern with more defensive actions.

ETHICS STATEMENT

This study respected the ethical principles established by the UNESCO Declaration on Bioethics and Human Rights. The study was approved by the Ethics Committee of University of Murcia (Spain) with ID 1944/2018.

AUTHOR CONTRIBUTIONS

All authors participated in the design, documentation, development, and writing of the manuscript. This paper was reviewed by all authors and all of them were responsible for its contents and providing they are responsible for the final version.

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REFERENCES

Agras, H., Ferragut, C., and Abraldes, J. A. (2016). Match analysis in futsal: a systematic review. *Int. J. Perform. Anal. Sport* 16, 652–686. doi: 10.1123/jsr.2017-0279

Almeida, C. H., Volossovitch, A., and Duarte, R. (2016). Penalty kick outcomes in UEFA club competitions (2010-2015): the roles of situational, individual and performance factors. *Int. J. Perform. Anal. Sport* 16, 508–522. doi: 10.1080/24748668.2016.11868905

Bangsbo, J., Mohr, M., and Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *J. Sports Sci.* 24, 665–674. doi: 10.1080/02640410500482529

Carling, C., Bloomfield, J., Nelsen, L., and Reilly, T. (2008). The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. *Sports Med.* 38, 839–862. doi: 10.2165/00007256-200838100-00004

Carling, C., Williams, A. M., and Reilly, T. (2005). Handbook of soccer match analysis: a systematic approach to improving performance. *J. Sports Sci. Med.* 5:171.

Castellano, J., Casamichana, D., and Lago-Peñas, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *J. Hum. Kinet.* 31, 99–106. doi: 10.2478/v10078-012-0015-7

Daza, G., Andrés, A., and Tarragó, R. (2017). Match statistics as predictors of team's performance in elite competitive handball. *RICYDE* 48, 149–161.

Di Salvo, V., Benito, P. J., Calderon, F. J., Di Salvo, M., and Pigozzi, F. (2008). Activity profile of elite goalkeepers during football match-play. *J. Sports Med. Phys. Fit.* 48, 443–446.

Fariña, R. A., Fábrica, G., Tambusso, P. S., and Alonso, R. (2013). Taking the goalkeeper's side in association football penalty kicks. *Int. J. Perform. Anal. Sport* 13, 96–109. doi: 10.1080/24748668.2013.11868634

FIFA (2011). *FIFA Women's World Cup Germany 2011. Technical Report and Statistics*. Available at: https://img.fifa.com/image/upload/pcahcegynzgqmcyv4mdu.pdf

Folgado, H., Duarte, R., Marques, P., and Sampaio, J. (2015). The effects of congested fixtures period on tactical and physical performance in elite football. *J. Sports Sci.* 33, 1238–1247. doi: 10.1080/02640414.2015.1022576

Gabbett, T. J., and Mulvey, M. J. (2008). Time-motion analysis of small-sided training games and competition in elite women soccer players. *J. Strength Cond. Res.* 22, 543–552. doi: 10.1519/JSC.0b013e3181635597

García-Angulo, A., and Ortega, E. (2015). Análisis bibliométrico de la producción científica sobre el portero en fútbol. *Revista Iberoamericana de Psicología del Ejercicio y el Deporte* 10, 205–214.

Gómez-López, M. (1999). Desarrolloy finalización de las acciones ofensivas: análisis comparativo USA 94, Francia 98 y Liga Española 98-99. *Rev. Digit. Educación Física Deportes* 17 [Electronic Version].

Hewitt, A., Norton, K., and Lyons, K. (2014). Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking. *J. Sports Sci.* 32, 1874–1880. doi: 10.1080/02640414.2014.898854

Higham, D. G., Hopkins, W. G., Pyne, D. B., and Anson, J. M. (2014). Performance indicators related to points scoring and winning in international rugby sevens. *J. Sports Sci. Med.* 13, 358–364.

Hughes, M., and Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *J. Sports Sci.* 20, 739–754. doi: 10.1080/026404102320675602

Hughes, M., and Franks, I. (2005). Analysis of passing sequences, shots and goals in soccer. *J. Sports Sci.* 23, 509–514. doi: 10.1080/02640410410001716779

Ibañez, S. J., Pérez-Goye, J. A., Courel-Ibañez, J., and García-Rubio, J. (2018). The impact of scoring first on match outcome in women's professional football. *Int. J. Perform. Anal. Sport* 18, 318–326. doi: 10.1080/24748668.2018.1475197

Jara, D., Ortega, E., Gómez, M. A., Sainz, and de Baranda, P. (2018). Effect of pitch size on technical-tactical actions of the goalkeeper in small-sided games. *J. Hum. Kinet.* 62, 157–166. doi: 10.1515/hukin-2017-0167

Lago-Peñas, C., and Dellal, A. (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. *J. Hum. Kinet.* 25, 93–100. doi: 10.2478/v10078-010-0036-z

Lago-Peñas, C., Lago-Ballesteros, J., and Rey, E. (2011). Differences in performance indicators between winning and losing teams in the UEFA Champions League. *J. Hum. Kinet.* 27, 135–146.

Liu, H., Gómez, M. A., and Lago-Peñas, C. (2015). Match performance profiles of goalkeepers of elite football teams. *Int. J. Sports Sci. Coach.* 10, 669–682. doi: 10.1260/1747-9541.10.4.669

Liu, H., Gomez, M. A., Lago-Peñas, C., and Sampaio, J. (2015). Match statistics related to winning in the group stage of 2014 brazil FIFA world cup. *J. Sports Sci.* 33, 1205–1213. doi: 10.1080/02640414.2015.1022578

Liu, H., Hopkins, W., Gómez, M. A., and Molinuevo, J. S. (2013). Inter-operator reliability of live football match statistics from OPTA Sportsdata. *Int. J. Perform. Anal. Sport* 13, 803–821. doi: 10.1080/24748668.2013.11868690

Mackenzie, R., and Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *J. Sports Sci.* 31, 639–676. doi: 10.1080/02640414.2012.746720

Martínez-Lagunas, V., Niessen, M., and Hartmann, U. (2014). Women's football: player characteristics and demands of the game. *J. Sport Health Sci.* 3, 258–272. doi: 10.1016/j.jshs.2014.10.001

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., and Bangsbo, J. (2008). Match activities of elite women soccer players at different performance levels. *J. Strength Cond. Res.* 22, 341–349. doi: 10.1519/JSC.0b013e318165fef6

O'Donoghue, P. (2005). Normative profiles of sports performance. *Int. J. Perform. Anal. Sport* 5, 104–119. doi: 10.1080/24748668.2005.11868319

Ortega-Toro, E., García-Angulo, A., Giménez-Egido, J.-M., García-Angulo, F. J., and Palao, J. (2018). Effect of modifications in rules in competition on participation of male youth goalkeepers in soccer. *Int. J. Sports Sci. Coach.* 13, 1040–1047. doi: 10.1177/1747954118769423

Park, Y. S., Choi, M. S., Bang, S. Y., and Park, J. K. (2016). Analysis of shots on target and goals scored in soccer matches: implications for coaching and training goalkeepers. *S. Afr. J. Res. Sport Phys. Educ. Recreation* 38, 123–137.

Peráček, P., Varga, K., Gregora, P., and Mikulič, M. (2017). Selected indicators of an individual game performance of a goalkeeper at the European Championship among the 17-year-old elite soccer players. *J. Phys. Educ. Sport* 17, 188–193.

Pollard, R., and Gómez, M. A. (2014). Comparison of home advantage in men's and women's football leagues in Europe. *Eur. J. Sport Sci.* 14, 77–83. doi: 10.1080/17461391.2011.651490

Rebelo, A., Brito, J., Maia, J., Coelho-e-Silva, M. J., Figueiredo, A. J., Bangsbo, J., et al. (2013). Anthropometric characteristics, physical fitness and technical performance of under-19 soccer players by competitive level and field position. *Int. J. Sports Med.* 34, 312–317. doi: 10.1055/s-0032-1323729

Reilly, T. (1997). Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *J. Sports Sci.* 15, 257–263. doi: 10.1080/026404197367263

Rienzi, E., Drust, B., Reilly, T., Carter, J., and Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *J. Sports Med. Phys. Fit.* 40, 162–169.

Romero, E., Utrilla, P. M., and Morcillo, J. A. (1997). La velocidad en el juego de ataque: análisis táctico de los goles de la Eurocopa'96 de fútbol. *Fútbol. Cuadernos técnicos* 8, 36–43.

Sainz de Baranda, P. (2002). Eurocopa 2000: análisis del portero. Cuadernos del Entrenador. *Revista de la Federación Española de Fútbol.* 93, 47–57.

Sainz de Baranda, P., Llopis, L., and Ortega, E. (2005a). *Metodología Global Para el Entrenamiento del Porter de Fútbol.* Sevilla: Wanceulen Editorial Deportiva.

Sainz de Baranda, P., Ortega, E., and Garganta, J. (2005b). "Estudio de la acción y participación del portero en la fase ofensiva, en fútbol de alto rendimiento," in *Estudio 5*, ed. J. Pinto (Oporto: Universidad de Porto), 74–84.

Sainz de Baranda, P., Ortega, E., Llopis, L., Novo, J. F., and Rodríguez, D. (2005c). Análisis de las acciones defensivas del portero en el fútbol 7. *Apunts. Educación física y deportes.* 2, 45–52.

Sainz de Baranda, P., Ortega, E., and Palao, J. M. (2008). Analysis of goalkeepers' defence in the World Cup in Korea and Japan in 2002. *Eur. J. Sport Sci.* 8, 127–134. doi: 10.1080/17461390801919045

Sainz de Baranda, P., and Serrato, D. (2000). Análisis del portero de fútbol en el Mundial de Francia '98. *Train. Fútbol.* 57, 24–41.

Sarmento, H., Marcelino, R., Anguera, M. T., Campaniço, J., Matos, N., and Leitão, J. C. (2014). Match analysis in football: a systematic review. *J. Sport Sci.* 32, 1831–1843. doi: 10.1080/02640414.2014.898852

Seaton, M., and Campos, J. (2011). Distribution competence of a football clubs goalkeepers. *Int. J. Perform. Anal. Sport* 11, 314–324. doi: 10.1080/24748668.2011.11868551

Soroka, A., and Bergier, J. (2010). Actions with the ball that determine the effectiveness of play in women's football. *J. Hum. Kinet.* 26, 97–104. doi: 10.2478/v10078-010-0053-y

Szwarc, A., Lipinska, P., and Chamera, M. (2010). The efficiency model of goalkeeper's actions in soccer. *Baltic J. Health Phys. Activity* 2:132. doi: 10.2478/v10131-0013-x

Taylor, B. J., Mellalieu, D. S., James, N., and Barter, P. (2010). Situation variable effects and tactical performance in professional association football. *Int. J. Perform. Anal. Sport* 10, 255–269. doi: 10.1080/24748668.2010.11868520

Tenga, A., Holme, I., Ronglan, L. T., and Bahr, R. (2010). Effect of playing tactics on goal scoring in Norwegian professional soccer. *J. Sport Sci.* 28, 237–244. doi: 10.1080/02640410903502774

Van Der Kamp, J. (2006). A field simulation study of the effectiveness of penalty kick strategies in soccer: late alterations of kick direction increase errors and reduce accuracy. *J. Sport Sci.* 24, 467–477. doi: 10.1080/02640410500190841

Villemain, A., and Hauw, D. (2014). A situated analysis of football goalkeepers' experiences in critical game situations. *Percept. Mot. Skills* 119, 811–824. doi: 10.2466/25.30.PMS.119c30z0

Wagner, H., Finkenzeller, T., Würth, S., and von Duvillard, S. P. (2014). Individual and team performance in team-handball: a review. *J. Sports Sci. Med.* 13, 808–816.

White, A., Hills, S. P., Cooke, C. B., Batten, T., Kilduff, L. P., Cook, C. J., et al. (2018). Match-play and performance test responses of soccer goalkeepers: a review of current literature. *Sports Med.* 48, 2497–2516. doi: 10.1007/s40279-018-0977-2

Yagüe, J. M., and Martin, J. L. (1995). El ataque del portero en el mundial de fútbol USA'94. Cuadernos del Entrenador. *Revista de la Federación Española de Fútbol.* 67, 38–48.

Yagüe, J. M., and Paz, J. (1995). Aproximación al conocimiento de la eficacia en el fútbol. Cuadernos del Entrenador. *Revista de la Federación Española de Fútbol.* 64, 46–52.

Yamanaka, K., Hughes, M., and Lott, M. (1993). "An analysis of playing patterns in the 1990 World Cup for association football," in *Science and Football*, eds T. Reilly, A. Lees, K. Davids, and W. Murphy (London: E & FN Spon), 206–214.

Yang, G., Leicht, A. S., Lago, C., and Gómez, M. A. (2018). Key team physical and technical performance indicators indicative of team quality in the soccer Chinese super league. *Res. Sports Med.* 26, 158–167. doi: 10.1080/15438627.2018.1431539

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REVIEW
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Australian Football Skill-Based Assessments: A Proposed Model for Future Research

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Identifying sporting talent remains a difficult task due to the complex nature of sport. Technical skill assessments are used throughout the talent pathway to monitor athletes in an attempt to more effectively predict future performance. These assessments, however, largely focus on the isolated execution of key skills devoid of any game context. When assessments are representative of match-play and applied in a setting where all four components of competition (i.e., technical, tactical, physiological, and psychological) are assessed within an integrated approach, prediction of talent is more likely to be successful. This article explores the current talent identification technical skill assessments, with a particular focus on Australian Football, and proposes a 5-level performance assessment model for athlete assessment. The model separates technical game skill on a continuum from Level-1 (i.e., laboratory analysis) to Level-5 (i.e., match-play). These levels, using the assumptions of the expert performance model and representative learning design theory, incorporate a step-wise progression of performance demands to more closely represent match-play conditions. The proposed model will provide researchers and practitioners with a structured framework to consider when assessing, or developing, new assessments of technical game-based skill.

Keywords: talent identification, Australian Football, representative learning design, skill assessment, kicking, motor competence, development, performance

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INTRODUCTION

Talent is a multi-dimensional concept and requires the effective and efficient organization of an individual's technical, tactical, physiological, and psychological competencies to be applied in a method that meets the requirements of both the environment and the sporting situation (Abbott et al., 2005; Vaeyens et al., 2008). Talent identification programs endeavor to discover this "talent" in individuals with the greatest potential to respond to a training intervention and reach the highest level in their chosen sport (Hoare and Warr, 2000; Abbott and Collins, 2004). The ability to identify talented players in team sports is not only a financially rewarding business but a key component of future winning teams and long term success (Gee et al., 2010; Larkin and Reeves, 2018).

Identifying sporting talent remains a complex task due to the evolving nature of sport and the limited number of athletes selected to play at the elite level (Simonton, 1999; Honer and Votteler, 2016). Australian Football (AF) talent scouts consider a variety of subjective measures (such as the technical, tactical, physiological, and psychological components) to inform their decisions. These opinions are then combined with objective isolated skill data (e.g., the AF kicking efficiency test) in an attempt to more effectively predict future performance.

Ericsson and Smith (1991) created the expert performance approach (EPA) which entailed three stages. The first involves observation of performance *in situ* to identify key components that can be reproduced and assessed in the laboratory. The second stage examines these performances within field-based assessments (i.e., AF kicking efficiency test) in an attempt to understand the factors that contribute to expert performance. The final stage involves efforts to detail the adaptive learning and explicit acquisition processes relevant to the development of expertise, with potential implications for practice and instruction.

The term representative learning design has more recently been discussed in the literature (Krause et al., 2019) and should be considered within the second and third stage of the EPA. Representative learning design (RLD) is a framework that assesses how closely information provided in a task is representative of the specific performance context (Krause et al., 2019). To increase how representative a task is there needs to be functional coupling between perception and action processes, an adequate amount of informational characteristics from within the competitive environment, and consider the interrelating constraints on movement characteristics (Pinder et al., 2011, 2015). For an assessment to replicate competition it must have functionality (i.e., the degree to which a player can use the same informational sources present during competition) and action fidelity (i.e., the degree to which a player's movements replicate competition) (Stoffregen et al., 2003; Pinder et al., 2011). Krause et al. (2018) used the RLD framework to design an assessment tool to assess and enhance tennis practice session designs to maximize the potential for skill development to transfer into match-play (Krause et al., 2019). The authors found when comparing practice sessions to match play of junior tennis players, practice tasks are not representative of the shot and movement characteristics typical of match play. Overall, this study highlights the importance of the first stage in the EPA model, the identification of key components, in combination with the RLD framework when designing and assessing tasks.

Talent identification programs have generated a series of discussions regarding their value, with some authors questioning their use and predictability during athlete development (Pankhurst et al., 2013; Honer and Votteler, 2016); where others have used these programs with success (Hoare and Warr, 2000). Whilst these debates are warranted, talent identification programs are well ingrained in elite sport and should aim to identify promising athletes from a multidisciplinary approach rather than a reductionist approach. Where tasks are reductionist in approach, they are performed in a controlled environment where unidimensional components (i.e., speed) are assessed in isolation from the performance context, and may not have enough representation to enhance learning in specific sports (Davids et al., 2013b).

The challenge for talent identification and development (TID) programs is not in identifying current talent, but rather in classifying what factors will restrict the development of talent over time. Whilst there are numerous papers identifying current differences in higher and lesser skilled AF players (Veale et al., 2010; Woods et al., 2017), there are only limited attempts at identifying factors underpinning development across the AF pathway (Farrow et al., 2017; Gastin et al., 2017). Further, team sport talent identification programs, focussed on isolated skill development independent of the game environment, may lack the identification of key components such as decision making, game tempo adjustment, and tactical awareness (Burgess and Naughton, 2010). This is supported by Hoare and Warr (2000) who suggest objective assessments that measure tactical and technical awareness are needed as many players are strong athletically but lack these crucial components.

The aim of this paper is to review current Australian Football technical skill assessments, whilst considering the expert performance model and representative learning design theory, to develop a structured framework for practitioners to consider when assessing, or developing, new assessments of technical game based skill. This article applies these foundation concepts to exploring AF skill assessment. A 5-level performance assessment model (PAM) is proposed, attempting to order skill assessments along the performance continuum.

METHODS

The PAM model was developed from an extensive search of the AF literature using the Preferred Reporting Reviews and Meta-Analyses (PRISMA) statement as a guideline (Moher et al., 2009). Studies were included in the final review if they contained the following: (1) AF kicking proficiency test; (2) AF kicking test assessment; (3) AF kicking proficiency. The search strategy commenced with electronic database searches in SPORTDiscus, PubMed, and Google Scholar. Further studies were then examined from secondary sources such as the reference list of articles found from the initial search (Robertson et al., 2014). Search terms were limited to *Australian Football*, *Australian Football League*, *kicking*, *small-sided game*, *skill assessment*, and *skill test*. In total, 282 relevant studies were returned with 19 studies examining the technical skill of the AF drop-punt kick. Ten studies examined the drop-punt from a biomechanical perspective, seven investigated the technical skill from either a performance perspective, for talent identification purposes, or for the classification of playing position. Only two papers investigated the reliability and validity of the current AF kicking test (see **Table 1**).

5-LEVEL PERFORMANCE ASSESSMENT MODEL

During match-play all four components of performance (i.e., technical, tactical, physical, and psychological) are required to work in unison whilst the highest demand of intensity/pressure is being placed upon them. The 5-level PAM provides a progression of skill assessment from a performance demand perspective and how representative the assessment is to measure technical skills. At the base of the model is the notational analysis, which is the foundation stone for the PAM. Notational analysis identifies key skills and actions performed within the competitive environment.

TABLE 1 | Australian Football kicking test and proficiency investigation papers.

Author(s)	Year	Participants	Investigation
AF kicking test investigations			
*Cripps et al.	2015	121 Sub-elite AFL Players	Inter-rater reliability and validity of AFL kicking and handball tests
*Woods et al.	2015	25 elite U18 AF players and 25 non-state AF players	The use of skill tests to predict status in junior AF
AF kicking proficiency investigations			
*Cripps et al.	2017	282 U16 AF State Academy	The biological maturity, anthropometric, physical, and technical assessment of talent identified AF players
*Gastin et al.	2017	156 amateur 10–15 year old's	Age related differences in maturity, physical fitness, match running performance, and skill execution proficiency
Heasman et al.	2008	22 AFL games	Development and validation of a player impact ranking system in AF
Joseph et al.	2017	24 elite U18 AF players	The relationship between repeated kicking performance and maximal aerobic capacity
Tangalos et al.	2015	156 amateur 10–15 year old's	The relationship between fitness, skill and player performance
*Woods et al.	2016	42 talented and 42 non-talent identified U18 AF players	The application of a multi-dimensional assessment approach to talent identification in AF
*Woods et al.	2018	211 U18 state representatives	Classification of playing position in elite junior AF using technical skill indicators

**Studies that included both kicking and handballing.*

It is a technique for observing performance and recording the frequencies of these events. As such, in the PAM model, key in-game skills would be notionally analyzed and assessed using the appropriate level on the PAM. Accordingly, the 5-Level PAM proposes match-play is the ultimate level of assessment and resides at the highest point of the performance continuum at Level-5 (see **Figure 1**).

Foundation Stone: Notational Analysis

This stone is an application of the first stage of the EPA by identifying key components from match-play to be assessed. Notational analysis from actual game performance is needed to determine the key skill-based outcomes such as technical performance skills. For example, this level may identify ball possession duration, kick distance or locomotion whilst kicking the ball. Without this level of analysis, assessment selection would remain largely subjective and potentially inaccurate.

In AF, notational analysis identified two critical skills to pass and score – handballing and kicking (Sullivan et al., 2014a; Kempton et al., 2015). Although handballing is an effective method to pass the ball (Parrington et al., 2013), in elite junior AF kicking is used more frequently (Woods et al., 2018) and is the only method by which a goal can be scored. The ability to proficiently kick the ball in a game situation (i.e., pass to the intended target or score) is a critical factor, with the drop punt the most commonly used kick in AF (Ball, 2008). Robertson et al. (2015) highlighted the importance of kicking in one AFL team over a 2-year period. Winning teams had more kicks and were able to use the ball more efficiently to both pass the ball and to score. This study revealed teams who had more kicks and greater goal conversion (>4.2%) than their opposition won on 49 of 54 occasions (Robertson et al., 2015). Although kicking is a very specific skill in AF and has been associated with team success, from a talent identification perspective it has been poorly tested and measured in comparison to other AF performance variables (e.g., speed without the ball) (Woods et al., 2015b).

The distance a kick travels is another important consideration. Long kicks (i.e., >40 m) have been associated with a team's impact score (Heasman et al., 2008) as they create more opportunities for the kicker to score, pass and are harder to defend (Ball, 2008). However, they are generally delivered to a contest (i.e., where several players for each team compete for the ball) where retaining possession becomes more difficult (Appleby and Dawson, 2002). In comparison, Appleby and Dawson (2002) noted short kicks (i.e., <40 m) are commonly delivered to teammates who have moved away from their opponent and are by themselves. This reduces the amount of time the ball spends in the air, reducing the opportunity for opponents to intercept the ball and increasing a team's effectiveness at retaining possession of the ball (Appleby and Dawson, 2002).

The analysis of skill effectiveness has been used to differentiate between first round and later round draft picks. Findings have shown players drafted from U18 level to elite AF in the first and second rounds had more kicks, effective disposals, contested possessions, and contested marks in the U18 National Championships than athletes selected later in the draft (Woods et al., 2016). Furthermore, drafted players from the Championships, were able to deliver the ball more times within the attacking 50 m zone than non-drafted players (Woods et al., 2015a). Unfortunately, this study did not specify whether these kicks were effective or not, but as this criterion lead to being drafted it is reasonable to assume they were effective. Finally, delivering the ball inside the 50 m zone was deemed more influential to talent scouts than rebound 50's (a player removing the ball from their defensive 50 m zone) as these kicks lead to scoring situations (Woods et al., 2015a). Notational analysis therefore, is the foundation for any research investigating key aspects of a performance environment. By

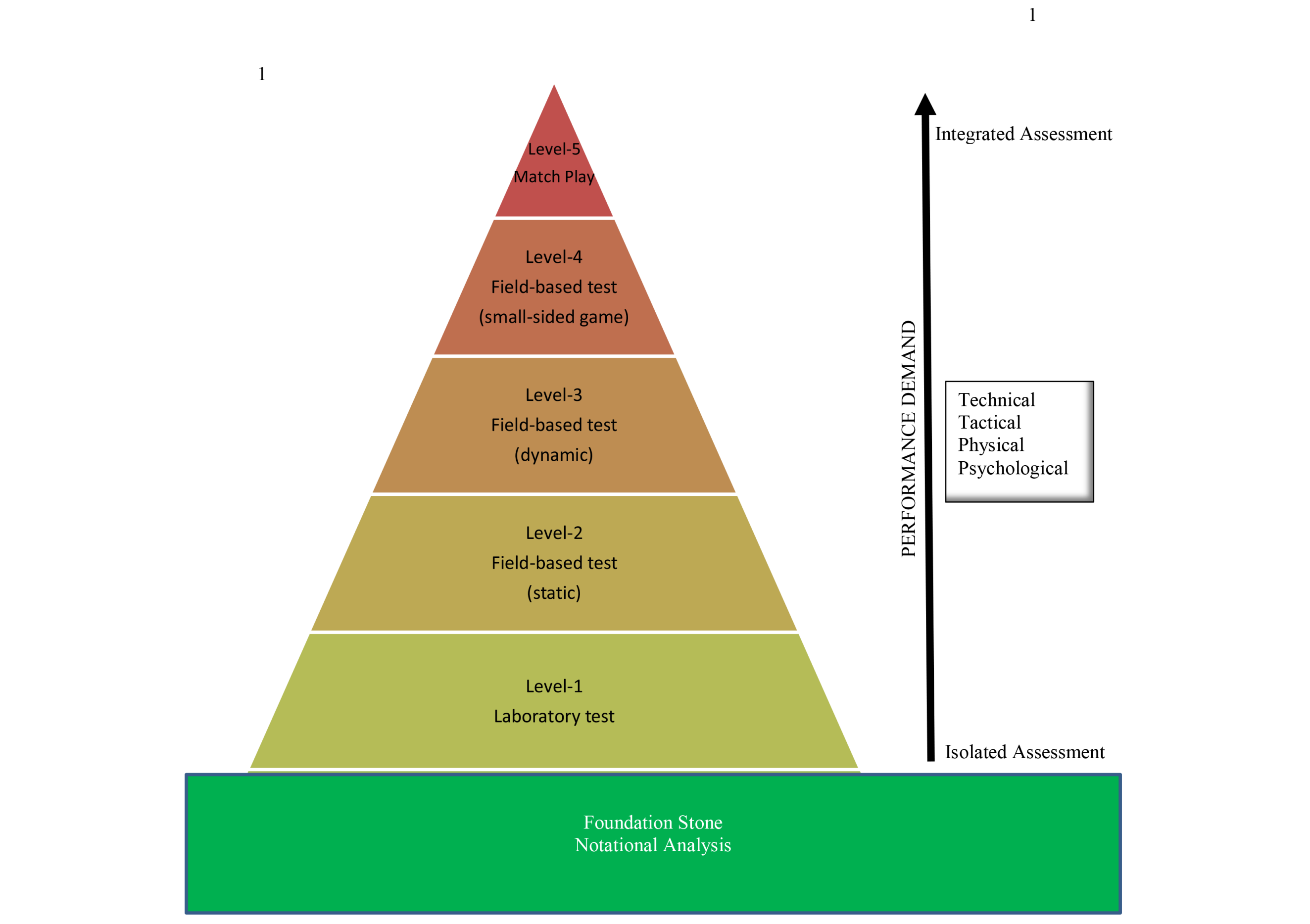

FIGURE 1 | The 5-Level Performance Assessment Model for team-sports.

using this process key performance skills which warrant further investigation can be identified.

Level-1: Laboratory Test

Laboratory based assessments are performed under well controlled environments and provide highly accurate outcomes (Henriksson et al., 2016). Using the RLD framework, this level would have low representation and therefore is positioned the furthest away from in-game performance. Traditionally, researchers have used laboratory-based tasks in an attempt to reliably capture an aspect of performance which inadvertently separates perception from action (Farrow et al., 2017). In AF, these tests have been largely used to assess, speed and anthropometrics (Pyne et al., 2005; Veale et al., 2008) and to a lesser extent, tactical capabilities (decision making abilities) (Breed et al., 2018) and technical characteristics (biomechanical assessments to analyze key components of the moving body segments to produce a skill) (Dichiera et al., 2006).

Level-1 assessments, such as maximal oxygen uptake (VO_2 max) (Lorenzen et al., 2009), are an important consideration in AF. On average, AFL players are covering just under 13,000 m per game with over 3000 m being performed at high intensity (between 4.17 and 10.00 ms^{-1}) (Aughey, 2010; Coutts et al., 2010). Additionally, this level would be appropriate for identifying particular biomechanical movement patterns, such as the effect lower limb joint angles have on kicking accuracy (Dichiera et al., 2006). Whilst these assessments do provide valuable feedback for coaches and participants (e.g., they can provide appropriate intervention strategies) they do contain certain limitations. Laboratory assessments do not ascertain how proficient a player is with their skill execution under match conditions and they may not consider a player changing their kinematic movements to compensate for any deficiencies they may have when executing a skill (Royal et al., 2006; Coventry et al., 2015).

Level-2: Field-Based Test (Static)

Level-2 on the performance continuum explores skill execution through field-based testing within a static environment (i.e., AF kicking efficiency test). Although this level is more representative than laboratory tests, it largely focuses on the isolated technical element of key skills required in AF (i.e., the technical ability to kick the ball with limited presence of the physiological, tactical and psychological demands of AF). As such, this test would remain a low rating for representativeness, positioned one level higher on the continuum. Biomechanical researchers have used this level to obtain a more natural assessment of kicking actions. For example, Ball (2008) assessed the isolated technical elements of distance kicking of 28 AFL players on the ground where players trained and played. It was noted greater foot speeds and shank angular velocities, with an increase in last step length, were required to deliver the ball further (Ball, 2008). In a small study investigating the goal-kicking accuracy in two junior AF players, using an inertial measurement system, it was noted the participants had individual differences with goal kicking accuracy suggesting goal kicking assessment in junior athletes require an individual-based analysis (Blair et al., 2017).

In an attempt to more accurately identify and assess talent the Australian Football League (AFL) introduced a draft combine. This combine occurs annually with potential draftees invited to complete a testing battery of standardized technical (e.g., kicking efficiency test), physical (e.g., 2 km time trial), psychological (e.g., personality test), and medical tests (e.g., eye test) conducted over a 4-day period. These measures are then combined with talent scouts subjective opinions of in-game performance to help classify, identify and select players (Burgess et al., 2012). While there are six physical tests, measuring speed (20 m sprint), change of direction (agility test), running endurance (Yo-Yo test and 2 km time trial), and power (standing vertical jump, running vertical jump), currently, there are only two technical skill tests used in the AFL Draft Combine: a goal kicking test and a kicking efficiency test.

The goal kicking test involves players having five shots at goal (i.e., two set shots, two snap shots, and one on the run) within a 70 s period. The kicking efficiency test involves players taking six kicks from a designated distance (i.e., two at 20 m, two at 30 m, and two at 40 m) to a pre-determined location in a random order. Whilst there has been extensive use of the tests at the AFL Draft Combine, there has been minimal research conducted on the use of these AF technical skill assessments. Cripps et al. (2015) indicated the kicking efficiency test is appropriate for assessing kicking in a static environment (i.e., a setting where the skill is performed in an isolated manner, absent of opposition in a relatively predictable environment), whilst also being able to provide feedback to developing athletes regarding dominant and non-dominant disposals over a range of distances. Despite these findings, Cripps et al. (2015) concluded more research is required to determine if the test can also distinguish between higher and lower skilled players and whether kicking ability changes with age. In contrast Woods et al. (2015b) assessed 50 U18 male players (25 state representatives and 25 non-state representatives) and found when kicking accuracy and ball speed were combined, playing status was able to be predicted.

Skill assessment is an important consideration and when combined with physiological competencies, the ability to predict future individual success was increased (Tangalos et al., 2015). The use of technical skill testing to predict performance has been effective in team and individual sports such as handball (Lidor et al., 2005), soccer (Ali et al., 2008), and rugby (Gabbett et al., 2011a). It has been suggested a player's proficiency in skill execution can potentially influence playing performance and therefore team performance to a larger extent (Gabbett and Ryan, 2009; Gabbett et al., 2011b). This not only highlights the importance of skill in regard to game influence and draft selection, but also emphasizes the importance of further skill development and how it may contribute to match performance (through maintaining possession and effectively delivering the ball) and player development.

Whilst the technical and physiological tests do provide some valuable information (such as the potential to identify skill strengths and weaknesses), they are predominantly performed in a relatively closed setting, separating the skill from the demands of match performance. Research on the kicking efficiency test indicates no significant correlation between coaches' perceptions of skill and kicking test scores ($r = -0.13$, $P = 0.75$). Construct validity for the test was shown to be poor, however; the kicking test did demonstrate partial content validity and a strong inter-rater reliability score (ICC = 0.96, $P < 0.01$) (Cripps et al., 2015).

Overall, Level-2 assessments are more practical to implement (as they are easier to set up and conduct than laboratory tests), making them not only appropriate at the elite level but also at the sub-elite level. Although Level-2 is accurate at identifying specific body segment skill movements, these movement patterns are done in isolation of game performance demands. This approach has been suggested as one reason as to why talent identification (TID) programs are not effective (Unnithan et al., 2012; Pinder et al., 2013) and why future research should move forward from this approach and include more multidimensional aspects of performance (Pearson et al., 2006). Although this approach would be more complex to develop than univariate assessment, they are more dynamic and may better capture the nuances of talent and how it evolves across development (Johnston et al., 2018). An additional level is therefore required where the skill is executed in a more representative assessment.

Level-3: Field-Based Test (Dynamic)

Field-based dynamic tests are a further progression along the representation and stability of the environment whilst remaining structured. Where Level-2 tests are pre-planned, Level-3 tests are more open and match-like. They require a minimum of three match-specific components to be integrated at the one time (e.g., technical, tactical, and physiological) and demand a higher level of performance intensity than field-based static tests thereby making them a medium representation of match-play and positioned one level higher than the previous two levels. In ecological dynamics, it has been discussed how the continuous performer-environment interaction is critical to making effective decisions and organizing their actions during performance (Brunswick, 1956; Gisbon, 1979; Travassos et al., 2012).

The process of perception-action coupling occurs throughout Level-3 to facilitate behavior based on the visual information available in the performance environment. Within team sport match-play, successful actions of athletes will vary due to the unpredictable environmental elements and constraints (e.g., opposition movement). Therefore, movements are largely anticipatory in nature based upon key information from their actions and the external environment (Araujo et al., 2006). When assessing the anticipatory visual cues of 25 tennis players (13 skilled and 12 novice) it was found skilled players were more accurate with live and video displays (but not with point-light displays) than novices (Shim et al., 2005). This highlights the importance of information presented to be representative of the performance environment as stimuli presence or absence may shape player behavior (Greenwood et al., 2016).

For example, the use of bowling machines in cricket practice have enabled players to rehearse their physical actions to be trained, however, their use is limited due to the lack of perceptual stimulus displayed. When there is a lack of perceptual stimulus (i.e., bowlers arm, hand, hip, trunk movement) players re-organize their coordination and timing, leading to movement patterns which are not representative of match-play (i.e., peak height of back swing was higher and drive initiation of the downswing occurred earlier and lasted longer when batting against a machine) (Renshaw et al., 2007). Although these studies would suggest human opposition is the preferred option, it is important to be mindful that humans may be more inconsistent, not as fast and may not be able to produce as much volume thereby limiting the amount of quality practice a player has. Careful consideration therefore needs to be applied to designing tests for athletes to complete as there appears to be a continuum as to how representative a test can be.

To the author's knowledge, there have been no published articles exploring the use of field-based dynamic tests (i.e., Level-3) for the purpose of talent identification in AF. This is an important consideration as in a review of TID in male soccer is was discussed how the combination of a player's technical and tactical skills in combination with their anthropometric and physiological characteristics is a complex relationship requiring careful attention (Sarmento et al., 2018). This relationship should be considered according to the age, maturational status and specific playing position of each player to avoid discriminating against younger or late-maturing players and the effect these may have on performance capabilities (Sarmento et al., 2018). Tangalos et al. (2015) investigated the relationships between indices of fitness and skill on player performance in 10–15 year old amateur AF players. The author's found when skill (coach rating) and fitness (20 m shuttle test) were combined, there is a good correlation with the number of disposals an athlete will achieve as well as the number of effective disposals (Tangalos et al., 2015). As the main purpose of a performance test is to demonstrate how that test relates to the competitive environment (Tangalos et al., 2015), researchers need to understand the dynamics of AF and the technical elements. To achieve this, the notational analysis gathered at the Foundation Stone could be used to identify performance specific movement patterns, skill executions and physical demands allowing critical skills to be identified within the context they are performed. For example, identifying how a player obtains the ball, what movement patterns they perform with the ball and how they deliver the ball could then be applied to a dynamic skill test, enabling key factors such as skill executions and movement patterns to be combined together.

The ability to identify the physical and informational constraints from the environment and use opportunities for actions to achieve performance goals (Davids et al., 2013b) is a critical skill that talent scouts are looking for in recruits (Woods et al., 2015a). As such, Level-3 may assist talent scouts in identifying players who are able to do this. In sports like track and field, cricket, and gymnastics, athletes use perceptual variables to regulate their approach to performing the task (i.e., in cricket athletes use the umpire as a way of ascertaining depth perception and to regulate their gait during run up) (Greenwood et al., 2012). Elite coaches' are also aware of the importance of task constraints in learning design and use non-linear pedagogy to design training around the individual athletes constraints (i.e., their physical, physiological, cognitive, and emotional characteristics) to allow the athlete to solve the performance problem (Greenwood et al., 2012).

Overall, Level-3 contains a more integrated approach of match-play components and a higher requirement from the performance demands (i.e., pressure) than Level-2. The skill execution is assessed with an outcome focus (i.e., kick effectiveness) rather than a performance focus (i.e., the mechanics of the kicking action). When investigating the kinematic effects of a short term fatigue protocol on drop-punt kicking, it was concluded players are able to make kinematic adaptations in order to maintain foot speed while punting for maximal distance (Coventry et al., 2015). Therefore, a player at this level may be effective in their delivery of the ball, however, their mechanics may alter from the preferred technique. This assessment result could potentially be used as a way of determining a player's ability to execute a skill under particular constraints. A limitation of Level-3 is the absence of opposition and the ability to assess how proficient a player is with their skill execution in a more open and dynamic playing environment. Therefore, a fourth level is required where this can be addressed.

Level-4: Field-Based Test (Small-Sided Game)

Level-4 is the implementation of field-based small sided games, where all four components of performance are assessed at the one time. This integrated approach of the components enables this test to be high in representation and therefore positioned one level below match-play assessment. Field-hockey coaches have noted that whilst technique is important, so too was practicing in a tactical context where match-play is simulated, as the latter improved players tactical understanding, decision making ability and their understanding of player patterns (Slade, 2015). The absence of live opponents in the current AF skill tests may alter the perceptual cues available to the performer and consequently the performer may use alternative, non-match like movement patterns, leading to an unreliable evaluation of that particular skill performance (Roca and Williams, 2016). In AF there is not one typical stimulus that a player is going to react to (i.e., the umpire blowing their whistle) but a continuous flow of stimuli from the environment that needs to be perceived and responded to (Davids et al., 2005). It has been discussed that a flaw in sports science research is the inability to accurately sample the perceptual variables of performance environments in which skilled athletes operate (Dicks et al., 2009).

When contemplating talent identification in AF, it is apparent more sport specific research is required to obtain clarity on the interconnecting components. Reviews such as the one conducted by Robinson et al. (2018) have highlighted the high level of variability in the elements separating higher and lesser skilled players. A possible suggestion to achieving greater continuity is to have studies based on sound theoretical principles and valid research designs (Bergkamp et al., 2018). New assessments should consider the interacting constraints, movement behaviors, contain adequate environmental variables and ensure the functional coupling between perception and action processes (Pinder et al., 2011). Additionally, they should challenge athletes to make accurate and timely decisions whilst executing the skill under some level of fatigue (Dawson et al., 2004). It is therefore evident a significant gap exists within the AFL talent assessment procedures.

Small-sided games are modified games played on reduced ground areas, often using adapted rules and involve smaller number of players than traditional games (Hill-Haas et al., 2011). The use of small-sided games (SSGs) at Level-4 could be appropriate as they replicate movement constraints (i.e., pressure when kicking the ball, locomotor patterns), information variables from the specific environment and the functional coupling between perception and action processes from competition. Furthermore, the goals in the assessment context (i.e., kicking efficiency) are based on comparable information (i.e., decision making) to the performance environment (Pinder et al., 2011; Loader et al., 2012). When a representative environment allows athletes to display their tactical understanding and their ability to make timely and accurate decisions, combined with their ability to proficiently execute game related skills, players can be accurately identified as either higher skilled or lesser skilled (Oslin et al., 1998; Davids et al., 2013a).

Match-play occurs within an unstable, dynamic and unpredictable environment. Traditional assessment methods (such as those discussed at Level-1 and Level-2), have a tendency to isolate the key components of technical, tactical, physiological and psychological competencies, thereby making the movement patterns more predictable and consequently limiting their application to match-play. There is a strong need for coaches to develop activities where these components are more interconnected whilst replicating the most intense contact demands of competition without a decrease in running performance (Johnston et al., 2015). The use of SSGs and practice matches as a way of developing skill and selecting team members is a well-established concept that most, if not all, sports utilize (Hoare and Warr, 2000; Gabbett, 2009). Team sport coaches of rugby (Gabbett et al., 2012b), soccer (Hill-Haas et al., 2011), and AF (Davies et al., 2013) have implemented small sided games as part of their training regimen in an attempt to develop decision making (O'Connor et al., 2017), skill execution (Klusemann et al., 2012), and tactical awareness skills (Chatzopoulos et al., 2006). This style of training creates an environment where the interaction between players are constantly changing in a dynamic manner thereby creating opportunities to challenge the athlete to make timely decisions whilst efficiently disposing of the ball in a simulated match environment (Davids et al., 2013a).

The size of the small-sided game perimeter has varied within the literature due to the focus being on specific fitness qualities rather than talent assessment. In AF, playing areas such as 30 m × 20 m, 45 m × 30 m, 23.2 m × 20 m, 30 m × 20 m have all been used to compare the agility demands of SSGs (Davies et al., 2013). These SSGs involved elite AF players competing in a small-sided handballing game where the reduction in players resulted in small increases in total agility maneuvers (a maximum or near-maximum change of direction or deceleration to influence a contest). Although the only skill performed was handballing, an earlier soccer study using different constraints, found similar results (Duarte et al., 2009). Duarte et al. (2009) reported when there was a decrease in the number of soccer players from 4v4 to 2v2, with a pitch size of 20 m × 20 m, player intensity increased and more frequent tactical actions occurred. It was hypothesized this was due to more surface area being available per player. In contrast to these two studies, a rugby league study analyzing the effect of field size on the physiological and skill demands of players involved in SSGs, noted no significant skill involvement differences when using a 10 m × 40 m playing area versus a 40 m × 70 m playing area. Increases in distances covered at moderate, high and very high intensities, however, were noted in games played on the larger field size with senior elite players recording higher amounts than junior elite players (Gabbett et al., 2012a). When using SSGs as a way of assessing talent it is important the perimeter applied allows the skills in AF to occur naturally (i.e., kicking and handballing). It is therefore suggested the surface area per player should be representative of the surface area each player has during match-play.

The duration of each bout is an important consideration when discussing SSGs. Research has shown in a 3v3 soccer contest, bout duration did not have an effect on the number of technical actions performed per minute or proficiency (Fanchini et al., 2011). The authors did, however, note, as duration increased from 2 to 6 min there was a decrease in exercise intensity. Sampaio and Macas (2012) have suggested as players become more skilled they run less as their movement patterns are more intentional due to a greater tactical awareness of the game. When trying to emulate match-play intensity, 4-min bouts are suggested as the best choice. In an elite 4v4 soccer game, of 4 min in duration (with 3 min passive recovery), it was shown SSG intensity was comparable to generic aerobic interval training with the total distance covered per minute, total number of duels and lost ball possessions all being greater in the SSG than actual game play (Impellizzeri et al., 2006). Furthermore, manipulating the constraint of fewer ball touches (i.e., 1 or 2) increased the difficulty for players to perform technical actions making it more specific to match demands (Dellal et al., 2012).

Small-sided game play allows players more opportunities to gain possession of the ball to display their skill proficiency as well as more opportunities to apply game strategy and tactical maneuvers in an easily manipulated and convenient setting. This form of assessment replicates match-play conditions from an integrated physiological, tactical, and technical perspective. Considering player performance should be analyzed from within a simulated, competitive environment it appears SSG assessment is the best solution (other than actual match-play at Level-5) for assessing competition skill performance (Davids et al., 2013a). To effectively develop a small-sided game assessment, researchers could examine the notational analysis of match-play dynamics from the foundation stone. They could then apply these findings by modifying the SSG variables such as pitch area, the number of players participating, the rules by which the players are abiding by and the intensity at which the game is played. For example, a smaller number of players combined with a large pitch size will make players work at a higher exercise intensity (Hill-Haas et al., 2011).

Overall, Level 4 provides a more open playing environment along the continuum where the rules replicate match-play. The skill assessment will more closely resemble match-play assessment of their ability to not only obtain possession of the ball but deliver the ball under match like demands (i.e., pressure). This analysis could then be used in assessing player talent selection, player development tracking, the effectiveness of intervention programs and potentially how a player will perform during match-play. A limitation of Level-4 might be the reluctance of the coach to implement the game with contact (thereby reducing the representativeness of the assessment).

Level-5: Match-Play

Match-play assessment resides at the highest point in the model, as this ultimately highlights a player's ability to perform within the sport. When recruiters were interviewed as what they perceived as important for U13 soccer performance they identified the technical (i.e., first touch), tactical (i.e., decision making), and the psychological attributes (i.e., trainability) as being highly important, with other attributes such as physiological, anthropometrical, and sociological being less important suggesting recruiters apply a holistic multidisciplinary approach to talent selection (Larkin and O'Connor, 2017). This finding was supported in another soccer study interviewing eight Danish national team coaches (Christensen, 2009). Within this study it was highlighted how coaches regarded game intelligence (i.e., tactical awareness), peak competences (i.e., technical skill), willingness to learn, work ethic, and dedication as the most important qualities when selecting talented players. These studies highlight how match-play performance is a key component in the talent identification process in comparison to objective skill assessments.

It is common practice for AF coaches to select teams based off competition performance, however, the effectiveness of this method has had limited investigation in the literature. Black et al. (2016) identified how higher skilled players perform greater physical and technical performances following peak periods of match-play in comparison to lesser skilled players. When coaches subjectively rated player match performance, Johnston et al. (2012) found the higher skilled players had more kicks and disposals per minute, covered less distance and performed fewer high-speed efforts than lesser skilled players. This finding was supported in another AF study where skill performance, in comparison to physical activity, was found to be more important to a coaches' perception of performance (Sullivan et al., 2014b). In contrast to these two studies, Johnston et al. (2016) investigated the relationship between movement demands, match events and match performance in AFL players. They noted how higher skilled players had higher match durations, covered greater total distance and spent more time running at high speeds per minute than lesser skilled players.

Combined, this research supports how match-play could be used as an integrated assessment. Unfortunately, there are limited opportunities for a player to be selected to play at the highest level and once selected there may be limited chances for the player to display their capabilities. For example, external variables such as weather, opposition tactics and flow of play may impact the amount of possessions a player has. Therefore, in an attempt to identify talent, an array of tests along the continuum may be required to more effectively assess specific components of performance. As such, it should be acknowledged a limitation of the current model is it does not consider other factors influencing talent detection and development (e.g., social, coaching, physical, physiological, and psychological) (Williams and Reilly, 2000; Pazo Haro et al., 2012). Therefore, the assessment of technical skill ability is just one piece of the talent identification conundrum.

CONCLUSION

There are many factors to consider when implementing a technical skill assessment. The prediction of talent is more likely to be successful when tests are more representative of match-play and assessed within an integrated approach. The EPA model, which contains three stages – identification of key components, the assessment of these components and the acquisition of these components, has been combined with the RLD framework to review current Australian Football technical skill assessments and develop a structured framework for practitioners to consider when assessing, or developing, new assessments of technical game-based skills.

A 5-level performance assessment model has been proposed that explores the skill assessment continuum. As the tests apply the notational analysis and move from Level-1 (laboratory analysis) to Level-5 (match-play assessment) there is a step-wise progression in the performance demands and integration of the four components to more closely represent match-play conditions (representative design). For example, Level-1 can provide a detailed isolated analysis of the kicking action in a controlled and stable environment, the kicking action is pre-determined with no opposition pressure. Level-2 is also an isolated analysis, with no opposition pressure and delivering the ball to a pre-determined location. This level assesses the technical component of the kick in a field-based setting with the focus on skill proficiency. Level-3 is a more dynamic field-based assessment, involving the combination of several match-specific components at the one time (e.g., technical, physical, psychological). The constraints are more open (e.g., the ball needs to be passed to a moving teammate), however, there are no opposition present. Level-4 looks at integrating all of the components under similar performance demands in a field-based small-sided game. Normal game rules apply, and opponents are present, which allows for a greater assessment of match-play skill execution than technical competency. Match-play resides at Level-5 as this is the ultimate level of skill assessment, highlighting a player's ability to perform in the sport. For example, a player's ability to effectively dispose of the ball under scoreboard pressure or opposition tactics (e.g., playing area pressure). Assessments from these tests could be used in conjunction with each other to profile players, track player development and display player strengths whilst identifying specific areas of improvement along the AF talent pathway.

AUTHOR CONTRIBUTIONS

NB wrote the article. JB helped with the conceptual idea. KB and PL helped with the conceptual idea and the editing.

REFERENCES

Abbott, A., Button, C., Pepping, G. J., and Collins, D. (2005). Unnatural selection: talent identification and development in sport. *Nonlinear Dynamics Psychol. Life Sci.* 9, 61–88.

Abbott, A., and Collins, D. (2004). Eliminating the dichotomy between theory and practice in talent identification and development: considering the role of psychology. *J. Sports Sci.* 22, 395–408. doi: 10.1080/02640410410001675324

Ali, A., Foskett, A., and Gant, N. (2008). Validation of a soccer skill test for use with females. *Int. J. Sports Med.* 29, 917–921. doi: 10.1055/s-2008-1038622

Appleby, B., and Dawson, B. (2002). Video analysis of selected game activities in Australian Rules Football. *J. Sci. Med. Sport* 5, 129–142. doi: 10.1016/S1440-2440(02)80034-2

Araujo, D., Davids, K., and Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychol. Sport Exerc.* 7, 653–676. doi: 10.1016/j.psychsport.2006.07.002

Aughey, R. J. (2010). Australian football player work rate: evidence of fatigue and pacing? *Int. J. Sports Physiol. Perform.* 5, 394–405. doi: 10.1123/ijspp.5.3.394

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomech.* 7, 10–23. doi: 10.1080/14763140701683015

Bergkamp, T. L. G., Niessen, A. S. M., den Hartigh, R. J. R., Frencken, W. G. P., and Meijer, R. R. (2018). Comment on: "talent identification in sport: a systematic review". *Sports Med.* 48, 1517–1519. doi: 10.1007/s40279-018-0868-6

Black, G. M., Gabbett, T. J., Naughton, G. A., and McLean, B. D. (2016). The effect of intense exercise periods on physical and technical performance during elite Australian Football match-play: a comparison of experienced and less experienced players. *J. Sci. Med. Sport* 19, 596–602. doi: 10.1016/j.jsams.2015.07.007

Blair, S., Duthie, G., Robertson, S., and Ball, K. (2017). Biomechanics of goal-kicking accuracy in Australian Football using an inertial measurement system. *Paper Presented at the 35th Conference of the International Society of Biomechanics in Sports*, Cologne.

Breed, R., Mills, O., and Spittle, M. (2018). Can video-based perceptual-cognitive tests differentiate between skill level, player position, and experience in elite Australian Football? *J. Expertise* 1, 79–93.

Brunswick, E. (1956). *Perception and Teh Representative Design of Psychological Experiments*, 2nd Edn. Berkeley, CA: University of California Press.

Burgess, D., Naughton, G., and Hopkins, W. (2012). Draft-camp predictors of subsequent career success in the Australian Football League. *J. Sci. Med. Sport* 15, 561–567. doi: 10.1016/j.jsams.2012.01.006

Burgess, D. J., and Naughton, G. A. (2010). Talent development in adolescent team sports: a review. *Int. J. Sports Physiol. Perform.* 5, 103–116. doi: 10.1123/ijspp.5.1.103

Chatzopoulos, D., Drakou, A., Kotzamanidou, M., and Tsorbatzoudis, H. (2006). Girls' soccer performance and motivation: games vs technique approach. *Percept. Mot. Skills* 103, 463–470. doi: 10.2466/pms.103.2.463-470

Christensen, M. (2009). "An eye for talent': talent identi cation and the 'practical sense' of top-level soccer coaches'. *Sociol. Sport* 26, 365–382. doi: 10.1123/ssj.26.3.365

Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., and Rampinini, E. (2010). Match running performance in elite Australian Rules Football. *J. Sci. Med. Sport* 13, 543–548. doi: 10.1016/j.jsams.2009.09.004

Coventry, E., Ball, K., Parrington, L., Aughey, R., and McKenna, M. (2015). Kinematic effects of a short-term fatigue protocol on punt-kicking performance. *J. Sports Sci.* 33, 1596–1605. doi: 10.1080/02640414.2014.1003582

Cripps, A. J., Hopper, L. S., and Joyce, C. (2015). Inter-rater reliability and validity of the Australian football league's kicking and handball tests. *J. Sports Sci. Med.* 14, 675–680.

Davids, K., Araujo, D., Correia, V., and Vilar, L. (2013a). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exerc. Sport Sci. Rev.* 41, 154–161. doi: 10.1097/JES.0b013e318292f3ec

Davids, K., Araujo, D., Vilar, L., Renshaw, I., and Pinder, R. (2013b). An ecological dynamics approach to skill acquisition: implications for development of talent in sport. *Talent Dev. Excell.* 5, 21–34.

Davids, K., Renshaw, I., and Glazier, P. (2005). Movement models from sports reveal fundamental insights into coordination processes. *Exerc. Sport Sci. Rev.* 33, 36–42.

Davies, M. J., Young, W., Farrow, D., and Bahnert, A. (2013). Comparison of agility demands of small-sided games in elite Australian football. *Int. J. Sports Physiol. Perform.* 8, 139–147. doi: 10.1123/ijspp.8.2.139

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., and Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. *J. Sci. Med. Sport* 7, 278–291. doi: 10.1016/S1440-2440(04)80023-9

Dellal, A., Owen, A., Wong, D. P., Krustrup, P., van Exsel, M., and Mallo, J. (2012). Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Hum. Mov. Sci.* 31, 957–969. doi: 10.1016/j.humov.2011.08.013

Dichiera, A., Webster, K. E., Kuilboer, L., Morris, M. E., Bach, T. M., and Feller, J. A. (2006). Kinematic patterns associated with accuracy of the drop punt kick in Australian Football. *J. Sci. Med. Sport* 9, 292–298. doi: 10.1016/j.jsams.2006.06.007

Dicks, M., Davids, K., and Button, C. (2009). Representative task designs for the study of perception and action in sport. *Int. J. Sport Psychol.* 40, 506–524. doi: 10.3758/s13428-013-0429-8

Duarte, R., Batalha, N., Folgado, H., and Sampaio, J. (2009). Effects of exercise duration and number of players in heart rate responses and technical skills during futsal small-sided games. *Open Sports Sci. J.* 2, 37–41. doi: 10.2174/1875399X00902010037

Ericsson, A., and Smith, J. (1991). *Toward a General Theory of Expertise: Prospects and Limits*. New York, NY: Cambridge University Press.

Fanchini, M., Azzalin, A., Castagna, C., Schena, F., McCall, A., and Impellizzeri, F. M. (2011). Effect of bout duration on exercise intensity and technical performance of small-sided games in soccer. *J. Strength Cond. Res.* 25, 453–458. doi: 10.1519/JSC.0b013e3181c1f8a2

Farrow, D., Reid, M., Buszard, T., and Kovalchik, S. (2017). Charting the development of sport expertise: challenges and opportunities. *Int. Rev. Sport Exerc. Psychol.* 11, 238–257. doi: 10.1080/1750984X.2017.1290817

Gabbett, T., and Ryan, P. (2009). Tackling technique, injury risk, and playing performance in high-performance collision sport athletes. *Int. J. Sports Sci. Coach.* 4, 521–533. doi: 10.1260/174795409790291402

Gabbett, T. J. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *Int. J. Sports Sci. Coach.* 4, 273–283. doi: 10.1260/174795409788549553

Gabbett, T. J., Abernethy, B., and Jenkins, D. G. (2012a). Influence of field size on the physiological and skill demands of small-sided games in junior and senior rugby league players. *J. Strength Cond. Res.* 26, 487–491. doi: 10.1519/JSC.0b013e318225a371

Gabbett, T. J., Jenkins, D. G., and Abernethy, B. (2012b). Influence of wrestling on the physiological and skill demands of small-sided games. *J. Strength Cond. Res.* 26, 113–120. doi: 10.1519/JSC.0b013e31821d97f4

Gabbett, T. J., Jenkins, D. G., and Abernethy, B. (2011a). Relationships between physiological, anthropometric, and skill qualities and playing performance in professional rugby league players. *J. Sports Sci.* 29, 1655–1664. doi: 10.1080/02640414.2011.610346

Gabbett, T. J., Jenkins, D. G., and Abernethy, B. (2011b). Relative importance of physiological, anthropometric, and skill qualities to team selection in professional rugby league. *J. Sports Sci.* 29, 1453–1461. doi: 10.1080/02640414.2011.603348

Gastin, P. B., Tangalos, C., Torres, L., and Robertson, S. (2017). Match running performance and skill execution improves with age but not the number of disposals in young Australian footballers. *J. Sports Sci.* 35, 2397–2404. doi: 10.1080/02640414.2016.1271137

Gee, C., Marshall, J., and King, J. (2010). Should coaches use personality assessments in the talent identification process? A 15 year predictive study on professional hockey players. *Int. J. Coach. Sci.* 4, 25–34.

Gisbon, J. (1979). *The Ecological Approach to Visual Perception*. Boston, MA: Houghton Mifflin.

Greenwood, D., Davids, K., and Renshaw, I. (2012). How elite coaches' experiential knowledge might enhance empirical research on sport performance. *Int. J. Sports Sci. Coach.* 7, 423–426. doi: 10.1260/1747-9541.7.2.423

Greenwood, D., Davids, K., and Renshaw, I. (2016). The role of a vertical reference point in changing gait regulation in cricket run-ups. *Eur. J. Sport Sci.* 16, 794–800. doi: 10.1080/17461391.2016.1151943

Heasman, J., Dawson, B., Berry, J., and Stewart, G. (2008). Development and validation of a player impact ranking system in Australian football. *Int. J. Perform. Anal. Sport* 8, 156–171. doi: 10.1080/24748668.2008.11868457

Henriksson, T., Vescovi, J. D., Fjellman-Wiklund, A., and Gilenstam, K. (2016). Laboratory- and field-based testing as predictors of skating performance in competitive-level female ice hockey. *Open Access. J. Sports Med.* 7, 81–88. doi: 10.2147/OAJSM.S109124

Hill-Haas, S. V., Dawson, B., Impellizzeri, F. M., and Coutts, A. J. (2011). Physiology of small-sided games training in football: a systematic review. *Sports Med.* 41, 199–220. doi: 10.2165/11539740-000000000-00000

Hoare, D. G., and Warr, C. R. (2000). Talent identification and women's soccer: an Australian experience. *J. Sports Sci.* 18, 751–758. doi: 10.1080/02640410050120122

Honer, O., and Votteler, A. (2016). Prognostic relevance of motor talent predictors in early adolescence: a group- and individual-based evaluation considering different levels of achievement in youth football. *J. Sports Sci.* 34, 2269–2278. doi: 10.1080/02640414.2016.1177658

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., et al. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *Int. J. Sports Med.* 27, 483–492. doi: 10.1055/s-2005-865839

Johnston, K., Wattie, N., Schorer, J., and Baker, J. (2018). Talent Identification in sport: a systematic review. *Sports Med.* 48, 97–109. doi: 10.1007/s40279-017-0803-2

Johnston, R. D., Gabbett, T. J., and Jenkins, D. G. (2015). Influence of number of contact efforts on running performance during game-based activities. *Int. J. Sports Physiol. Perform.* 10, 740–745. doi: 10.1123/ijspp.2014-0110

Johnston, R. J., Watsford, M. L., Austin, D. J., Pine, M. J., and Spurrs, R. W. (2016). Movement profiles, match events, and performance in Australian football. *J. Strength Cond. Res.* 30, 2129–2137. doi: 10.1519/JSC.0000000000001333

Johnston, R. J., Watsford, M. L., Pine, M. J., Spurrs, R. W., Murphy, A., and Pruyn, E. C. (2012). Movement demands and match performance in professional Australian football. *Int. J. Sports Med.* 33, 89–93. doi: 10.1055/s-0031-1287798

Kempton, T., Sullivan, C., Bilsborough, J. C., Cordy, J., and Coutts, A. J. (2015). Match-to-match variation in physical activity and technical skill measures in professional Australian football. *J. Sci. Med. Sport* 18, 109–113. doi: 10.1016/j.jsams.2013.12.006

Klusemann, M. J., Pyne, D. B., Foster, C., and Drinkwater, E. J. (2012). Optimising technical skills and physical loading in small-sided basketball games. *J. Sports Sci.* 30, 1463–1471. doi: 10.1080/02640414.2012.712714

Krause, L., Farrow, D., Buszard, T., Pinder, R. A., and Reid, M. (2019). Application of representative learning design for assessment of common practice tasks in tennis. *Psychol. Sport Exerc.* 41, 36–45. doi: 10.1016/j.psychsport.2018.11.008

Krause, L., Farrow, D., Reid, M., Buszard, T., and Pinder, R. (2018). Helping coaches apply the principles of representative learning design: validation of a tennis specific practice assessment tool. *J. Sports Sci.* 36, 1277–1286. doi: 10.1080/02640414.2017.1374684

Larkin, P., and O'Connor, D. (2017). Talent identification and recruitment in youth soccer: recruiter's perceptions of the key attributes for player recruitment. *PLoS One* 12:e0175716. doi: 10.1371/journal.pone.0175716

Larkin, P., and Reeves, M. (2018). Junior-elite football: time to re-position talent identification? *Soccer Soc.* 19, 1183–1192. doi: 10.1080/14660970.2018.1432389

Lidor, R., Falk, B., Arnon, M., Cohen, Y., Segal, G., and Lander, Y. (2005). Measurement of talent in team handball: the questionable use of motor and physical tests. *J. Strength Cond. Res.* 19, 318–325. doi: 10.1519/00124278-200505000-00014

Loader, J., Montgomery, P., Williams, M., Lorenzen, C., and Kemp, J. (2012). Classifying training drills based on movement demands in Australian football. *Int. J. Sports Sci. Coach.* 7, 57–67. doi: 10.1260/1747-9541.7.1.57

Lorenzen, C., Williams, M., Turk, P., Meehan, D., and Cicioni Kolsky, D. (2009). Relationship between velocity reached at VO2 max and time-trial performances in elite Australian rules footballers. *Int. J. Sports Physiol. Perform.* 4, 408–411. doi: 10.1123/ijspp.4.3.408

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., and Prisma Group (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 6:e1000097. doi: 10.1371/journal.pmed.1000097

O'Connor, D., Larkin, P., and Williams, A. (2017). What learning environments help improve decision-making? *Phys. Educ. Sport Pedagogy* 22, 647–660. doi: 10.1080/17408989.2017.1294678

Oslin, J., Mitchell, S., and Griffin, L. (1998). The game performance assessment instrucment (gpai): development and preliminary validation. *J. Teach. Phys. Educ.* 17, 231–243. doi: 10.1123/jtpe.17.2.231

Pankhurst, A., Collins, D., and Macnamara, A. (2013). Talent development: linking the stakeholders to the process. *J. Sports Sci.* 31, 370–380. doi: 10.1080/02640414.2012.733821

Parrington, L., Ball, K., and MacMahon, C. (2013). Game-based analysis of handballing in Australian football. *Int. J. Perform. Anal. Sport* 13, 759–772. doi: 10.1080/24748668.2013.11868687

Pazo Haro, C., Saenz-Lopez Bunuel, P., and Fradua Uriondo, L. (2012). Influence of sport context on training elite soccer players. *Rev. Psicol. Deporte* 21, 291–299.

Pearson, D. T., Naughton, G. A., and Torode, M. (2006). Predictability of physiological testing and the role of maturation in talent identification for adolescent team sports. *J. Sci. Med. Sport* 9, 277–287. doi: 10.1016/j.jsams.2006.05.020

Pinder, R. A., Davids, K., Renshaw, I., and Araujo, D. (2011). Representative learning design and functionality of research and practice in sport. *J. Sport Exerc. Psychol.* 33, 146–155. doi: 10.1123/jsep.33.1.146

Pinder, R. A., Headrick, J., and Oudejans, R. (2015). "Issues and challenges in developing representative tasks in sport," in *The Routledge Handbook of Sports Expertise*, 2nd Edn, eds J. Baker and D. Farrow (London: Routledge), 269–281.

Pinder, R. A., Renshaw, I., and Davids, K. (2013). The role of representative design in talent development: a comment on "Talent identification and promotion programmes of Olympic athletes". *J. Sports Sci.* 31, 803–806. doi: 10.1080/02640414.2012.718090

Pyne, D. B., Gardner, A. S., Sheehan, K., and Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *J. Sci. Med. Sport* 8, 321–332. doi: 10.1016/S1440-2440(05)80043-X

Renshaw, I., Oldham, A., Davids, K., and Golds, T. (2007). Changing ecological constraints of practice alters coordination of dynamic. *Eur. J. Sport Sci.* 7, 157–167. doi: 10.1080/17461390701643026

Robertson, S., Back, N., and Bartlett, J. D. (2015). Explaining match outcome in elite Australian rules football using team performance indicators. *J. Sports Sci.* 34, 637–644. doi: 10.1080/02640414.2015.1066026

Robertson, S. J., Burnett, A. F., and Cochrane, J. (2014). Tests examining skill outcomes in sport: a systematic review of measurement properties and feasibility. *Sports Med.* 44, 501–518. doi: 10.1007/s40279-013-0131-0

Robinson, K., Baker, J., Wattie, N., and Schorer, J. (2018). Talent identification in sport: a systematic review of 25 years of research. *Sports Med.* 48, 97–109.

Roca, A., and Williams, A. M. (2016). Expertise and the interaction between different perceptual-cognitive skills: implications for testing and training. *Front. Psychol.* 7:792. doi: 10.3389/fpsyg.2016.00792

Royal, K. A., Farrow, D., Mujika, I., Halson, S. L., Pyne, D., and Abernethy, B. (2006). The effects of fatigue on decision making and shooting skill performance in water polo players. *J. Sports Sci.* 24, 807–815. doi: 10.1080/02640410500188928

Sampaio, J., and Macas, V. (2012). Measuring tactical behaviour in football. *Int. J. Sports Med.* 33, 395–401. doi: 10.1055/s-0031-1301320

Sarmento, H., Anguera, M. T., Pereira, A., and Araujo, D. (2018). Talent identification and development in male football: a systematic review. *Sports Med.* 48, 907–931. doi: 10.1007/s40279-017-0851-7

Shim, J., Carlton, L. G., Chow, J. W., and Chae, W. S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *J. Mot. Behav.* 37, 164–175. doi: 10.3200/JMBR.37.2.164-175

Simonton, D. (1999). Talent and its development: an emergenic and epigenetic model. *Psychol. Rev.* 106, 435–457. doi: 10.1037/0033-295X.106.3.435

Slade, D. (2015). Do the structures used by international hockey coaches for practising field-goal shooting reflect game centred learning within a representative learning design? *Int. J. Sport Sci. Coach.* 10, 655–668. doi: 10.1260/1747-9541.10.4.655

Stoffregen, T., Bardy, B., Smart, L., and Pagulayan, R. (2003). "On the nature and evaluation of fidelity in virtual environments," in *Virtual and Adaptive Environments: Applications, Implications, and Human Performance Issues*, eds L. J. Hettinger and M. W. Haas (Mahwah, NJ: Lawrence Erlbaum Associates).

Sullivan, C., Bilsborough, J. C., Cianciosi, M., Hocking, J., Cordy, J. T., and Coutts, A. J. (2014a). Factors affecting match performance in professional Australian football. *Int. J. Sports Physiol. Perform.* 9, 561–566. doi: 10.1123/ijspp.2013-0183

Sullivan, C., Bilsborough, J. C., Cianciosi, M., Hocking, J., Cordy, J. T., and Coutts, A. J. (2014b). Match score affects activity profile and skill performance in professional Australian football players. *J. Sci. Med. Sport* 17, 326–331. doi: 10.1016/j.jsams.2013.05.001

Tangalos, C., Robertson, S., Spittle, M., and Gastin, P. B. (2015). Predictors of individual player match performance in junior Australian football. *Int. J. Sports Physiol. Perform.* 10, 853–859. doi: 10.1123/ijspp.2014-0428

Travassos, B., Araujo, D., Davids, K., Vilar, L., Esteves, P., and Correia, V. (2012). Informational constraints shape emergent functional behaviors during performance of interceptive actions in team sports. *Psychol. Sport Exerc.* 13, 216–223. doi: 10.1016/j.psychsport.2011.11.009

Unnithan, V., White, J., Georgiou, A., Iga, J., and Drust, B. (2012). Talent identification in youth soccer. *J. Sports Sci.* 30, 1719–1726. doi: 10.1080/02640414.2012.731515

Vaeyens, R., Lenoir, M., Williams, A. M., and Philippaerts, R. M. (2008). Talent identification and development programmes in sport : current models and future directions. *Sports Med.* 38, 703–714. doi: 10.2165/00007256-200838090-00001

Veale, J. P., Pearce, A. J., and Carlson, J. S. (2010). The Yo-Yo intermittent recovery test (Level 1) to discriminate elite junior Australian football players. *J. Sci. Med. Sport* 13, 329–331. doi: 10.1016/j.jsams.2009.03.006

Veale, J. P., Pearce, A. J., Koehn, S., and Carlson, J. S. (2008). Performance and anthropometric characteristics of prospective elite junior Australian footballers: a case study in one junior team. *J. Sci. Med. Sport* 11, 227–230. doi: 10.1016/j.jsams.2006.12.119

Williams, A. M., and Reilly, T. (2000). Talent identification and development in soccer. *J. Sports Sci.* 18, 657–667. doi: 10.1080/02640410050120041

Woods, C. T., Cripps, A., Hopper, L., and Joyce, C. (2017). A comparison of the physical and anthropometric qualities explanatory of talent in the elite junior Australian football development pathway. *J. Sci. Med. Sport* 20, 684–688. doi: 10.1016/j.jsams.2016.11.002

Woods, C. T., Joyce, C., and Robertson, S. (2015a). What are talent scouts actually identifying? Investigating the physical and technical skill match activity profiles of drafted and non-drafted U18 Australian footballers. *J. Sci. Med. Sport* 19, 419–423. doi: 10.1016/j.jsams.2015.04.013

Woods, C. T., Raynor, J. A., Bruce, L., and McDonald, Z. (2015b). The use of skill tests to predict status in junior Australian football. *J. Sports Sci.* 33, 1132–1140. doi: 10.1080/02640414.2014.986501

Woods, C. T., Veale, J., Fransen, J., Robertson, S., and Collier, N. F. (2018). Classification of playing position in elite junior Australian football using technical skill indicators. *J. Sports Sci.* 36, 97–103. doi: 10.1080/02640414.2017.1282621

Woods, C. T., Veale, J. P., Collier, N., and Robertson, S. (2016). The use of player physical and technical skill match activity profiles to predict position in the Australian football league draft. *J. Sports Sci.* 35, 325–330. doi: 10.1080/02640414.2016.1164334

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Long-Term Analysis of Elite Basketball Players' Game-Related Statistics Throughout Their Careers

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The aim of the present study was to analyze the changes of game-related statistics in expert players across their whole sports careers. From an initial sample including 252 professional basketball players competing in Spanish first division basketball league (ACB) in the 2017–2018 season, 22 met the inclusion criteria. The following game-related statistics were studied: average points, assist, rebounds (all normalized by minute played), 3-point field goals percentage, 2-point field goals percentage, and free throws percentage per season. Each variable was individually investigated with a customized excel spreadsheet assessing individual variations and career trends were calculated. The results showed a positive trend in most of the investigated players in assists (91% of cases) and free throw percentages (73% of cases). Similar percentages of positive and negative trends were observed for all the other game-related statistics (range: 41–59% for negative and positive, respectively). In conclusion, an increase in assist and free throw performance was shown in the investigated players across their playing career. This information is essential for basketball coaches suggesting the use of most experienced players in the final moments of the game.

Keywords: evolution, statistics, tendencies, career, team sports, professional

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INTRODUCTION

Basketball is a team sport characterized by the execution of series of skills in multiple situations occurring across the game. In particular, game-related statistics are fundamental and their level might depend on the players' characteristics and training experience. Most of the game related statistics depends on multifactorial variables (i.e., offensive and defensive tactics) determining a complex dynamic system during games, which is difficult to control in its totality. The use of performance analysis in sport with the determination of the most important game related statistics during the game aims to improve the team performance, increasing the knowledge of the performance of each player. Specifically, game-related statistics are key tools for basketball coaches providing reliable information about teams' performance such as those distinguishing between successful and unsuccessful teams. Previous investigations widely studied the game-related statistics mostly assessing team performance in order to determine the most valuable players and the importance of certain positions such as guards, forward and centers (e.g., Sampaio et al., 2006a), to evaluate the impact of rule changes (e.g.; Gómez et al., 2006a; Ibáñez et al., 2018), the effect of home advantage (e.g.; Carron et al., 2005; Pollard, 2008; Watkins, 2013), the importance of starters and bench players regarding their contribution to the game (e.g.; Sampaio et al., 2006b), the scoring strategies differentiating between winning and losing teams in women's basketball FIBA Eurobasket (e.g.; Conte and Lukonaitiene, 2018). It is important to note that in basketball several game related statistics have been used, while only some of them were deemed fundamental. Previous discriminant analyses quantitatively determined the team performance indicators (TPI), identified as a variable able to define the most important aspect of performance (Hughes and Bartlett, 2002) and compare different leagues (Sampaio and Leite, 2013), which most affect the game outcome (Gomez et al., 2008; Ibánez et al., 2008). In particular, Yu et al. (2008), established a list of the most influential TPI's (Technical Performance Indices) such as points per game (PPG), field goals made (FGM), rebounds, assists, turnovers, blocks, fouls, and steals. Sampaio et al. (2013) included also free throws as an important technical performance indicator. The TPIs with the most impact on the outcome of a season in Spanish first division (ACB) teams were shooting percentage (both 2-point and 3-point percentage), assists and rebounds (García et al., 2013; Gómez et al., 2008). However, to the best of our knowledge, no previous investigations assessed players' individual game related statistics across a long period of time. Indeed, players' experience might play a fundamental role in improving players' game related statistics effectiveness. Therefore, studies addressing this topic are warranted.

The performance of a player across his career might play a fundamental role in distinguishing between elite and non-elite players. Indeed, acquiring playing experience, players could have a better performance due to the demand of basketball game to perform complex actions that require high anticipatory skills in difficult situations. Indeed, these high anticipatory skills can be translated into scoring and passing related variables concerning about game-related statistics (Sampaio et al., 2015), and therefore they become an important variable deeming further analysis in basketball. In fact, elite players perceive better their environmental information and are capable of adapting their behavior accordingly and consequently perform better compared to other non-elite players (Aglioti et al., 2008). Therefore, playing experience might be essential in increasing players' anticipatory skills and consequently their game performance.

It has been previously showed that performance slowly decrease after reaching the peak period of the player career (Baker et al., 2013). In basketball, Baker et al. (2013), found that the typical basketball career lasts about 11 years, with the longest career studied being 23 years of playing at an elite level. However, it is not clear the performance changes across players career, and their trend (i.e., positive or negative) calling for further studies in this area. Therefore, the aim of this study was to descriptively analyze TPI changes throughout the career of expert basketball players, assessing the possible performance trend.

MATERIALS AND METHODS

Participants

From an initial sample of 252 professional basketball players competing in ACB, 22 players (9 backcourt and 13 frontcourt) were selected for this study based on the following inclusion criteria determined by a group of experts, who were identified according to Swann et al. (2015) guidelines: (a) male players, currently playing in the ACB league in the season 2017–2018; (b) to have a minimum playing experience of 10 years (including only season in which they effectively played) in the first division of any country with at least an average of 25% of number of games and minutes played per season; (c) to possess a minimum of 5 years playing experience in first division of any league amongst the top 30 countries in the FIBA Ranking (at February 28, 2018); (d) to have played at least 75% of their professional careers in any country's first division league, consequently no years played in lower division leagues were analyzed. The aim of these criteria was to ensure the highest quality of the sample for expert players with a solid number of games and minutes played each season (Swann et al., 2015).

Procedure

The databases used to obtain the game related statistics of each season for the studied players were the ACB official web page[1] for any season played in the ACB league, and the RealGM website[2], or the official ACB guide released by the Spanish Basketball Association for any season played outside Spain. These databases are normally used in studies related with basketball, and basketball statistics and are considered valid and reliable (Gómez et al., 2018).

The following game-related statistics for each season were recorded and analyzed: average points, assist, rebounds, 3-point field goals percentage, 2-point field goals percentage and free throws percentage per season. The variable point, assists and rebounds were normalized by minute played with the following formula (example for points scored: mean seasonal points scored/mean seasonal minute played *40 min). All the data for these game-related statistics, for every season and every player included in this study were storage in a database and once they were used for the statistical analysis.

Statistical Analysis

All statistical analyses were performed with a customized excel spreadsheet specifically developed to monitor individual changes and trends in a rigorous quantitative way (Hopkins, 2017). Recently, this excel spreadsheet has been adopted to assess individual changes in team sports (Siahkouhian and Khodadadi, 2013; Loturco et al., 2017; Colyer et al., 2018; Hurst et al., 2018) and specifically in basketball (Pliauga et al., 2018). This statistics approach could be used as a possible alternative to previously used methodologies such as the ANOVA factor (Yu et al., 2008) or the Jonckheere–Terpstra test (Leite and Sampaio, 2012). The individual trends across playing career for each investigated player were then quantified and the percentage of players documenting a positive, negative or steady (when the result is zero) slope were calculated using the following formula $y = m \cdot x + n$. **Figures 1–6** are an example of the individual points and trendlines obtained via the Hopkins spreadsheet and that were later analyzed.

[1] http://www.acb.com
[2] https://basketball.realgm.com

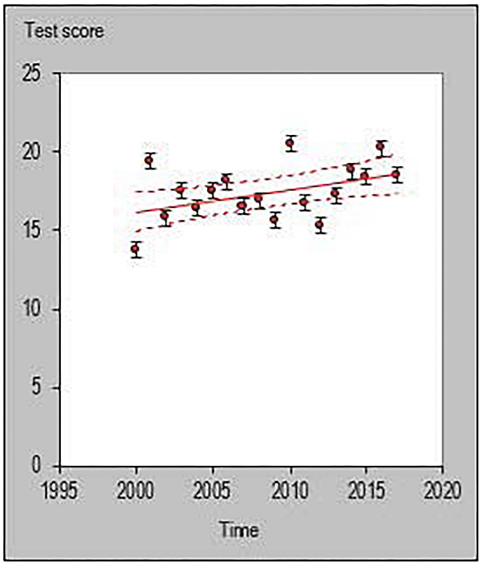

FIGURE 1 | Individual trend of one participant for average points per season normalized by minute.

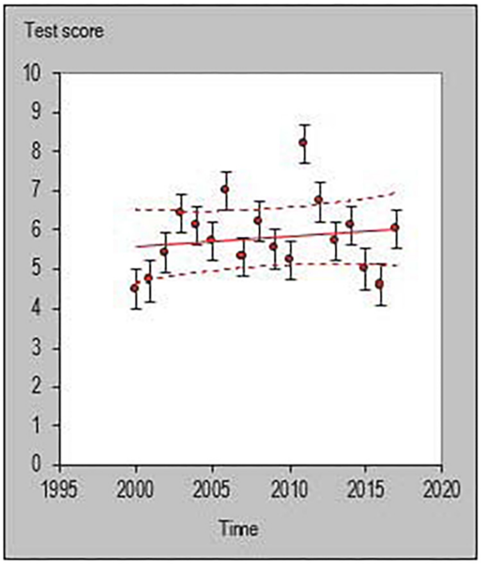

FIGURE 2 | Individual trend of one participant for average rebounds per season normalized by minute.

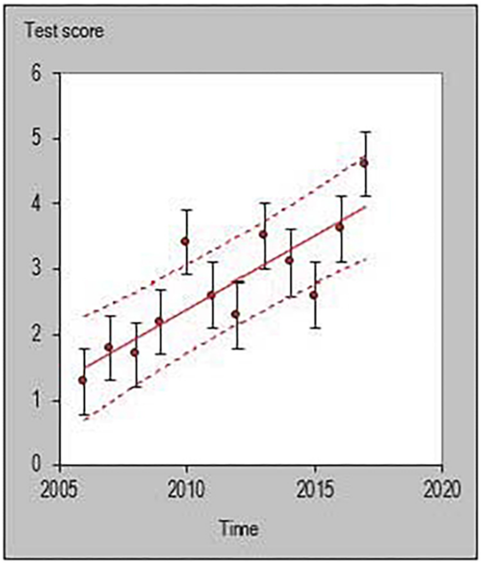

FIGURE 3 | Individual trend of one participant for average assists per season normalized by minute.

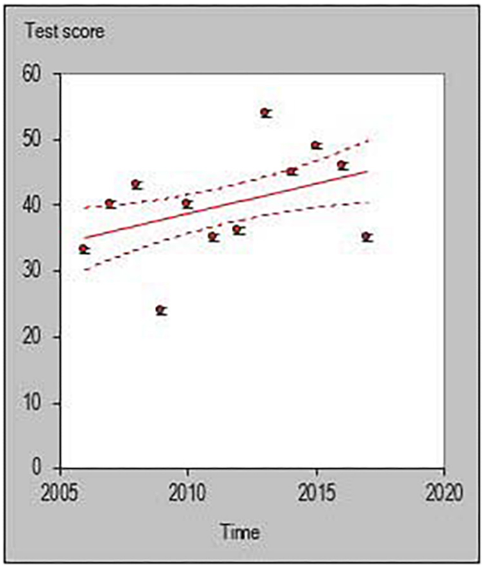

FIGURE 4 | Individual trend of one participant for 3-point percentage per season.

RESULTS

The mean slope for each performance indicator and the number of cases in which the slope was positive, steady, or negative are shown in **Table 1**. Results revealed that most of the players have a positive trend in assists (91% of the cases) free throws (73% of the cases), and 3-point percentage although with a lower value (59%). Conversely, there were no differences of positive and negative trends reported for the other investigated parameters (**Table 1**).

DISCUSSION

The aim of this study was to analyze the trends TPIs throughout the career of expert basketball players. The results revealed that assists and free throws were the two TPIs mostly showing a positive trend during players' careers. Specifically, the 91% of the studied players have a positive tendency in assists, with a mean slope of 0.15, and 73% of them have a positive tendency in free throws, with a mean slope of 0.95. Also, 59% of the players increase their 3-point

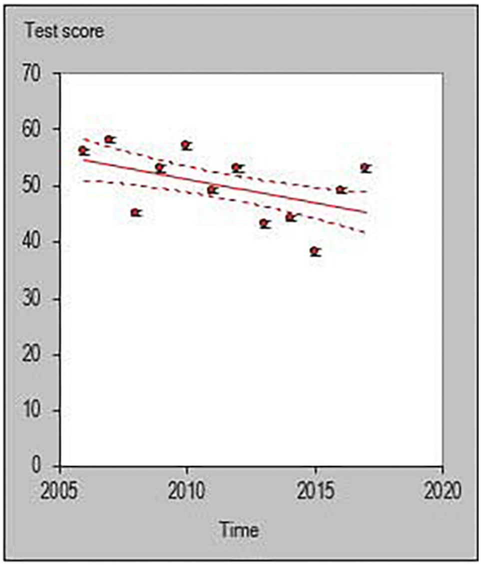

FIGURE 5 | Individual trend of one participant for 2-point percentage per season.

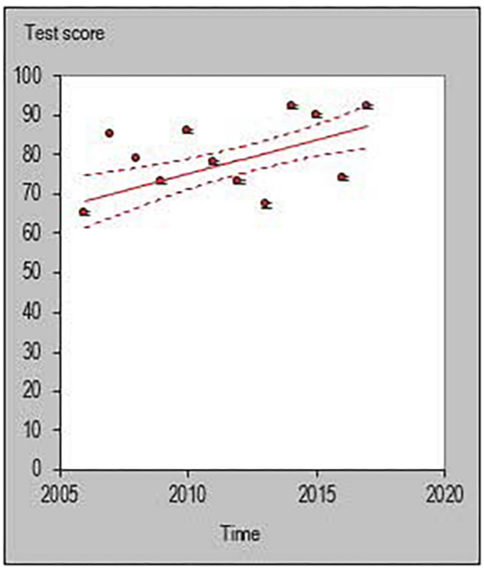

FIGURE 6 | Individual trend of one participant for free throw percentage per season.

TABLE 1 | Mean slope and number of cases of each variable.

	Expert players (*N* = 22)				
	Positive	**Mean slope**	**Steady**	**Negative**	**Mean slope**
Points	10	0,24	0	12	−0,37
Assists	20	0,15	1	1	−0,1
Rebounds	10	0,12	0	12	−0,07
3-point %	13	0,86	1	8	−0,53
2-point %	10	0,37	0	12	−0,49
Free throw %	16	0,95	0	6	−0,35

percentage, but this result might have been influenced by the fact that more frontcourt than backcourt players met our inclusion criteria.

Basketball is a sport where situations change quickly and continuously as a result of the combination of factors such as the position of opponents in the field and their tactical behavior, the position of the ball and the timing of the offensive movements (Altavilla and Raiola, 2014). Therefore, players are required to decide an appropriate response with a proper timing and executing it in a correct spacing. Often, players are subject to defensive pressure and the more skilled and experienced players might be able to anticipate events and perform unhurried actions as a result of their improved ability to "read the game" (Sampaio et al., 2004). In this context, executing a successful pass (i.e., assist) assume a fundamental importance in basketball. Indeed, when analyzing the mechanism of this technical action, the assist requires a combination of good decision making in court, coordination, anticipation, timing, and a good execution (Melnick, 2001; Gómez et al., 2006b). Previous research demonstrated that assists and free throw percentage are two of the most factors to win a game (Dias, 2007; Gómez and Lorenzo, 2007; Sampaio et al., 2015). Moreover, Sampaio et al. (2004), suggested that assists are indicators of players' maturity and experience, increasing in number as the player gets a better ability to read the game due to the years of playing experience. The results of our investigation highlighted supporting results, since most of the investigated players increased their assist performance across their playing career. This information seems essential for basketball coaches, who can rely on the performance of more experienced basketball players characterized by a better tactical awareness in order to execute successful passes and increase the scoring possibilities during the game. Indeed, Melnick (2001) showed a positive correlation between number of assists of a team and a better win-loss record through a season.

Free throws have also been demonstrated to be performance indicators differentiating between winning and losing teams in particular in close games (Ibánez et al., 2008; Conte et al., 2018; Gómez et al., 2018). Therefore, it was expected that players increasing their experience and possibly assuming a leadership and fundamental role in their team would increase their free throw performance during their career. Accordingly, our results demonstrated an increased trend across players' career for free throws and therefore possibly increasing their teams' possibility to be successful. In this sense, experience accumulated in games and practices is the most crucial factor for developing expertise in one aspect (Gómez et al., 2018). An increase in the percentages of free throws can be associated with the fact that players have already mastered the shooting during their years of training. Interestingly, a previous investigation showed that free throws shooting trajectories are more efficient and possess a lower variability in more experienced players compared to less experienced players (Button et al., 2003).

The practical application of our result is that coaches should favor the participation of most experienced players in last minutes of close games, when usually there are higher number of fouls generating free throws opportunities.

Other variables such as points, rebounds, and 2-point percentage did not show any trend increase across the players' career. A possible reason for this finding is that these variables might be more influenced by physical factors (i.e., strength, power, and fitness), which showed a decrease during the lifespan (Horton et al., 2008). Even though experienced players compensate this decrease in their physical abilities with a better understanding of the games' tactical aspects, better timing and spacing and better decision-making abilities, it seems not enough to show a positive trend according to the results of our investigation.

Although this investigation provides basketball coaches with useful information, some limitations should be mentioned. Firstly, the results might have been influenced by some confounding factors such as injuries across the season, the playing status (i.e., starting vs. bench players), economical aspects such as players' contracts and players and/or coaching staffs changing teams during investigated period. Therefore, future studies are warranted in order to overcome these limitations possibly controlling these factors. However, to the best of our knowledge, this investigation provides the first evidence about the individual trend in players' performance across their playing career and notably increase the knowledge in this field. Moreover, further studies should be designed in order to assess players' individual season-by-season changes across their playing career.

CONCLUSION

The results of this investigation suggest that as the players acquire years of experience in first division elite teams, their assists per game and free throw percentage increase. Conversely, other game-related statistics such as points, rebounds, 3-point percentage, and 2-point percentage showed both positive and negative trends in the investigated players resulting in a high between players variability. Finally, further research is required in this field using an individualized approach to increase the knowledge about players' performance across their playing career.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

Aglioti, S., Cesari, P., Romani, M., and Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nat. Neurosci.* 11, 1109–1116. doi: 10.1038/nn.2182

Altavilla, G., and Raiola, G. (2014). Global vision to understand the game situations in modern basketball. *J. Phys. Educ. Sport* 14, 493–496.

Baker, J., Koz, D., Kungl, A. M., Fraser-Thomas, J., and Schorer, J. (2013). Staying at the top: Playing position and performance affect career length in professional sport. *High Ability Stud.* 24, 63–76. doi: 10.1080/13598139.2012.738325

Button, C., Macleod, M., Sanders, R., and Coleman, S. (2003). Examining movement variability in the basketball free-throw action at different skill levels. *Res. Q. Exerc. Sport* 74, 257–269. doi: 10.1080/02701367.2003.10609090

Carron, A. V., Loughhead, T. M., and Bray, S. R. (2005). The home advantage in sport competitions: Courneya and Carron's (1992) conceptual framework a decade later. *J. Sports Sci.* 23, 395–407. doi: 10.1080/02640410400021542

Colyer, S. L., Stokes, K. A., Bilzon, J., Holdcroft, D., and Salo, A. I. T. (2018). The effect of altering loading distance on skeleton start performance: is higher pre-load velocity always beneficial? *J. Sports Sci.* 36, 1930–1936. doi: 10.1080/02640414.2018.1426352

Conte, D., and Lukonaitiene, I. (2018). Scoring Strategies Differentiating between Winning and Losing Teams during FIBA EuroBasket Women 2017. *Sports* 6:50. doi: 10.3390/sports6020050

Conte, D., Tessitore, A., Gjullin, A., Mackinnon, D., Lupo, C., and Favero, T. (2018). Investigating the game-related statistics and tactical profile in NCAA division I men's basketball games. *Biol. Sport* 35, 137–143. doi: 10.5114/biolsport.2018.71602

Dias, J. M. (2007). The stats value for winning in the world basketball championship for men 2006. *Fit. Perform.* 6, 57–61. doi: 10.3900/fpj.6.1.57.e

García, J., Ibáñez, S. J., Martínez, R., Leite, N., and Sampaio, J. (2013). Identifying Basketball Performance Indicators in Regular Season and Playoff Games. *J. Hum. Kinet.* 36, 163–170. doi: 10.2478/hukin-2013-0016

Gómez, M. A., Avugos, S., Oñoro, M. A., Lorenzo, A., and Bar-Eli, M. (2018). Shaq is not alone: free-throws in the final moments of a basketball game. *J. Hum. Kinet.* 62, 135–144. doi: 10.1515/hukin-2017-0165

Gómez, M. A., and Lorenzo, A. (2007). Análisis discriminante de las estadísticas de juego entre bases, aleros y pívots en baloncesto masculino. *Apunts* 87, 86–92.

Gómez, M. A., Lorenzo, A., Barakat, R., Ortega, E., and Palao, J. M. (2008). Differencesin game-related statistics of basketball performance between men's winning and losing teams according to game location. *Percept. Mot. Skills* 106, 98–107. doi: 10.2466/pms.106.1.43-50

Gómez, M. A., Lorenzo, A., Sampaio, J., and Ibáñez, S. J. (2006a). Differences in game-related statistics between winning and losing teams in women's basketball. *J. Hum. Mov. Stud.* 51, 357–369.

Gómez, M. A., Tsamourtzis, E., and Lorenzo, A. (2006b). Defensive systems in basketball ball possessions. *Int. J. Perform. Anal. Sport* 6, 98–107. doi: 10.1080/02640414.2013.792942

Gomez, M. A., Lorenzo, A., Sampaio, J., Ibanez, S. J., and Ortega, E. (2008). Game related statistics that discriminated winning and losing teams from the Spanish men's professional basketball teams. *Coll. Antropol.* 32, 451–456.

Hopkins, W. G. (2017). A Spreadsheet for Monitoring an Individual's Changes and Trend. *Sportscience* 21, 5–9.

Horton, S., Baker, J., and Schorer, J. (2008). Expertise and aging: maintaining skills through the lifespan. *Euro. Rev. Aging Phys. Act.* 5, 89–96. doi: 10.1007/s11556-008-0034-5

Hughes, M. D., and Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *J. Sports Sci.* 20, 739–754. doi: 10.1080/026404102320675602

Hurst, C., Batterham, A. M., Weston, K. L., and Weston, M. (2018). Short and long-term reliability of leg extensor power measurement in middle-aged and older adults. *J. Sports Sci.* 36, 970–977. doi: 10.1080/02640414.2017.1346820

Ibáñez, S. J., García-Rubio, J., Gómez, M. A., and González-Espinosa, S. (2018). The Impact of Rule Modifications on Elite Basketball Teams' Performance. *J. Hum. Kinet.* 64, 181–193. doi: 10.1515/hukin-2017-0193

Ibánez, S. J., Sampaio, J., Feu, S., Lorenzo, A., Gómez, M. A., and Ortega, E. (2008). Basketball game related statistics that discriminate between team's season-long success. *Euro. J. Sport Sci.* 8, 369–372. doi: 10.1080/17461390802261470

Leite, N. M. C., and Sampaio, J. E. (2012). Long-Term Athletic Development across Different Age Groups and Gender from Portuguese Basketball Players. *Int. J. Sports Sci. Coach.* 7, 285–300. doi: 10.1260/1747-9541.7.2.285

Loturco, I., Pereira, L. A., Kobal, R., Kitamura, K., Cal Abad, C. C., Marques, G., et al. (2017). Validity and Usability of a New System for Measuring and Monitoring Variations in Vertical Jump Performance. *J. Strength Cond. Res.* 31, 2579–2585. doi: 10.1519/JSC.0000000000002086

Melnick, M. J. (2001). Relationship between team assists and win-loss record in the National Basketball Association. *Percept. Mot. Skills* 92, 595–602. doi: 10.2466/pms.2001.92.2.595

Pliauga, V., Lukonaitiene, I., Kamandulis, S., Skurvydas, A., Sakalauskas, R., Scanlan, A., et al. (2018). The effect of block and traditional periodization training models on jump and sprint performance in collegiate basketball players. *Biol. Sport* 35, 373–382. doi: 10.5114/biolsport.2018.78058

Pollard, R. (2008). Home Advantage in football: a current review of an unsolved puzzle. *Open Sports Sci. J.* 1, 12–14. doi: 10.2174/1875399X00801010012

Sampaio, J., Ibáñez, S., and Lorenzo, A. (2013). "Basketball," in *Routledge Handbook of Sport Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (London: Routledge), 357–366.

Sampaio, J., Ibáñez, S. J., and Feu, S. (2004). Discriminative power of basketball game-related statistics by level of competition and sex. *Percept. Mot. Skills* 99, 1231–1238. doi: 10.2466/pms.99.3f.1231-1238

Sampaio, J., Ibáñez, S., Lorenzo, A., and Gomez, M. (2006a). Discriminative game related statistics between basketball starters and nonstarters when related to team quality and game outcome. *Percept. Mot. Skills* 103, 486–494.

Sampaio, J., Janeira, M., Ibáñez, S., and Lorenzo, A. (2006b). Discriminant analysis of game-related statistics between basketball guards, forwards and centres in three professional leagues. *Euro. J. Sport Sci.* 6, 173–178. doi: 10.1080/17461390600676200

Sampaio, J., and Leite, N. (2013). "Performance Indicators in Game Sports," in *Routledge Handbook of Sports Performance Analysis (1st ed.)*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (New York, NY: Routledge Handbooks).

Sampaio, J., McGarry, T., Calleja-González, J., Jiménez Sáiz, S., Schelling i del Alcázar, X., and Balciunas, M. (2015). Exploring Game Performance in the National Basketball Association Using Player Tracking Data. *PLoS One* 10:e0132894. doi: 10.1371/journal.pone.0132894

Siahkouhian, M., and Khodadadi, D. (2013). Narita target heart rate equation underestimates the predicted adequate exercise level in sedentary young boys. *Asian J. Sports Med.* 4, 175–180. doi: 10.5812/asjsm.34255

Swann, C., Moran, A., and Piggott, D. (2015). Defining elite athletes: issues in the study of expert performance in sport psychology. *Psychol. Sport Exerc.* 16, 3–14. doi: 10.1016/J.PSYCHSPORT.2014.07.004

Watkins, P. (2013). Revisiting the Home Court Advantage in College Basketball. *Int. J. Sport Soc.* 3, 33–42. doi: 10.18848/2152-7857/CGP/v03i01/53892

Yu, K., Su, Z., and Zhuang, R. (2008). An Exploratory Study of Long-Term Performance Evaluation for Elite Basketball Players. *Int. J. Sports Sci. Eng.* 2, 195–203.

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Reproducibility and Validity of a Stroke Effectiveness Test in Table Tennis Based on the Temporal Game Structure

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Purpose: This study aimed to develop a stroke effectiveness test in table tennis based on the temporal game structure to assess the ball speed and ball placement of the players, with a purpose to analyze its reproducibility and validity.

Methods: Nineteen male table tennis players participated in this study. The test was performed twice during the first session and once during the second session to assess the intrasession and intersession reproducibility, respectively. Moreover, the test was examined on its ability to discriminate between regional (n = 10) and local performance-level (n = 9) players and on the relationship between the test results and the table tennis performance to assess the discriminant and concurrent validity, respectively. In general, the test consisted of 11 simulated rallies of 2–5 balls with the effort and rest ratio of 0.5, and focused on attack with offensive strokes at defensive balls delivered by a robot randomly between the left and right positions on the table.

Results: Ball speed, ball placement, and ball speed-ball placement index showed satisfactory reliability (ICC range 0.78–0.96, P < 0.05) and agreement (CV range 2.7–16.2%) outcomes. Additionally, the Bland–Altman plots show the systematic error of the analyses closer to 0, and that most values were within the limits of agreements. Concerning validity analyses, regional players had higher scores of ball placement (+51.3%; P = 0.01, ES = 1.33) and ball speed-ball placement index (+56.1%; P = 0.0009, ES = 1.87) as well as made fewer errors (–25.4%; P = 0.017, ES = 1.20) than local players. Moreover, ball placement (r = –0.79, P = 0.04), ball speed-ball placement index (r = –0.78, P = 0.04), and percentage error (r = 0.88, P = 0.01) presented a strong and significant correlation with table tennis performance. However, ball speed was slightly different between the regional than local players

(+1.7%; P = 0.78, ES = 0.13) and this variable was not related to table tennis performance (r = 0.32, P = 0.49).

Conclusion: Our findings show evidences that the test is reproducible. Moreover, discriminant and concurrent validity are confirmed for ball placement and ball speed-ball placement index.

Keywords: racket sports, sport-specific test, sport pedagogy, speed, accuracy, performance analysis

INTRODUCTION

Table tennis is an intermittent sport comprising periods of effort and rest (Lees, 2003). It is one of the fastest ball games in the world, where the player is required to use a body of competencies (e.g., technical, tactical, and physical skills) (Faber, 2016) within a finite time duration to play during each rally of the match (Sève et al., 2002; Suzuki and Yamamoto, 2015). In accordance with this, the match characteristics of table tennis should be used by coaches to plan teaching and training, aimed at achieving an optimal performance by the athletes (Sève et al., 2002; Zagatto et al., 2010; Kondric et al., 2013). Thus, it is relevant that the protocols used to test the table tennis players represent the table tennis match (Kondric et al., 2013). Herein, we address these issues and focus on the development of a newly technical test based on the temporal characteristics of the match.

Previous investigations have proposed several tests to evaluate the perceptual-motor skills (Faber et al., 2014a,b, 2015), aerobic and anaerobic parameters (Morel and Zagatto, 2008; Zagatto et al., 2008, 2011; Zagatto and Gobatto, 2012), and technical skills (Le Mansec et al., 2016) in table tennis players. Almost most of the tests for measuring physiological and technical skills were applied in a specific table tennis exercise (i.e., in an ecological task), their protocols were characterized by a continuous profile, with use of only forehand (FH) offensive strokes at balls sent by a robot at fixed areas of ball contact with the table. Zagatto et al. (Morel and Zagatto, 2008; Zagatto et al., 2008, 2011; Zagatto and Gobatto, 2012) developed a number of specific table tennis tests to assess physiological parameters, which in general comprised incremental (e.g., intensities incremented every 2–3 min – effort periods – interspersed with pauses of 30 s until voluntary exhaustion) and constant (e.g., 3-4 effort periods from 2 to 10 min, separated by a minimum break of 2 h) protocols. In these studies, balls were sent systematically at 2–4 fixed areas on the table. Moreover, Le Mansec et al. (2016) developed a technical test characterized by 45 continuous topspin strokes at balls sent every 3 s (2 min and 15 s of effort) in only one position to the center of the table.

However, table tennis is characterized by short rallies (3.4 s. on average) comprised few strokes (4.0 shots per rally on average), each stroke performed every 1.7 s. (35.3 shots per min on average), with longer pauses in between rallies (11.6 s. on average) (Zagatto et al., 2010; Leite et al., 2017). This sport includes a wide range of FH and backhand (BH) techniques performed at balls bounce in different playing surfaces over the table (Munivrana et al., 2015a,b). In addition, investigations show evidences the rally length is fairly consistent among players with different performance-level (3.2–3.6 s.) whereas rest period in between rallies is lower in regional players (7.0 s) than athletes at national (9.3 s) and elite (18.6 s) performance-level. It results in higher values of the effort and rest ratio (0.50) at regional in relation to national players (0.34) and considerably higher values than at international athletes (0.18) (Zagatto et al., 2010; Leite et al., 2017). A table tennis test based on all these aspects is relevant to evaluate players in match-like conditions, like we can see in other racket sports, as tennis (Vergauwen et al., 1998; Kolman et al., 2017). However, to our knowledge, no study purposes to develop a reliable and valid test that includes the aforementioned characteristics and evaluates stroke effectiveness in table tennis players.

Technical skills, mainly characterized by strokes, are the basis for the execution of adequate tactics in a given situation (Wang et al., 2013). Stroke may be evaluated based on the mechanical aspects of technique and how skills are performed (i.e., stroke analysis) as well as it may be assessed based on the outcomes of skills performed, irrespective of how correctly a skill has been performed (i.e., stroke effectiveness) (O'Donoghue et al., 2013). Ball velocity and placement have been used in tests applied to racket sports to examine stroke effectiveness (Vergauwen et al., 1998; Le Mansec et al., 2016; Kolman et al., 2017). Munivrana et al. (2015b) evidenced that the ball speed and ball placement are amongst the main basic tactical means for table tennis players realize their own tactical ideas during the match. These are recognized as important elements that the players must master to play the match successfully (Qun et al., 1992; Malagoli Lanzoni et al., 2011). Faster ball speeds may induce favorable conditions to win the rally, since it imposes lesser time for the opponent to react (Le Mansec et al., 2016). Moreover, players use the ball placement to avoid the opponent's preferred strokes (Malagoli Lanzoni et al., 2014), exploit opponent's weaknesses and to move the ball out of the opponents control. Ball speed and ball spin, that is often used during the strokes to increase the accuracy of ball placement, are interrelated and restricted each other (Qun et al., 1992). Indeed, the speed-accuracy trade-off hypothesis states that movements become less accurate the faster we performed them (Fitts, 1954). In accordance with this, a recent investigation calculated the ball speed–ball placement index and demonstrated that this index is relevant to discriminate the players with different levels of performance (Le Mansec et al., 2016).

On the basis of the aforementioned statement, this study aims to develop a stroke effectiveness test based on the temporal structure of table tennis matches that may be able to assess the abilities of the players to perform ball speed and ball placement, with a purpose to assess the reproducibility [i.e., the results of the test are consistent when the players perform the test repeatedly (Hopkins, 2000; De Vet et al., 2006)] and validity [i.e., the test measures what it purports to measure (Impellizzeri and Marcora, 2009)] of the test. Reproducibility and validity are the two most important attributes that warrant consideration in the evaluation of new instruments in sports science (Hopkins, 2000). We focus the development of the test applied to regional performance-level players in a tactical situation of offensive strokes performed at defensive balls.

MATERIALS AND METHODS

Participants

In total 19 male table tennis players participated in this study. Ten players were classified as the regional performance-level group (RP) according criteria proposed by Zagatto et al. (2010), which includes athletes that had more than 5 years of systematic and regular training, and that competed in regional and national tournaments. Regional players were recruited from the Southeastern region, Brazil [i.e., the region detected as the one with better conditions for athlete's development in Brazil (Tozetto et al., 2017)] via table tennis training centers, clubs, and coaches. Local-performance level group (LP) was composed of nine undergraduate students with low experience in table tennis and without participation in regional or national tournaments. **Table 1** presents the characteristics of each group. Regional players had significantly more years of table tennis experience ($P < 0.001$) and trained more hours per week ($P < 0.0001$) than local players. This study was carried out in accordance with the recommendations of "Ethics Research Committee of the University of Campinas" with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the "Ethics Research Committee of the University of Campinas (UNICAMP)" (n. 1.928.165/2017).

Research Design

First, the reproducibility was examined with 16 players performed a session of a sport-specific test (duration ∼18 min), which started with a training-phase of warm up to familiarize them with the procedure. Furthermore, each player had to undergo the testing-phase twice to assess the intrasession reproducibility, with an 8-min resting period in between. Of the 16 players initially evaluated, 12 participated in the second session to assess the intersession reproducibility, which also included the training and testing-phases. Both sessions were separated by time duration of 2–5 days. In the second part of the study, the validity of the test was evaluated. The test was examined on its ability to discriminate between regional (n = 10) and local performance-level (n = 9) players and on the relationship between the test results and the table tennis performance. Known-groups validity is one approach to examine the construct validity of a test when there is no "gold standard." For this purpose, the test is administered to two groups that are known to have different levels of the construct to confirm whether the hypothesized difference is reflected in the scores of the two groups (Davidson, 2014). This approach has been used in validity studies applied to table tennis (Faber et al., 2014a,b). Concerning concurrent validity, table tennis performance was evaluated as the ranking determined by simulated tournament among the subjects.

TABLE 1 | Demographic and racket grip for the regional (RP) and local (LP) performance-level groups.

	RP (N = 10)	LP (N = 9)	P Value
Age (years)	23.9 ± 1.8	24.3 ± 2.6	0.91
Height (cm)	176.9 ± 2.1	174.6 ± 3.3	0.54
Weight (kg)	79.8 ± 3.1	68.1 ± 5.7	0.08
Table Tennis Experience (years)	7.5 ± 0.9	2.2 ± 0.3	<0.001
Training volume (hours/week)	10.0 ± 0.9	3.2 ± 0.5	<0.001
Racket Grip (Penholder/Classical)	1/9	3/6	

Data are expressed as mean ± SEM.

Development of a Stroke Effectiveness Test Based on the Temporal Game Structure of Table Tennis Matches

Training-Phase

The training-phase comprised three steps. In the first step, athletes played 1 min of balls sent every 3 s in only one position to the center of the table. In the second step, athletes played eight rallies, each one comprised 2–5 balls sent by a robot. Rallies were delivered in a random order. Balls were sent every 1.1 s in only one position to the center of the table. The effort and pause ratio between rallies of 0.5 was used within this step. Finally, in the third step, athletes simulated the testing-phase. During the entire training-phase, the ball was delivered by the robot (Robo-Pong 2050, Newgy, Hendersonville, TN, United States) at 25 km/h with backspin, placing it from 100 to 120 cm away from the net, and the players were instructed to play with FH or BH offensive strokes. Each step of the training-phase was performed twice, and with 2–3 min of resting period between each trial.

Testing-Phase

The test aimed to simulate 11 rallies of a table tennis match. Each rally comprised 2–5 balls delivered by the robot (i.e., 4–10 shots per rally) at 25 km/h and frequency of 54 balls $\cdot$ min^{-1} (i.e., each ball was delivered at every 1.1 s). Players performed four rallies of two balls lasting 2.2 s each (∼36% of the test), four rallies of three balls lasting 3.3 s each (∼36% of the test), two rallies of four balls lasting 4.4 s each (∼18% of the test) and one rally of five balls lasting 5.5 s each (∼9% of the test); in total, 33 balls were delivered during the test. The rallies occurred in a random but programmed order (4, 2, 3, 3, 2, 5, 2, 4, 2, 3, 3 balls delivered), and the players were unaware of this order. The effort and pause ratio between rallies of 0.5 was used within the test. Temporal characteristics of the test were based on those found in regional table tennis players during the official matches. These authors reported 1–12 shots per rally; 14–75 shots $\cdot$ min^{-1}; 35.4% of the rallies lasting 1.5–2.5 s, 24.7% lasting 2.5–3.5 s, 15.6% lasting 3.5–4.5 s, 9% lasting 4.5–5.5 s; and the effort and rest ratio of 0.5. (Zagatto et al., 2010).

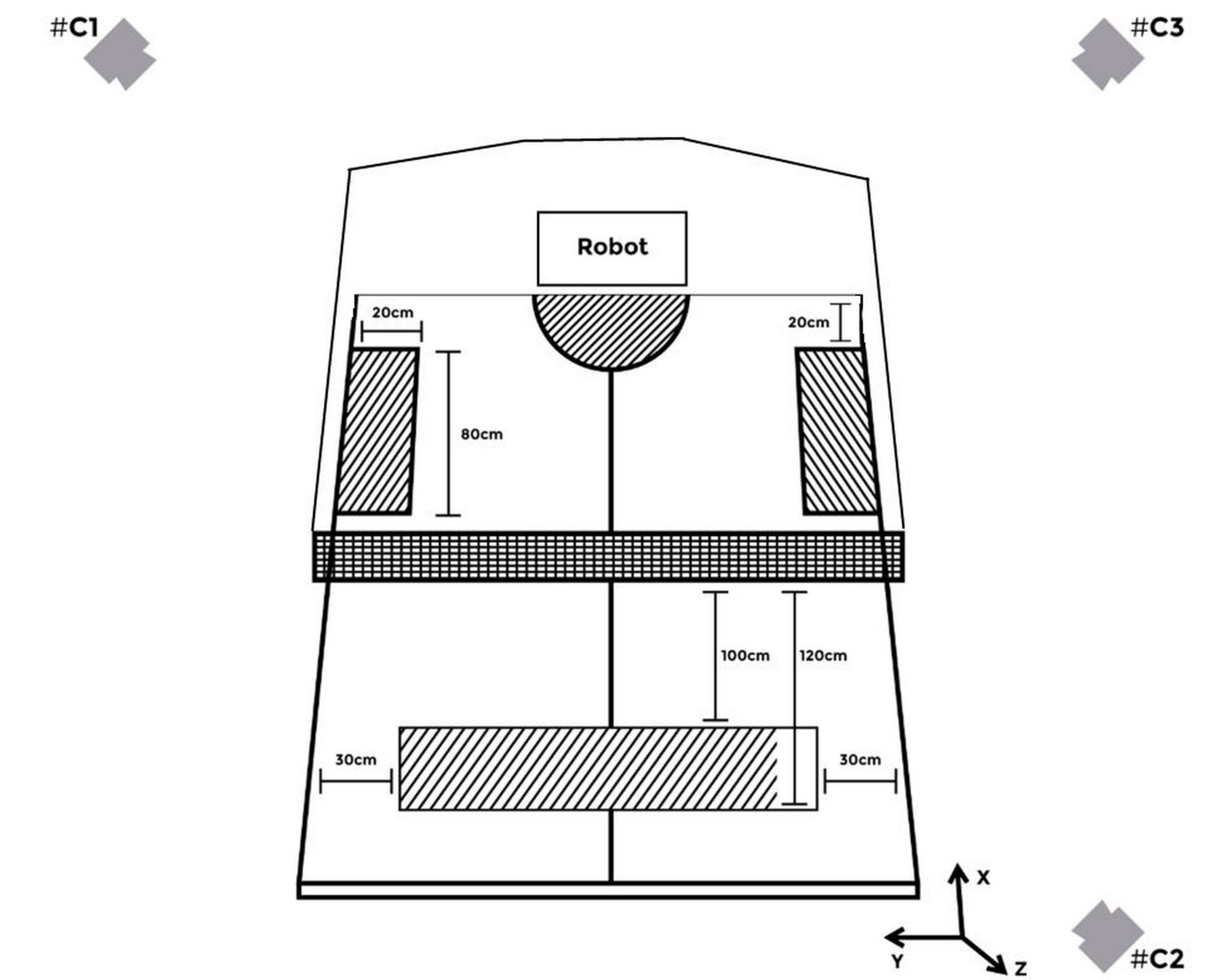

FIGURE 1 | Schematic of the top view of the experimental setup. Shaded areas closer to the robot correspond to the three targets that the players could to reach, and the shaded area the other side of the net corresponds to the target zone the balls was thrown by the robot. #C1 = camera 1, #C2 = camera 2, #C3 = camera 3.

The ball was delivered by the robot with backspin, placing it from 100 to 120 cm away from the net and from 30 cm away from the sides (right and left). Balls were thrown by the robot randomly between the left and right positions within this target zone. Players could play with FH or BH offensive strokes. The strokes were chosen by the players during the test. The three targets were in strategic locations, in accordance with previously proposed by Le Mansec et al. (2016). Two rectangular targets (80 cm length, 20 cm width) were positioned on the sides (right and left side of the robot) of the table, 20 cm from the edge of the table. The third target was a semicircle of 25 cm in diameter positioned at the center of the table and close to its edge (**Figure 1**). Players could hit the three targets in a sequence that they decided, with the aim to realize their own tactical ideas to win the rally during the test, as they would during an official match. The performance assessment (i.e., the accuracy score and the performance index (PI), as described further) was explained to the players before starting the test. During all tests, a playing context similar to those observed during official matches was maintained.

Data Collection and Processing

Three digital video cameras (Cassio EXFH25, 240 Hz) were positioned at 3 m height in order to cover the entire table and the movement of the athlete in the image view (**Figure 1**). The DVideo System (Campinas, Brazil) (Figueroa et al., 2008) was used for image calibration, ball tracking and 3D coordinate's reconstruction. The images were calibrated using 196 reference points with known coordinates, placed around the testing volume. A tridimensional orthogonal reference system was defined considering the x-axis to be horizontally positive at front of the athlete, y-axis to be horizontally positive to the left and z-axis to be vertically positive upward. The positions of the reference points were used to generate the calibration parameters for the cameras using the direct linear transformation method (Abdel-Aziz and Karara, 1971).

The position of the ball was tracked manually by previously trained operators. The ball was tracked in each frame from contact with the racket to contact with the table. The calibration parameters and the position of the ball in the video sequences were used to reconstruct the tridimensional coordinates of the ball. For data smoothing, a second order polynomial was adjusted to the ball's position using the MATLAB (2014R) environment. Moreover, the ball stroke velocity of successful shots (i.e., excluded all the shots that were hit out and into the net) was calculated right after the contact with the racket; thus, the average ball speed was calculated. The 3D position of each successful ball was projected on the table to identify the region of ball bounce on the table and to compute the accuracy score. The following procedure was used: when the ball reached the target, two points were granted; one point when the ball reached the table but did not touch the target and zero point when a fault was committed (Le Mansec et al., 2016). This procedure gave a score between 0 and 66 for each series. Finally, considering the ball speed–ball placement interrelation, a PI was calculated to link these two parameters with the following formula proposed by Le Mansec et al. (2016):

$$PI = average\ speed\ of\ the\ series \times accuracy\ score/100$$

Table Tennis Performance by Simulated Tournament

Table tennis performance was considered as the ranking estimated by means of a repechage tournament among the study players, which each athlete could lose one match and still be able to attain first place. The athlete was eliminated from the tournament after losing two matches. All table tennis matches were performed following the rules of the International Table Tennis Federation and played with a maximum of seven sets (the winner was required to win four-sets). The top three players were awarded trophies and medals.

Statistical Analysis

Normal distribution and homogeneity of the data were verified by the Shapiro–Wilk and Levene's tests, respectively. For the intra- and inter-operator reliability, the intraclass correlation (ICC) was used by evaluating the landing position of balls in one series by three operators (three times each operator). The reproducibility of the measurements was tested using intraclass correlation (ICC as two-way random model, absolute agreement), typical error (TE), smallest detectable difference (SDD), and coefficient of variation (CV) (Hopkins, 2000; De Vet et al., 2006). ICC of 0.70 or more was considered to be acceptable to prove the reliability of the test. TE, SDD, and CV were calculated as agreement parameters. Additionally, Bland–Altman analyses were also applied to provide a visual representation of measurement errors against true values (Bland and Altman, 1986). Discriminant validity was evaluated by comparing the scores on the ball speed, accuracy score, PI, and percentage error of the regional and local performance-level players using Student's t-test for independent groups. Effect size (ES) was also calculated to determine the magnitude of the difference between comparisons. The threshold adopted was: trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (0.80 and greater) (Cohen, 1992). The concurrent validity was investigated by correlating the ball speed, accuracy score, PI, and percentage error with the table tennis performance using the Spearman's correlation coefficient. Statistical significance was set at $P < 0.05$. Statistical procedures were carried out using IBM SPSS Statistics 24 for Windows (IBM Corp., Armonk, NY, United States) and GPOWER 3.1 software.

RESULTS

For the intra- and inter-operator analyses, ICC revealed a high reliability [0.9907–0.9997 ($P < 0.01$) and 0.9989–0.9999 ($P < 0.01$), respectively] for the evaluation of the landing position of the balls. **Tables 2**, **3** present the intrasession and intersession reproducibility outcomes, respectively. Ball speed, accuracy score and PI meet the criteria of an ICC > 0.70 for reliability. ICC's were high and significant for intrasession (0.78–0.96, $P < 0.01$) and intersession (0.78–0.94, $P < 0.05$) for all variables. The agreement parameters are also at an acceptable level for all variables, with CV ranged 2.7–16.2% for the intrasession and 6.6–14.5% for the intersession. Moreover, the Bland–Altman plots show the mean difference or systematic error of the intrasession and intersession analyses closer to 0 (ranged −0.5–0.7 and −0.8–0.9, respectively), and that most values were within the limits of agreements (**Figures 2**, **3** for intrasession and intersession, respectively).

The results of discriminant validity analyses are presented in **Table 4**. Ball speed of RP was slightly higher than LP (+1.7%); however, this difference was not significant (P > 0.05; ES < 0.19). On the other hand, significant higher values of accuracy score

TABLE 2 | Intrasession reproducibility outcomes for ball speed, accuracy score, and performance index of the table tennis players. (n = 16).

	S1	S2	ICC (*P*-value)	TE	SDD	CV
Ball speed (km/h)	43.1 ± 1.2	43.8 ± 1.1	0.96 (<0.001)	1.2	3.2	2.7
Accuracy score (/66)	21.7 ± 1.4	20.8 ± 1.5	0.82 (0.001)	3.3	9.1	15.0
Performance index	9.3 ± 0.6	9.1 ± 0.6	0.78 (0.004)	1.5	4.1	16.2

Data are expressed as mean ± SEM. Abbreviations: S1, first series of the first session; S2, second series of the first session; ICC, intraclass coefficient correlation; TE, typical error; SDD, smallest detectable difference; CV, coefficient of variation (%).

TABLE 3 | Intersession reproducibility outcomes for ball speed, accuracy score, and performance index of the table tennis players. (n = 12).

	S1	S3	ICC (*P*-value)	TE	SDD	CV
Ball speed (km/h)	42.7 ± 1.5	42.0 ± 1.2	0.78 (0.01)	2.8	7.7	6.6
Accuracy score (/66)	22.8 ± 1.5	23.3 ± 1.9	0.94 (<0.001)	2.1	5.9	9.3
Performance index	9.7 ± 0.6	9.8 ± 0.8	0.86 (0.002)	1.4	3.7	14.5

Data are expressed as mean ± SEM. Abbreviations: S1, first series of the first session; S3, first series of the second session; ICC, intraclass coefficient correlation; TE, typical error; SDD, smallest detectable difference; CV, coefficient of variation (%).

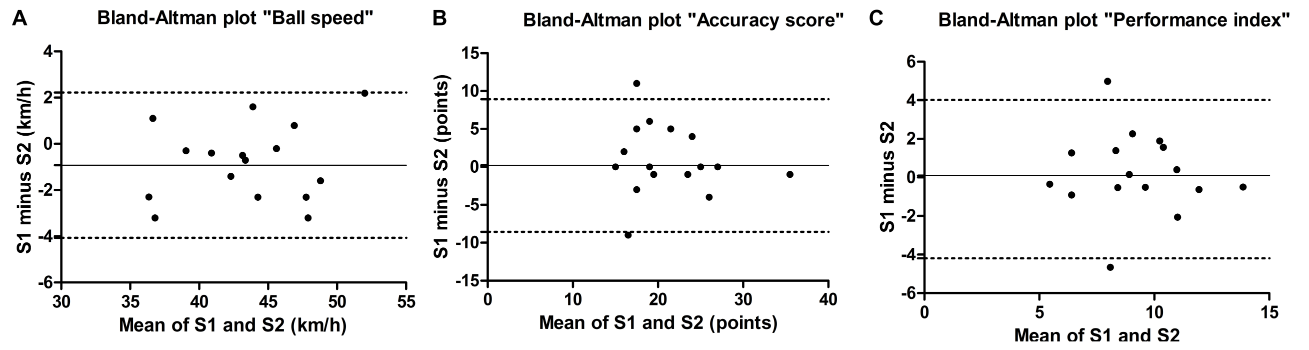

FIGURE 2 | Bland–Altman plots for **(A)** ball speed, **(B)** accuracy score, and **(C)** performance index. The continuous line represents the mean difference between the first series of the first session (S1) and the second series of the first session (S2). The dotted lines represent the 95% limits of agreement (*n* = 16).

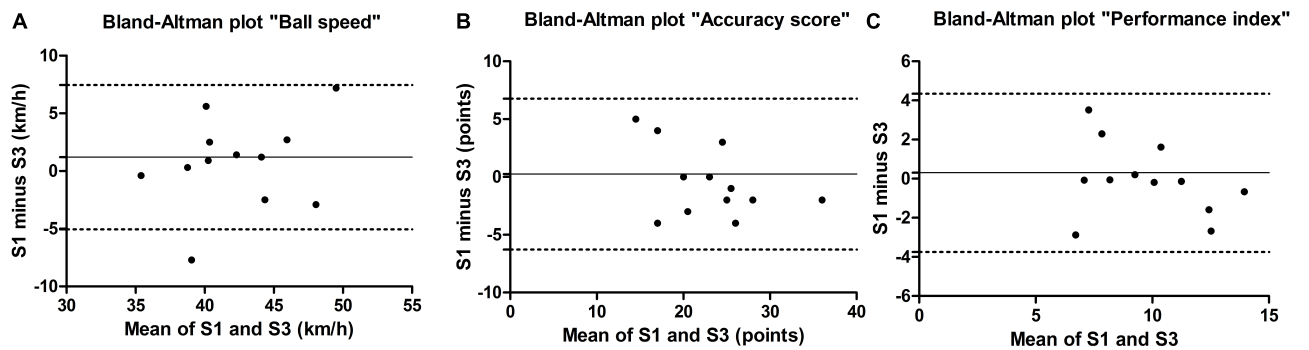

FIGURE 3 | Bland–Altman plots for **(A)** ball speed, **(B)** accuracy score, and **(C)** performance index. The continuous line represents the mean difference between the first series of the first session (S1) and the first series of the second session (S3). The dotted lines represent the 95% limits of agreement (*n* = 12).

(+51.3%) and PI (+56.1%) as well as lower percentage error (−25.4%) were found in RP compared to LP ($P < 0.05$). ES analysis confirmed a large magnitude of the difference between groups (ES > 0.80) for accuracy score, PI, and percentage errors. More specifically, RP reached the target zones significantly more often than LP (14.5 ± 3.3% for RP and 6.7 ± 1.2% for LP; P = 0.04; ES = 0.95). The right rectangle zone was 7-fold more reached in RP compared to LP (9.4 ± 3.8% for RP and 1.3 ± 0.9% for LP; P = 0.07; ES = 0.90). Percentage of the balls that reached the left rectangle (0.6 ± 0.4% for RP and 1.0 ± 0.7% for LP; P = 0.60; ES = 0.23) and semicircle (4.5 ± 1.0% for RP and 4.4 ± 1.4% for LP; P = 0.92; ES = 0.02) zones were similar between groups.

TABLE 4 | Ball speed, accuracy score, performance index for the regional (RP), and local (LP) performance-level groups.

	RP (*N* = 10)	LP (*N* = 9)	*P*-value	Effect Size
Ball speed (km/h)	45.8 ± 1.3	45.0 ± 2.6	0.78	0.13
Accuracy score (/66)	22.7 ± 2.0	15.0 ± 1.7	0.01	1.33
Performance index	10.2 ± 0.6	6.5 ± 0.6	0.0009	1.87
Percentage error (%)	45.5 ± 3.8	60.9 ± 4.6	0.017	1.20

Data are expressed as mean ± SEM.

In keeping with the above findings, the association between ball speed and table tennis performance was not significant (r = 0.32, P = 0.49); while, accuracy score (r = −0.79, P = 0.04), PI (r = −0.78, P = 0.04), and percentage error (r = 0.88, P = 0.01) presented a strong and significant correlation with table tennis performance (concurrent validity). This means that players with a high position at the simulated tournament tended to have a higher accuracy score and PI as well as a lower percentage error.

DISCUSSION

We aimed to develop a table tennis test of stroke effectiveness based on the temporal game structure to assess the ball speed and ball placement of the players, with a purpose to analyze its reproducibility and validity. Our main findings showed the proposed test was reproducible for all variables as well as presented a discriminative and concurrent validity for ball placement and ball velocity-ball placement index, providing promising results for monitoring the stroke effectiveness of the athletes in a tactical situation of offensive strokes performed at defensive balls.

The results for the intra- and inter-operator analyses showed evidence of an almost perfect reliability. Our specific-test was recorded with three cameras, thus the ball trajectory from the contact with the racket to the contact with the table (i.e., landing position) could be accurately registered. Although more complex, this robust methodology is an advantage compared to prior stroke performance test that used a radar system and a visual methodology to evaluate ball speed and placement, respectively (Le Mansec et al., 2016). Furthermore, our results show evidences that our proposed test provides a reproducible instrument for measure ball speed, ball placement, and velocity-accuracy index, which showed high levels of reliability (ICC range 0.78–0.96) and satisfactory levels of agreement (TE range 1.2–2.8 and CV range 2.7–16.2%) when players performed the test in a short period or several days later. These corroborate with the ICC ranging from 0.45 to 0.96 and CV ranging from 2 to 19% presented in reproducibility studies on the assessment of technical performance (Le Mansec et al., 2016), tactical-technical performance (Vergauwen et al., 1998; Kolman et al., 2017), perceptuo-motor skills (Faber et al., 2014a, 2015), and cognitive performance (van de Water et al., 2017) in racket sports players. Moreover, Bland–Altman plots showed the mean difference of the intrasession and intersession analyses closer to zero in our study, which represent reliable measures.

Concerning discriminant validity, we showed regional players had higher scores of ball placement and ball velocity-ball placement index as well as made fewer errors than local players. Prior studies applied to racket sport concur reporting the scores of ball placement, ball velocity-ball placement index, and percentage error discriminate players with different performance-level during technical (Le Mansec et al., 2016) and tactical-technical tests (Vergauwen et al., 1998; Kolman et al., 2017). Lateral stroke precision also tended to be better in RP than LP. Corroborating this result, Vergauwen et al. (1998) showed evidence the lateral stroke precision was relevant to discriminate tennis players with different levels of performance in a technical-tactical test. Moreover, Djokic (2002) observed that better ranked table tennis players (by the position on the International Table Tennis Federation Rank List) more use the lateral stroke placement compared to lower ranked players during official matches. Thus, further research should better explore the accuracy analysis of the lateral target areas to continue the development of table tennis tests. For example, the right zone was more reached than the left zone for regional players (15.5-fold on average). It is plausible to assume that players preferred to better explore the right than the left area, given the athletes could hit the targets in a sequence they decided. Splitting right area in half, we may also visualize the regional players reached most balls in half of the target closer to the edge (71%) than in half of the target closer to the net (29%). Strokes aimed toward the end part of the target stimulated higher ball speed (∼13%) while hitting the target closer to the net provided bigger angle, which are different ways to move the ball out of the opponent control during a real match. Finally, further research may also analyze which stroke was more effective to reach these areas, given the athletes could choose among different FH and BH techniques for offensive strokes to perform the proposed test [e.g., initial topspin, fast final topspin attack, preparatory drive attack, and final drive attack (Munivrana et al., 2015b)].

Ball speed slight differed between the groups during the proposed test. We focused on the successful shots to measure the ball speed, which could influence our results and constitute a possible explanation concerning the slight difference found between the groups. However, Vergauwen et al. (1998) also measure the ball speed in nonerror strokes and they observed the ball speed was relevant to discriminate tennis players with different performance-level during a test to examine stroke effectiveness in match-like conditions. An alternative explanation is table tennis players can use different playing styles. Offensive players tend to win the point by accelerating the speed of play (Martin et al., 2015) whereas all-round players prefer to return the ball and to force opponent's error, with less aggressive strokes (Milioni et al., 2018). The study penholder players used an offensive playing style while players who used classical racket grip were all-round players. In line with this, we found a lower percentage of offensive players in regional (10%) than local (33%) groups, which could partially clarify our findings. Finally, the ball speed and ball spin are often related to and restricted by each other (Qun et al., 1992). Thus, it is possible that regional players may have increased the use of ball spin during their strokes to increase the accuracy, but it reduced the velocity they hit the ball to perform the test. This is in accordance with the speed-accuracy trade-off (i.e., to reach greater accuracy, the execution time of a movement increases) (Fitts, 1954). Considering this assumption, it would be interesting to further investigate whether higher performance-level players are able to be accurate in their strokes with a lower impact on the ball speed than regional players during our test.

Concurrent validity concur the aforementioned findings, showing that the ball placement, PI, and percentage error were related with table tennis performance whereas ball speed was not associated with the players' position on the simulated tournament. Le Mansec et al. (2016) reported the scores of ball placement and ball velocity-ball placement index were related with the table tennis performance; however, this investigation also observed the ball speed evaluated during a continuous and specific-test was related with the players' position on the national ranking list.

Herein, the test explores the phase of attack with offensive strokes at defensive balls delivered by a robot close to the edge of the table, which could constitute a limitation of this investigation. Besides elements used in the phase of attack, the whole structure of technical-tactical elements in table tennis also includes those used in the phase of defense, and those used in the phase of preparing one's own and disabling the opponent's attack, which are performed at balls bounce in different playing surfaces over the table (i.e., net zone, middle zone, baseline/edge zone) (Munivrana et al., 2015a,b). In line with this, development of technical-tactical tests applied to tennis proposed different tactical situations (i.e., offensive, neutral and defensive rallies) by varying the direction of the ball sent by robot (Vergauwen et al., 1998; Kolman et al., 2017). In addition, changes in frequency of balls delivered by the robot may also be explored during different rallies (e.g., decreases the time between strokes could be informative as time pressure in defensive rallies). These issues may be explored in future investigations to continue the development of table tennis tests based on the temporal game structure started at present investigation. Another limitation is related to the table tennis performance analyses. We evaluated three different teams, each one ranked from a different table tennis circuit; thus, a simulated tournament constituted an alternative to rank the study players according their performance during real matches. However, the use of the simulated tournament as a measure of performance is a point of discussion, because the players' performance is based on only one moment of competition without a broader performance context as those observed in a table tennis circuit. Thus, it is interesting for future research to investigate whether the test is related to the table tennis players' position on a ranking list based on a table tennis circuit. Finally, future studies may also focus on designing tests to evaluate national and international players, since it is documented that the temporal game structure of table tennis is influenced by the performance level (Zagatto et al., 2010; Leite et al., 2017) and the results observed herein are representative of regional players.

CONCLUSION

This study presents a novel table tennis test of stroke effectiveness based on the temporal game structure, which is able to assess the ball speed, ball placement and the interrelation between these two tactical means in the players. This is the first study which the proposed specific-test were based on temporal characteristics of the table tennis match. Our findings show evidences that the test is reproducible, with satisfactory reliability and agreement outcomes. Moreover, discriminant and concurrent validity are confirmed, except for individual scores on ball speed. Practical implications for coaches can be to use this test at the beginning and at the end of a teaching and training period, for monitoring the effectiveness of offensive strokes of the players to deal with defensive opponents. Differences between the second and the first test session on the PI larger than the SDD of 3.7–4.1 are indicative of athletes' improvement within a teaching and training period.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

TB and PdM designed the study, conducted analyses, and wrote the manuscript. MM, TT, RR, YS, and KS assisted in acquisition, analysis and interpretation of data, and reviewed the article. LG made substantial contribution including conception of the study and a critical revision of the article. All the authors read and approved the final manuscript.

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REFERENCES

Abdel-Aziz, Y. I., and Karara, H. M. (1971). "Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry," in *Proceedings of the Symposium on Close-Range Photogrammetry*, Champaign, IL.

Bland, J. M., and Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 327, 307–310. doi: 10.1016/S0140-6736(86)90837-8

Cohen, J. (1992). A power primer. *Psychol. Bull.* 112, 155–159. doi: 10.1037/0033-2909.112.1.155

Davidson, M. (2014). "Known-groups validity," in *Encyclopedia of Quality of Life and Well-Being Research*, ed. A. C. Michalos (Dordrecht: Springer), 3481–3482. doi: 10.1007/978-94-007-0753-5_1581

De Vet, H. C. W., Terwee, C. B., Knol, D. L., and Bouter, L. M. (2006). When to use agreement versus reliability measures. *J. Clin. Epidemiol.* 59, 1033–1039. doi: 10.1016/j.jclinepi.2005.10.015

Djokic, Z. (2002). Structure of competitors' activities of top table tennis players. *Int. J. Table Tennis Sci.* 5, 74–90.

Faber, I. R. (2016). *Diamonds in the Rough: Searching For High Potential in Youth Table Tennis Players*. Ph.D. thesis, Radboud University Medical Center and Saxion University of Applied Sciences, Enschede, OV.

Faber, I. R., Elferink-Gemser, M. T., Oosterveld, F. G. J., and Nijhuis-Van der Sanden, M. W. G. (2014a). Revision of two test items of the dutch motor skills assessment measuring ball control in young table tennis players. *Ann. Res. Sport Phys. Activ.* 5, 53–69. doi: 10.14195/2182-7087_5_10

Faber, I. R., Oosterveld, F. G., and Nijhuis-Van der Sanden, M. W. (2014b). Does an eye-hand coordination test have added value as part of talent identification in table tennis? A validity and reproducibility study. *PLoS One* 9:e85657. doi: 10.1371/journal.pone.0085657

Faber, I. R., Nijhuis-Van Der Sanden, M. W., Elferink-Gemser, M. T., and Oosterveld, F. G. (2015). The Dutch motor skills assessment as tool for talent development in table tennis: a reproducibility and validity study. *J. Sports Sci.* 33, 1149–1158. doi: 10.1080/02640414.2014.986503

Figueroa, P. J., Leite, N. J., and Barros, R. M. (2008). A flexible software for tracking of markers used in human motion analysis. *Comput. Methods Programs Biomed.* 72, 155–165. doi: 10.1016/S0169-2607(02)00122-0

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *J. Exp. Psychol.* 47, 381–391. doi: 10.1037/h0055392

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Med.* 30, 1–15. doi: 10.2165/00007256-200030010-00001

Impellizzeri, F. M., and Marcora, S. M. (2009). Test validation in sport physiology: lessons learned from clinimetrics. *Int. J. Sports Physiol. Perform.* 4, 269–277. doi: 10.1123/ijspp.4.2.269

Kolman, N., Huijgen, B., Kramer, T., Elferink-Gemser, M., and Visscher, C. (2017). The Dutch technical-tactical tennis test (D4T) for talent identification and development: psychometric characteristics. *J. Hum. Kinet.* 55, 127–138. doi: 10.1515/hukin-2017-0012

Kondric, M., Zagatto, A. M., and Sekulic, D. (2013). The physiological demands of table tennis: a review. *J. Sports Sci. Med.* 12, 362–370.

Le Mansec, Y., Dorel, S., Nordez, A., and Jubeau, M. (2016). Sensitivity and reliability of a specific test of stroke performance in table tennis. *Int. J. Sports Physiol. Perform.* 11, 678–684. doi: 10.1123/ijspp.2015-0444

Lees, A. (2003). Science and the major racket sports: a review. *J. Sports Sci.* 21, 707–732. doi: 10.1080/0264041031000140275

Leite, J. V., Barbieri, F. A., Miyagi, W., Malta, E. S., and Zagatto, A. M. (2017). Influence of game evolution and the phase of competition on temporal game structure in high-level table tennis tournaments. *J. Hum. Kinet.* 55, 55–63. doi: 10.1515/hukin-2016-0048

Malagoli Lanzoni, I., Di Michele, R., and Merni, F. (2011). "Performance indicators in table tennis: a review of the literature," in *Proceedings of the 12th ITTF Sports Science Congress*, Rotterdam.

Malagoli Lanzoni, I., Di Michele, R., and Merni, F. (2014). A notational analysis of shot characteristics in top-level table tennis players. *Eur. J. Sport Sci.* 14, 309–317. doi: 10.1080/17461391.2013.819382

Martin, C., Favier-Ambrosini, B., Mousset, K., Brault, S., Zouhal, H., and Prioux, J. (2015). Influence of playing style on the physiological responses of offensive players in table tennis. *J. Sports Med. Phys. Fitness* 55, 1517–1523.

Milioni, F., de Mello Leite, J. V., Beneke, R., De Poli, R. A. B., Papoti, M., and Zagatto, A. M. (2018). Table tennis playing styles require specific energy systems demands. *PLoS One* 13:e0199985. doi: 10.1371/journal.pone.0199985

Morel, E. A., and Zagatto, A. M. (2008). Adaptation of the lactate minimum, critical power and anaerobic threshold tests for assessment of the aerobic/anaerobic transition in a protocol specific for table tennis. *Rev. Bras. Med. Esporte.* 14, 518–522. doi: 10.1590/S1517-86922008000600009

Munivrana, G., Furjan-Mandic, G., and Kondric, M. (2015a). Determining the structure and evaluating the role of technical-tactical elements in basic table tennis playing systems. *Int. J. Sports Sci. Coach.* 10, 111–132. doi: 10.1260/1747-9541.10.1.111

Munivrana, G., Petrinović, L. Z., and Kondrič, M. (2015b). Structural analysis of technical-tactical elements in table tennis and their role in different playing zones. *J. Hum. Kinet.* 47, 197–214. doi: 10.1515/hukin-2015-0076

O'Donoghue, P., Girard, O., and Reid, M. (2013). "Racket sports," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, J. Sampaio, and A. J. de Eira Sampaio (Abingdon, OFE: Routledge), 404–414.

Qun, W. H., Zhifeng, Q., Shaofa, X., and Enting, X. (1992). Experimental research in table tennis spin. *Int. J. Table Tennis Sci.* 1, 73–78.

Sève, C., Saury, J., Theureau, J., and Durand, M. (2002). Activity organization and knowledge construction during competitive interaction in table tennis. *Cogn. Syst. Res.* 3, 501–522. doi: 10.1016/S1389-0417(02)00054-2

Suzuki, H., and Yamamoto, Y. (2015). Robustness to temporal constraint explains expertise in ball-over-net sports. *Hum. Mov. Sci.* 41, 193–206. doi: 10.1016/j.humov.2015.02.009

Tozetto, A. V. B., Rosa, R. S. D., Mendes, F. G., Galatti, L. R., Souza, E. R. D., Collet, C., et al. (2017). Birthplace and birthdate of Brazilian Olympic medalists. *Rev. Bras. Cineantropom. Desempenho. Hum.* 19, 364–373. doi: 10.5007/1980-0037.2017v19n3p364

van de Water, T., Huijgen, B., Faber, I., and Elferink-Gemser, M. (2017). Assessing cognitive performance in badminton players: a reproducibility and validity study. *J. Hum. Kinet.* 55, 149–159. doi: 10.1515/hukin-2017-0014

Vergauwen, L., Spaepen, A. J., Lefevre, J., and Hespel, P. (1998). Evaluation of stroke performance in tennis. *Med. Sci. Sports Exerc.* 30, 1281–1288. doi: 10.1097/00005768-199808000-00016

Wang, M. Y., Liu, Y. C., and Chen, C. J. (2013). "Techniques and tactics analysis related to personality in table tennis doubles," in *Proceedings of the 13th ITTF Sports Science Congress*, Paris.

Zagatto, A. M., and Gobatto, C. A. (2012). Relationship between anaerobic parameters provided from MAOD and critical power model in specific table tennis test. *Int. J. Sports Med.* 33, 613–620. doi: 10.1055/s-0032-1304648

Zagatto, A. M., Miranda, M. F., and Gobatto, C. A. (2011). Critical power concept adapted for the specific table tennis test: comparisons between exhaustion criteria, mathematical modeling, and correlation with gas exchange parameters. *Int. J. Sports Med.* 32, 503–510. doi: 10.1055/s-0030-1270470

Zagatto, A. M., Morel, E. A., and Gobatto, C. A. (2010). Physiological responses and characteristics of table tennis matches determined in official tournaments. *J. Strength Cond. Res.* 24, 942–949. doi: 10.1519/JSC.0b013e3181cb7003

Zagatto, A. M., Papoti, M., and Gobatto, C. A. (2008). Validity of critical frequency test for measuring table tennis aerobic endurance through specific protocol. *J. Sports Sci. Med.* 7, 461–466.

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Low Range of Shoulders Horizontal Abduction Predisposes for Shoulder Pain in Competitive Young Swimmers

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The prevalence of shoulder pain (SP) among competitive swimmers is high, and may profoundly restrict their ability to compete. This prospective cohort study investigated the association between 3 blocks of performance factors (anthropometric characteristics, sport experience and training regimen) and the presence of SP. The aims of the present study were: (a): to determine the profile of shoulder flexibility in young swimmers, (b) to analyze whether a restricted range of movement (ROM) could be a predictor of subsequent SP in young swimmers. 24 competitive young swimmers were measured in the 2016 pre-season. Measures of passive maximal shoulder extension (SE), flexion (SF), horizontal abduction (SHAB), abduction (SAB), horizontal adduction (SHADD), external (SER) and internal (SIR) rotation ROMs were taken. SP was prospectively monitored during the subsequent season using questionnaires. The data was analyzed via a binary logistic regression and ROC curves were calculated. At the follow-up, 16 swimmers (50%) had developed unilateral SP. Only reduced SHAB ROM was associated with SP [SP group 36.6° vs. pain-free group 41.5°; $p = 0.005$, $d = -0.96$ (moderate effect sizes)]. Using the coordinates of the curves, the angle of SHAB ROM that most accurately identified individuals at risk of developing SP was determined to be 39° (sensibility 0.656 and 0.375 specificity). Swimmers with limited ROM (≤39°) have 3.6 times higher risk of developing SP than swimmers with normal ROM (>39°). This study clearly shows that low range of SHAB is a risk factor for developing SP in competitive young swimmers. In the studied data, a SHAB range of 39° was found to be the most appropriate cut-off point for prognostic screening.

Keywords: flexibility, injury, overhead movement, sport, pain

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INTRODUCTION

Shoulder pain (SP) has been described as the most common musculoskeletal disorder in competitive swimmers (Wanivenhaus et al., 2012) causing an impact on training, competition and swimming goals (McLaine et al., 2018). In several cohort studies, SP prevalence in swimmers is high, and may range from 40 to 91% depending on the age group and definition (McMaster, 1999; Bak, 2010; Sein et al., 2010).

Competitive swimming often train 11 months of the year (Hibberd et al., 2016) and swin over 20 h per week distributed between 5 and 7 days (Sein et al., 2010; Tate et al., 2012). Furthermore, the training intensity during the practices is quite high (Harrington et al., 2014; Ristolainen et al., 2014).

The average swimmer swims approximately 42000 to 110000 m per week depending on the competitive level (recreational swimmers vs. international swimmers) (Bradley et al., 2016). With an average stroke count of 10 complete strokes per 25 m lap (Heinlein and Cosgarea, 2010) this can equate to an average of 16800–44000 rotations of each shoulder per week.

The shoulders and upper extremities represent nearly 90% of the propulsive power for all four main strokes (Heinlein and Cosgarea, 2010). The percentage of propulsive power of the stroke comes 70–85% from the pull and 20–30% from the kick and these percentages differ according to the swimming technique (King, 1995). Swimming requires several different shoulder motions, most being performed in clockwise and counter-clockwise directions with varying degrees of internal and external rotation and scapular protraction and retraction (McLaine et al., 2018). Shoulder extension, adduction and internal rotation movements are relevant and highly reproduced in the swimming technique during the propulsive phases of the different strokes (Wanivenhaus et al., 2012).

Highly repetitive overhead loading, high volume of training and years of swimming experience places tremendous stress and adaptations on the shoulder girdle musculature and the glenohumeral joint complex adapts to the training demands (Heinlein and Cosgarea, 2010; Dischler et al., 2017; Higson et al., 2018). Swimmers have been observed as having increased thoracic kyphosis, rounded shoulders and a forward head, which can decrease subacromial-space distance (Hibberd et al., 2016; Struyf et al., 2017). In addition, demanding training programs (including swimming, strength and dry land conditioning) predisposes the swimmers shoulder to adaptive changes including decreased internal rotation and horizontal adduction ROM, and excessive external rotation with respect to no-athletes (Hibberd et al., 2016; De Martino and Rodeo, 2018).

Several studies investigated the relationship between ROM and SP in swimmers. The studies of Beach et al. (1992), Bak and Magnusson (1997), and Harrington et al. (2014) did not observe any significant relationship between SP and shoulder joint flexibility. However, Walker et al. (2012) found that swimmers with a low (<93°) external rotation ROM had an increased risk of developing shoulder pain but found no relationship between internal rotation ROM and shoulder pain; while Tate et al. (2012) found a relationship between reduced shoulder flexion, internal rotation ROM and shoulder pain in young female swimmers. Contreras-Fernández et al. (2010) found a decrease in shoulder internal and external rotation in 30 elite swimmers compared to the control group. On the contrary, Walker et al. (2012) found a relationship between SP and higher shoulder external rotation ROM (≥100°); finally, Contreras-Fernández et al. (2010) found significant differences between swimmers with or without shoulder pain in this movement. These results coincide with the systematic review of Hill et al. (2015), who reported that decreased shoulder internal rotation and either increased or decreased shoulder external rotation ROM is a risk factor for SP in swimmers.

However, no previous research has analyzed all shoulder movements in competitive swimmers in order to describe muscular and capsular adaptations of swimming (Beach et al., 1992). Sport and physical rehabilitation professionals need simple and useful tools such as reference values with "cut-off points" that classify swimmers with a normal or reduced (limited) ROM. Likewise, these professionals require reference values of the reduced ROM to help in the prevention of SP in competitive swimmers just as it has been previously determined for lower extremities in different sports injuries (Witvrouw et al., 2001; Backman and Danielson, 2011; Okamura et al., 2014; Tak et al., 2017).

Therefore, the aims of the present study were: (a): to determine the profile of shoulder flexibility in young swimmers, (b) to analyze whether restricted ROMs could be a predictor of subsequent SP in young swimmers.

MATERIALS AND METHODS

Participants

Twenty-four young swimmers (15 males and 9 females) completed this study. All the participants were competitive swimmers (range between U12 and U20) and were recruited from three different swimming youth academies. Swimmers who volunteered for this study were accepted regardless of their current level of shoulder symptoms because swimmers frequently practice with SP.

Before data collection, participants completed a questionnaire containing questions about their sport-related background (dominant swim style, current competitive level, dominant upper extremity (defined as the participant's preferred throw upper extremity), sport experience), demographics characteristics (age, body mass, stature and body mass index), and training regimen (weekly practice frequency, hours of swimming per week and day, resting periods, types de fitness and training load). The data from the questionnaires reported that the sample was homogeneous in potential confounding variables, except in height and years of training experience (**Table 1**). Besides, none of the participants were involved in systematic and specific stretching regimes in the last 6 months, apart from the 1–2 sets of 8–10 repetitions of static and dynamic stretches designated for the mains muscles of the upper extremities (e.g., pectoralis major and minor, latissimus dorsi, deltoid, trapezius, elevator scapulae and rotator cuff) that were performed daily during their pre-exercise warm-up and post-exercise cool down phases.

The exclusion criteria for all subjects were: (1) a history of cervical or thoracic pathology; (2) previous shoulder surgery; (3) previous shoulder injury in the past 6 months; and (4) presence of SP that prevented the correct execution of the tests, including inability to achieve relaxation during testing.

The study was conducted during the season of the year 2016–2017. The measurement of the range of movement (ROM) and anthropometric measures were performed in the pre-season. At the end of the sports season, a second part questionnaire

TABLE 1 | Demographic results on swimmers participating in the study[a].

	Males (*n* = 15)	Females (*n* = 9)	Total (*n* = 24)
Age (years)	15.7 ± 2.8	15.3 ± 0.9	15.6 ± 2.2
Body mass (kg)	61.4 ± 7.0	58.3 ± 6.5	60.3 ± 6.8
Height (cm)*	172.5 ± 5.6	165.2 ± 5.7	169.8 ± 6.5
BMI (kg/m²)	20.6 ± 1.6	21.4 ± 2.1	20.9 ± 1.8
Years of experience swimming*	7.5 ± 2.2	5.6 ± 1.5	6.8 ± 2.1
Training hours per week	15.4 ± 1.4	15.1 ± 2.1	15.3 ± 1.7

*[a]Values are expressed as mean ± standard deviation. *Significance statistic according to sex ($p \leq 0.002$). BMI, body mass index.*

was completed by the participants about the history of SP suffered, which provided us with information regarding type of injury, location (shoulder of the dominant and non-dominant limb), frequency (number of times), severity (days of absence to training or competition), moment (training or competition) and clinical treatment (yes or no). The shoulder injury definition used was based on previous research and defined *a priori* as significant interfering shoulder pain that interfered with training or competition, or progression in training and caused cessation or modification of training or racing (McMaster et al., 1998). Questionnaires were completed with the collaboration of the parents and the coach.

Before any participation, experimental procedures and potential risks were fully explained to both parents and children in verbal and written form, and written informed consent was obtained from the parents of all participants. This study respected the ethical principles established by the UNESCO Declaration on Bioethics and Human Rights. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics and Scientific Committee of the University of Murcia (Spain) (ID: 1702/2017).

Testing Procedure

The passive maximal shoulder extension (SE), flexion (SF), horizontal abduction (SHAB), abduction (SAB), horizontal adduction (SHADD), external (SER), and internal (SIR) rotation ROMs of the dominant and non-dominant upper extremity were assessed following the methodology previously described (Cejudo et al., 2015; **Figure 1**).

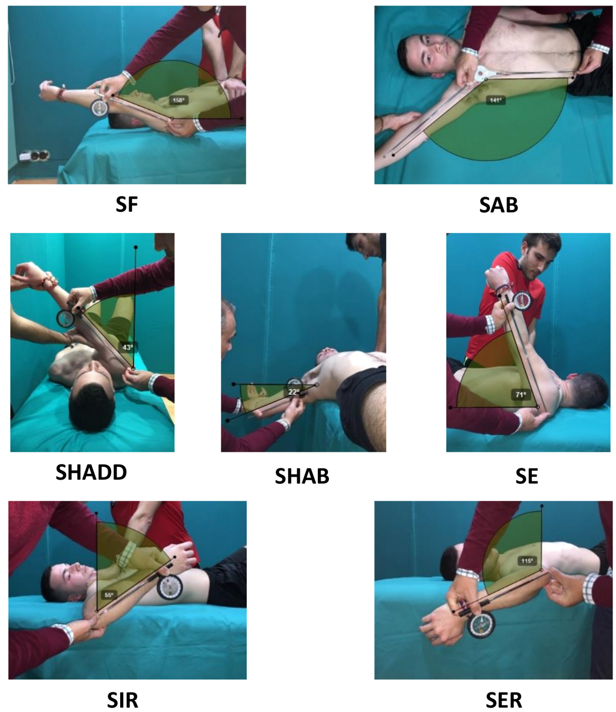

FIGURE 1 | Shoulder ranges of motion of the "ROM-SPORT" protocol: SF, shoulder flexion; SAB, shoulder abduction; SHADD, shoulder horizontal adduction; SHAB, shoulder horizontal abduction; SE, shoulder extension; SIR, shoulder internal rotation; SER, shoulder external rotation. Written and informed consent has been obtained for the publication of these images from the depicted adults and from the parents/legal guardians of the minors.

These tests were selected because they have been considered appropriate by the American Medical Association (Gerhardt et al., 2002) and included in manuals of Sports Medicine and Science (Palmer and Epler, 2002; Clarkson, 2003; Norkin and White, 2006) based on reliability and validity studies, anatomical knowledge, and extensive clinical and sport experience. In addition, previous studies have reported good to excellent to excellent intra-rater reliability for all measures (ICC: 0.85–0.99; variability: 6°–11° or less) (Mullaney et al., 2010; Cadogan et al., 2011).

A priori reliability was established by the primary investigator in a sample of convenience (university students; $n = 12$, ranged from age = 20–22 years) measured on two occasions, 3 day apart. The intraclass correlation coefficient (ICC) and the minimal detectable change at a 95% confidence interval (MDC_{95}) values for all measures on the dominant side ranged from 0.88 to 0.96 and 3.7° to 7.2°, respectively.

One week before the start of the study, all the participants completed a familiarization session with the purpose of knowing the correct technical execution of the exploratory tests by means of the practical realization of each one of them. The dominant extremity was defined as the participant's preferred throw upper extremity. All tests were carried out by the same two physical therapists under stable environmental conditions. Prior to the testing session, all participant performed a warm up. The overall duration of the entire warm-up was approximately 10 min (mobility of neck, shoulders, wrist, spine and pelvis, dynamic stretching by 2 sets of 15 repetitions each for the main muscles of the upper extremities each of dynamic stretches) following the considerations design by Bishop (2003), Torres et al. (2008), and Ayala et al. (2016).

After the warm-up, swimmers were instructed to perform, in a randomized order, two maximal trials of each ROM test for each joint shoulder, and the mean score for each test was used in the analyses. Swimmers were examined wearing sports clothes but without a sports shirt. The girls used a sports bra. A 30-s rest was given between trials, joint shoulder and tests.

For the measurement, an ISOMED Unilevel inclinometer (Portland, OR, United States) was used with extendable telescopic rod (Gerhardt et al., 2002), a metal goniometer with long arm (Baseline® Stainless) and "lumbosant" -lumbar support-to standardize the lumbar curvature (Santonja et al., 1995). Before each assessment session, the inclinometer was calibrated to 0° with either the vertical or horizontal. The angle between the longitudinal axis of the mobilized segment was recorded (following its bisector) with the vertical (SIR, SER, and SHADD ROMs) or the horizontal (SF, SE, and SHAB ROMs) (Gerhardt et al., 2002; Cejudo et al., 2015). Regarding the assessment of shoulder abduction movement (SAB), a metal goniometer with a long arm (Baseline® Stainless) was used. One or both of the following criteria determined the end-point for each test: (a) an examiner palpated or appreciated some compensation movement that increased the ROM, and/or (b) the participant felt a strong but tolerable stretch, slightly before the occurrence of pain (Cejudo et al., 2015).

Statistical Analysis

Prior to the statistical analysis, the distribution of the raw data sets was checked using the Kolomogorov–Smirnov and Levene tests to determine normal distribution and homoscedasticity, respectively. The results demonstrated that not all data had a normal distribution nor homoscedastic (normal distribution, $p > 0.05$: SE, SF, SHAB, and SIR, not normal distribution, $p < 0.05$: SHADD, SAB and SER). Descriptive statistics including means and standard deviations were calculated for all characteristics and ROM measures separately by the variable pain (shoulder pain-free versus SP versus total) (**Table 2**).

To examine the existence of asymmetry of ROM between the values of the dominant and non-dominant sides, either the Student's t-test (if the distribution of the data were normal) or the Wilcoxon test (if no normal distribution of the data was obtained) was used.

To examine possible differences in demographic variables and shoulder ROMs between the male and female groups for each movement, either the Independent t-Test (if the distribution of the data were normal) or the Mann–Whitney U-test (if no normal distribution of the data was obtained) was conducted.

To examine possible differences in continuous variables (anthropometric characteristics, sport-related background and training regimen variables, and 7 ROM assessments) between the shoulder pain-free and SP groups, we used either the Student's t-test (if the distribution of the data were normal) or the Mann–Whitney U-test (if no normal distribution of the data was obtained). Univariate analyses (independent t-tests) were performed to compare the continuous variables between the swimmers who did and did not have SP when there was a normal distribution. A non-parametric Mann–Whitney U-test was performed when the distribution did not meet the criterion of normality (age, height, years of experience, training hours per week, SAB, SHADD, and SEH). Additionally, Cohen's effect size was calculated for all results, and the magnitudes of the effect were interpreted according to the criteria of Hopkins et al. (2009), in which the effect sizes less than 0.2, from 0.2 to 0.59, from 0.6 to 1.19, from 1.20 to 2.00, from 2.00 to 3.99 and greater than 4.00 were regarded as trivial, small, moderate, large, very large and extremely large, respectively. The authors arbitrarily chose moderate as the minimal relevant effect level with practical application in the results.

The relationship between the independent variables and the dependent variable was examined by a backward stepwise binary logistic regression (Forward Selection (Conditional), inclusion probability $p \leq 0.05$, elimination probability $p \leq 0.10$) with OR analysis been used as in previous studies (Witvrouw et al., 2001; Fousekis et al., 2011) for estimating the simultaneous effects of several predictors instead of relative risk estimates (Hosmer and Lemeshow, 1989). Effect sizes for the OR were defined as follows: small effect OR = 1–1.25, medium effect OR = 1.25–2 and large effect OR $\geq$ 2 (Coombes et al., 2010).

To determine whether it is possible to find a clinically relevant cut-off point for ROM that can be used for pointing out individuals at a high risk of developing SP, receiver operating characteristic (ROC) curves were calculated. The area under the ROC curve represents the probability that a selection based on the risk factor for a randomly chosen positive case will exceed the result for a randomly chosen negative case. The area under the curve can range from 0.5 (no accuracy) to 1.0 (perfect accuracy). If it is found to be statistically significant, it means that using the risk factor as a determinant is better than guessing. Since the ROC curve plots sensitivity against 1 minus specificity, the coordinates of the curve can be considered possible cut-off points, and the most suitable cut-off can be chosen. Among the swimmers who sustained SP, Pearson's chi-squared test was used to examine the existence of a relationship between the range of motion classification (normal and limited) and SP.

Analysis was completed using SPSS version 20 (SPSS Inc., Chicago, IL, United States). For all analyses, significance was accepted at $p < 0.05$. Data are presented as means ± s.

RESULTS

During the 1-year period of the study SP was identified in 16 (50%) of the 32 shoulders analyzed. Statistical analysis showed no significant sex and asymmetry (dominant vs. non-dominant limbs) difference in the incidence of SP in this study ($p < 0.05$). Three swimmers had bilateral complaints, the same number of swimmers had unilateral pain in their dominant and non-dominant shoulder ($n = 5$).

Among the variables that were assessed before the beginning of the study, the only significant difference detected between the groups (SP vs. pain-free at follow-up) was in SHAB ROM (SP group 36.6° vs. pain-free group 41.5°; $p = 0.005$, $d = -0.96$

TABLE 2 | Results of variables for the 24 young swimmers (48 shoulders) who developed shoulder pain and those who did not (control).

Variable	Shoulder with Pain† (*n* = 16)	Shoulder pain-free† (*n* = 32)	Total† (*n* = 48)	*p*-value	Effect sizes Cohen's *d*
Age (years)	15.8 ± 1.9	15.4 ± 2.3	15.6 ± 2.2	0.222	Trivial (d = 0.18)
Body mass (kg)	61.5 ± 7.8	59.6 ± 6.2	60.3 ± 6.8	0.405	Small (d = 0.28)
Height (cm)	169.3 ± 8.5	170.0 ± 5.3	169.8 ± 6.5	0.860	Trivial (d = −0.10)
BMI (kg/m^2)	21.4 ± 1.9	20.6 ± 1.7	20.9 ± 1.8	0.120	Small (d = 0.45)
Years of experience	6.0 ± 1.2	7.1 ± 2.3	6.8 ± 2.1	0.131	Medium (d = −0.54)
Training hours per week	15.6 ± 1.2	15.1 ± 1.8	15.3 ± 1.7	0.773	Small (d = 0.30)
SE (grade)[a]	88.3 ± 11.1	92.8 ± 8.4	91.3 ± 9.5	0.102	Small (d = −0.48)
SF (grade)[a]	174.8 ± 12.6	180.8 ± 8.7	178.8 ± 10.4	0.070	Small (d = −0.59)
SHAB (grade)[a]*	36.6 ± 4.1	41.5 ± 5.5	39.8 ± 5.5	0.005	Moderate (d = −0.96)
SAB (grade)[b]	176.0 ± 9.4	176.9 ± 8.1	176.6 ± 8.4	0.722	Trivial (d = −0.16)
SHADD (grade)[b]	152.2 ± 9.2	155.1 ± 5.6	154.1 ± 7.1	0.268	Small (d = −0.41)
SIR (grade)[a]	69.3 ± 11.8	75.0 ± 12.6	73.1 ± 12.5	0.120	Small (d = −0.46)
SER (grade)[b]	129.1 ± 13.1	132.8 ± 11.9	131.6 ± 12.3	0.326	Small (d = −0.30)

*†Values are expressed as mean ± standard deviation BMI, body mass index; SE, shoulder extension; SF, shoulder flexion; SHAB, shoulder horizontal abduction; SAB, shoulder abduction; SHADD, shoulder horizontal adduction; SIR, shoulder internal rotation; SER, shoulder external rotation. *significant at $p \leq 0.05$ independent-samples t-test[a] or non-parametric Mann–Whitney U-test[b]; The magnitude of the effect size of the pooled Standardized mean differences (SMD) was interpreted as trivial or no effect if SMD < 0.2; small if SMD 0.2 to 0.59; moderate if SMD 0.6 to 1.19; large if SMD 1.20 to 2.00; very large if SMD 2.00 to 3.99 and extremely large if SMD greater than 4.00.*

TABLE 3 | Frequencies and logistical regression results: intrinsic risk factors for shoulder pain in 24 young swimmers (*n* = 48).

		Frequencies (%)		Statistics			
Variables		**Normal**	**Tight**	**Odds ratio**	**Standard Error**	**95% CI**	***p*-value**
Shoulders pain (16 vs. 32)							
SHAB	Shoulder pain-free	68.8	31.3	1.225	0.078	0.701 to 0.950	0.009
	Shoulder pain	37.5	62.5				

SHAB, shoulder horizontal abduction; OR, Odds Ratio (relative risk). Tightness (high risk) establish at 39° in the present study; OR > 1: increased Odds of shoulder pain; small effect OR = 1–1.25, medium effect OR = 1.25–2 and large effect OR ≥ 2 (Coombes et al., 2010); CI, Confidence Interval.

(moderate effect sizes). The group of swimmers with SP had a reduced range of 4.9° (**Table 2**).

With the stepwise logistic regression analysis, of all of the variables entered into the model (**Table 2**), only SHAB ROM showed a small predictor of SP occurrence in the swimmers assessed (OR = 1.225 (small); 95% CI.701 to 0.953, p = 0.009) (**Table 3**). In addition, the analysis of the frequencies showed 100% of successful cases in swimmers with SP who were categorized with limited SHAB ROM (tightness of the pectoralis major and anterior capsular contracture, cut-off < 39°) according to the present study. None of the other intrinsic factors imposed a significant relative risk for SP ($p > 0.05$).

The area under the ROC curves was 0.747, a good predictive model accuracy (Cortes and Mohri, 2004), for the SP (**Figure 2**), being statistically significant (p = 0.006; Standard Error: 0.069; 95% Confidence Interval: 0.611 to 0.883). Using the coordinates of the curves, the angle of SHAB ROM that most accurately identified individuals at risk of developing tendinopathy was determined to be 39° (sensibility 0.656 and 0.375 specificity). Finally, the Chi-square test observed differences between the proportions of swimmers with limited and normal range in SHAB, whether or not they have SP (p = 0.038; 95% Confidence Interval 1.04 to 12.9). Swimmers with limited ROM (≤39°) have 3.6 times higher risk of developing SP than swimmers with normal ROM (>39°).

DISCUSSION

Profile of Shoulder Flexibility

The first aim of this study was to determine the profile of shoulder flexibility in youth swimmers. It was found that the profile of shoulder flexibility in the 24 swimmers was 41.5° in the SHAB, 75° in the SIR, 92.8° in the SE, 132.8° in the SER, 155.1° in the SHADD, 176.9° in the SAB and 180.8° in the SF ROM. With respect to shoulder ROM data (SE, SER, and SHADD), this study found that swimmers with and without SP had higher values than what has been proposed for the general population (**Table 4**; Gerhardt, 1994; Gerhardt et al., 2002; Palmer and Epler, 2002; Clarkson, 2003; Peterson et al., 2005). It is possible that these higher values are due to musculoskeletal adaptations as a consequence of the physical-technical demands of swimming (Sainz de Baranda et al., 2015). When the results were compared with previous literature, the current study found higher ROM values than the angular values observed in 28 college swimmers, from 15 to 21 years old (SER, 47°; SIR, 105.5°; SE, 60.5; SHADD, 138.5)

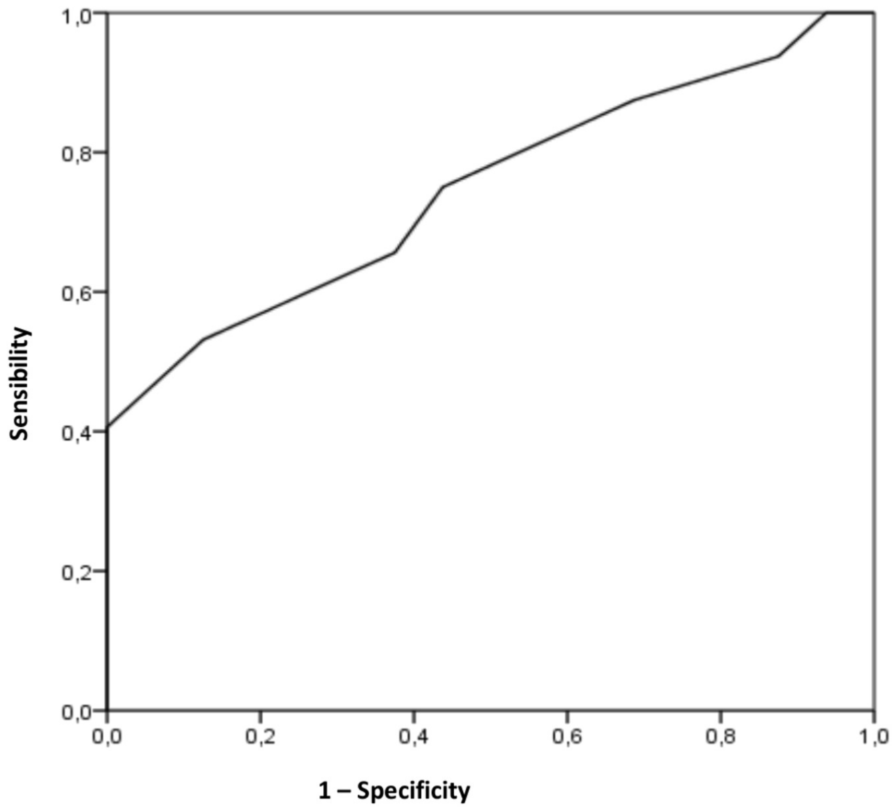

FIGURE 2 | Receiver operating characteristic curve for the shoulder horizontal abduction range, as a risk factor for developing tendinopathy in the shoulder pain. The area under the curve is 0.747 (p = 0.006); the coordinates represent possible cut-off point in shoulder horizontal abduction range (optimal cut-off point determined to be 39°).

TABLE 4 | Comparison of shoulder range data of swimmers with normative data of the general population†.

	SHAB	SIR	SE	SER	SHADD	SAB	SF
General population (grade)*	30–45[1,4]	65–90[2,7]	50–60[2,4]	90[2,3,7]	135[1,5]	180[2,4]	180[2,4]
Pain-free swimmers (grade)	41.5	75	92.8	132.8	155.1	176.9	180.8
Swimmers with shoulder pain (grade)	36.6	69.3	88.3	129.1	152.2	176	174.8

*SE, shoulder extension; SF, shoulder flexion; SHAB, shoulder horizontal abduction; SAB, shoulder abduction; SHADD, shoulder horizontal adduction; SIR, shoulder internal rotation; SER, shoulder external rotation. *Normative data established by 1: Gerhardt (1994); 2: Palmer and Epler (2002); 3: Gerhardt et al. (2002); 4: Clarkson (2003); 5: Peterson et al. (2005); †Values are expressed in degrees.*

(Beach et al., 1992), in 8 elite swimmers from 15 to 25 years old (SER, 110°; SIR, 68°) (Bak and Magnusson, 1997), in 133 swimmers from 17 to 35 years old (SER, 110.7°; SIR, 70.6°) (Bansal et al., 2007) and in 30 elite swimmers from 15 to 25 years old (SER, 81.8°; SIR, 62°) (Contreras-Fernández et al., 2010). However, Beach et al. (1992) determined a higher range of shoulder movement than in the present study in 28 college swimmers from 15 to 21 years old (SHAB, 44°; SAB, 195.5°; SF187.5°).

In the current study the ROM was similar in boys and girls and there were no significant differences when the ROM was analyzed by laterality (dominant limb vs. non-dominant limb); other studies agree with the current investigation not identifying statistically significant differences by sex (Greipp, 1985; Walker et al., 2012; Hibberd et al., 2016) and laterality (Contreras-Fernández et al., 2010; Rodeo et al., 2016; McLaine et al., 2018) in swimmers.

On the one hand, it could be possible that the similar training load per week and body mass index found in men and women are related to no differences in the ROM by sex. On the other hand, the similarity when the results were compared by laterality could be due to the symmetry in the execution of the four swimming styles (Wanivenhaus et al., 2012).

Intrinsic Risk Factors for the Development of SP

Several factors such as age, sex, weight, height, BMI, years of competitive experience, quantity of training hours per week, competitive level or ROM have been suggested as possible risk factors for SP (Bansal et al., 2007; Tate et al., 2012; Walker et al., 2012; Harrington et al., 2014; Ristolainen et al., 2014; Struyf et al., 2017). In the current study, significant differences were found when the results were compared between sufferers and non-sufferers of SP. Concretely, those who suffered from SP had significantly less ROM than non-sufferers ($p = 0.005$; $d = -0.96$ (moderate effect sizes). Furthermore, a lower SHAB ROM (reduced extensibility of pectoralis major and anterior capsular contracture) was identified as the only predisposing factor for the manifestation of SP in this multivariable model with swimmers. The pectoralis major, teres minor, serratus anterior were the most active muscles during the initial powerful adduction, extension, neutral rotation of the humerus in the early pull-through phase (maximum forward extension to 90° flexion), as this phase is the most important in the swimmer's propulsion (Wanivenhaus et al., 2012; De Martino and Rodeo, 2018).

The results of the present investigation are consistent with the suggestion of many experts in sports medicine who believe that muscular flexibility plays an important role in overuse injuries which includes subacromial impingement, rotator tendinosis, and biceps tendinosis (Bradley et al., 2016; Hibberd et al., 2016; Rodeo et al., 2016). However, few prospective studies have been performed to examine the shoulder joint ROM and its relationship with shoulder injuries or SP. In addition, it is worth noting that most of these studies have only analyzed the shoulder rotation ROM.

Walker et al. (2012) in their prospective study found that a decreased SIR ROM and an increased SER ROM was significantly associated with SP in competitive swimmers. Bansal et al. (2007) observed the same results in a descriptive study which compared swimmers with shoulder impingement pain with asymptomatic swimmers. Greipp (1985) determined a strong correlation between limited SE ROM and the incidence of "swimmer's shoulder" in College swimmers. Tate et al. (2012) showed in their cross-sectional study that decreased passive SIR and SF ROM in 8–11 years old swimmers and pectoralis minor tightness in 15–19 years old swimmers were significantly associated with SP. On the contrary, four studies found no association or a low correlation between shoulder ROMs (SHAB, SIR, SE, SER, SHADD, SAB, and SF) and shoulder pain in competitive swimmers (Beach et al., 1992; Bak and Magnusson, 1997; Contreras-Fernández et al., 2010; Harrington et al., 2014).

Determining Diagnostic Cut-Off for SHAB ROM With High Risk of Developing SP

Experts in clinical musculoskeletal assessment have established the cut-off point of limited SHAB ROM in the general adult population at 0° (Palmer and Epler, 2002; Clarkson, 2003; Peterson et al., 2005), whereas, Gerhardt (1994) and Clarkson (2003) established clinical normality in the SHAB ROM at 30° and 45° for the same population, respectively. However, these data are not the result of a prospective study but of the clinical experience of experts in musculoskeletal evaluation. In addition, no relationship between the data of normality and tightness was observed.

Walker et al. (2012) found the cut-off point in SER ROM at 93° in a longitudinal study with competitive swimmers from 11 to 27 years old. These authors identified that youth swimmers who had a low SER ROM ($<93°$) were more likely to develop SP. As for the present investigation, the optimal cut-off point for SHAB ROM was set at 39° in order to predict if there is a high risk of developing SP. Nevertheless, this cut-off point seems to be only suitable when it is used in youth swimmers, while it is not that applicable in other age groups, movements or sports. In addition, it has been observed that the pain of the swimmer's shoulder depends significantly on the ROM classification at this point (limited, $\leq 39°$ and normal, $>39°$).

Our findings suggest that further investigation of shoulder ROM as a risk factor for the development of SP in swimmers is worthwhile. One of the principal limitations of this research was the sample size that using only U12-20 competitive swimmers means that results are generalisable to the young population; also, the registry of shoulder pain should be complemented with medical diagnostic tests to identify the specific shoulder pathology (subacromial impingement, rotator tendinosis, subscapularis tendinosis and biceps tendinosis). We propose that the investigation of shoulder ROM in combination with other factors with an artificial intelligence analysis may enhance our understanding of risk factors for shoulder pain in swimmers and provide direction for injury prevention programs.

The first strength of the present study is to define the first shoulder flexibility profile in young swimmers. Most studies evaluate two or three shoulder movements. In our case, we consider it important to assess all shoulder movement. In this way, we have identified the movement and its corresponding reference value that predisposes to shoulder pain in the swimmers analyzed. It should also be noted that a simpler, faster and more reproducible procedure has been used than the digital inclinometer and goniometer to assess the ROM. This assessment is an interesting tool for explaining to professionals in this sport.

Possible Clinical Implications and Conclusion

These findings suggest that coaches and professionals in sport sciences should pay great attention to the regular assessment of ROM during the sport season, and consequent prescriptive measures should be taken and in order to correct the marked reduced ROM. Since reduced SHAB ROM might occur due to tightness in the pectoralis major and anterior capsular contracture (Palmer and Epler, 2002; Clarkson, 2003; Peterson et al., 2005), stretching and foam rolling are commonly used to restore ROM lost as a consequence of muscular or capsular limitations (McClure et al., 2007; Manske et al., 2010). The incidence of SP might be reduced if all swimmers with a SHAB lower than 39° improved their range of motion. Likewise, optimal shoulder ROM data will improve the physical and technical performance of swimmers in competition. A shoulder with an optimal ROM is important to perform the bilateral stroke without any assistance in body roll (Greipp, 1985; De Martino and Rodeo, 2018).

CONCLUSION

This study clearly shows that a low range of shoulders horizontal abduction predisposes toward the manifestation of shoulder pain in competitive young swimmers. A shoulder horizontal abduction range of 39° was set as the optimal cut-off point in order to predict shoulder pain among young swimmers. This useful information should be employed so as to identify individuals who have higher risk in swimming teams and to enable subsequent preventive actions. The application of stretching exercises in the pectoralis major and anterior capsule of the shoulder may help to reduce shoulder pain among swimmers in the future.

AUTHOR CONTRIBUTIONS

All authors participated in the design, documentation, development, and writing of the manuscript. This manuscript was reviewed by all authors and all of them are responsible for its contents and providing they are responsible for the final version.

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REFERENCES

Ayala, F., Moreno-Pérez, V., Vera-García, F. J., Moya, M., Sanz-Rivas, D., and Fernández-Fernández, J. (2016). Acute and time-course effects of traditional and dynamic warm-up routines in young elite junior tennis players. *PLoS One* 11:e0152790. doi: 10.1371/journal.pone.0152790

Backman, L., and Danielson, P. (2011). Low range of ankle dorsiflexion predisposes for patellar tendinopathy in junior elite basketball players, A 1-year prospective study. *Am. J. Sports Med.* 39, 2626–2633. doi: 10.1177/0363546511420552

Bak, K. (2010). The practical management of swimmer's painful shoulder: etiology, diagnosis, and treatment. *Clin. J. Sport Med.* 20, 386–390. doi: 10.1097/jsm.0b013e3181f205fa

Bak, K., and Magnusson, S. P. (1997). Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Am. J. Sports Med.* 25, 454–459. doi: 10.1177/036354659702500407

Bansal, S., Sinha, A. G. K., and Sandhu, J. S. (2007). Shoulder impingement syndrome among competitive swimmers in India. Prevalence, evaluation and risk factors. *J. Exerc. Sci. Fit.* 5, 102–108.

Beach, M. L., Whitney, S. L., and Dickoff-Hoffman, S. A. (1992). Relationship of shoulder flexibility, strength and endurance to shoulder pain in competitive swimmers. *J. Orthop. Sports Phys. Ther.* 16, 262–268. doi: 10.2519/jospt.1992.16.6.262

Bishop, D. (2003). Warm up II: performance changes following active warm up and how to structure the warm up. *Sports Med.* 33, 483–498. doi: 10.2165/00007256-200333070-00002

Bradley, J., Kerr, S., Bowmaker, D., and Gomez, J.-F. (2016). Review of shoulder injuries and shoulder problems in competitive swimmers. *Am. J. Sports Sci. Med.* 4, 57–73. doi: 10.12691/ajssm-4-3-1

Cadogan, A., Laslett, M., Hing, W., McNair, P., and Williams, P. (2011). Reliability of a new hand-held dynamometer in measuring shoulder range of motion and strength. *Man. Ther.* 16, 97–101. doi: 10.1016/j.math.2010.05.005

Cejudo, A., Sainz de Baranda, P., Ayala, F., and Santonja, F. (2015). Test-retest reliability of seven common clinical tests for assessing lower extremity muscle flexibility in futsal and handball players. *Phys. Ther. Sport* 16, 107–113. doi: 10.1016/j.ptsp.2014.05.004

Clarkson, H. M. (2003). *Proceso Evaluativo Músculoesquelético*. Barcelona: Paidotribo.

Contreras-Fernández, J., Espinoza-Aravena, R., Liendo-Verdugo, R., Torres-Galaz, G., and Soza-Rex, F. (2010). Análisis de la rotación interna y externa de la articulación glenohumeral y su relación con el dolor de hombro en nadadores de élite. *Rev. Andal. Med. Deporte* 3, 92–97.

Coombes, B. K., Bisset, L., and Vicenzino, B. (2010). Efficacy and safety of corticosteroid injections and other injections for management of tendinopathy: a systematic review of randomised controlled trials. *Lancet* 376, 1751–1767. doi: 10.1016/S0140-6736(10)61160-9

Cortes, C., and Mohri, M. (2004). "AUC optimization vs. error rate minimization," in *Advances in Neural Information Processing Systems*, eds S. Thrun, L. Saul, and B. Schölkopf (Cambridge: MIT Press).

De Martino, I., and Rodeo, S. A. (2018). The swimmer's shoulder: multi-directional instability. *Curr. Rev. Musculoskelet. Med.* 11, 167–171. doi: 10.1007/s12178-018-9485-0

Dischler, J. D., Baumer, T. G., Finkelstein, E., Siegal, D. S., and Bey, M. J. (2017). Association between years of competition and shoulder function in collegiate swimmers. *Sports Health* 10, 113–118. doi: 10.1177/1941738117726771

Fousekis, K., Tsepis, E., Poulmedis, P., Athanasopoulos, S., and Vagenas, G. (2011). Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. *Br. J. Sports Med.* 45, 709–714. doi: 10.1136/bjsm.2010.077560

Gerhardt, J. (1994). *Documentation of Joint Motion*. Oregon: ISOMED.

Gerhardt, J., Cocchiarella, L., and Lea, R. (2002). *The Practical Guide to Range of Motion Assessment*. Chicago: American Medical Association.

Greipp, J. F. (1985). Swimmer's shoulder: the influence of flexibility and weight training. *Phys. Sportsmed.* 13, 92–105. doi: 10.1080/00913847.1985.11708859

Harrington, S., Meisel, C., and Tate, A. (2014). A cross-sectional study examining shoulder pain and disability in division I female swimmers. *J. Sport. Rehabil.* 23, 65–75. doi: 10.1123/jsr.2012-0123

Heinlein, S. A., and Cosgarea, A. J. (2010). Biomechanical considerations in the competitive swimmer's shoulder. *Sports Health* 2, 519–525. doi: 10.1177/1941738110377611

Hibberd, E. E., Laudner, K., Berkoff, D. J., Kucera, K. L., Yu, B., and Myers, J. B. (2016). Comparison of upper extremity physical characteristics between adolescent competitive swimmers and nonoverhead athletes. *J. Athl. Train.* 51, 65–69. doi: 10.4085/1062-6050-51.2.04

Higson, E., Herrington, L., Butler, C., and Horsley, I. (2018). The short-term effect of swimming training load on shoulder rotational range of motion, shoulder joint position sense and pectoralis minor length. *Shoulder Elbow* 10, 285–291. doi: 10.1177/1758573218773539

Hill, L., Collins, M., and Posthumus, M. (2015). Risk factors for shoulder pain and injury in swimmers: a critical systematic review. *Phys. Sportsmed.* 43, 412–420. doi: 10.1080/00913847.2015.1077097

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–12. doi: 10.1249/mss.0b013e31818cb278

Hosmer, D. W., and Lemeshow, S. (1989). *Applied Logistic Regression*. New York, NY: John Wiley and Sons.

King, D. (1995). Glenohumeral joint impingement in swimmers. *J. Athl. Trains.* 27, 44–49.

Manske, R. C., Meschke, M., Porter, A., Smith, B., and Reiman, M. (2010). A randomized controlled single-blinded comparison of stretching versus stretching and joint mobilization for posterior shoulder tightness measured by internal rotation motion loss. *Sports Health* 2, 94–100. doi: 10.1177/1941738109347775

McClure, P., Balaicuis, J., Heiland, D., Broersma, M. E., Thorndike, C. K., and Wood, A. (2007). A randomized controlled comparison of stretching procedures for posterior shoulder tightness. *J. Orthop. Sports Phys. Ther.* 37, 108–114. doi: 10.2519/jospt.2007.2337

McLaine, S. J., Bird, M.-L., Ginn, K. A., Hartley, T., and Fell, J. W. (2018). Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers? *J. Sci. Med. Sport* doi: 10.1016/j.jsams.2018.11.008 [Epub ahead of print].

McMaster, W. C. (1999). Shoulder injuries in competitive swimmers. *Clin. Sports Med.* 18, 349–359. doi: 10.1016/s0278-5919(05)70150-2

McMaster, W. C., Roberts, A., and Stoddard, T. (1998). A correlation between shoulder laxity and interfering pain in competitive swimmers. *Am. J. Sports Med.* 26, 83–86. doi: 10.1177/03635465980260013201

Mullaney, M. J., McHugh, M. P., Johnson, C. P., and Tyler, T. F. (2010). Reliability of shoulder range of motion comparing a goniometer to a digital level. *Physiother. Theory Pract.* 26, 327–333. doi: 10.3109/09593980903094230

Norkin, C., and White, J. (2006). *Goniometría. Evaluación de la Movilidad Articular*. Madrid: Marban.

Okamura, S., Wada, N., Tazawa, M., Sohmiya, M., Ibe, Y., Shimizu, T., et al. (2014). Injuries and disorders among young ice skaters: relationship with generalized joint laxity and tightness. *Open Access J. Sports Med.* 5, 191–195. doi: 10.2147/oajsm.s63540

Palmer, M. L., and Epler, M. E. (2002). *Fundamentos de las Técnicas de la Evaluación Musculoesquelética*. Barcelona: Paidotribo.

Peterson, F., Kendall, E., and Geise, P. (2005). *Kendall's Músculos. Pruebas, Funciones y Dolor Postural*. Madrid: Marbán.

Ristolainen, L., Kettunen, J. A., Waller, B., Heinonen, A., and Kujala, U. M. (2014). Training-related risk factors in the etiology of overuse injuries in endurance sports. *J. Sport Med. Phys. Fit.* 54, 78–87.

Rodeo, S. A., Nguyen, J. T., Cavanaugh, J. T., Patel, Y., and Adler, R. S. (2016). Clinical and ultrasonographic evaluations of the shoulders of elite swimmers. *Am. J. Sports Med.* 44, 3214–3221. doi: 10.1177/0363546516657823

Sainz de Baranda, P., Cejudo, A., Ayala, F., and Santonja, F. (2015). Perfil óptimo de flexibilidad de la extremidad inferior en jugadoras de fútbol sala. *Rev.int.med.cienc.act.fís.deporte* 15, 647–662.

Santonja, F., Ferrer, V., and Martínez, I. (1995). Exploración clínica del síndrome de isquiosurales cortos. *Selección* 4, 81–91.

Sein, M. L., Walton, J., Linklater, J., Appleyard, R., Kirkbride, B., Kuah, D., et al. (2010). Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *Br. J. Sports Med.* 44, 105–113. doi: 10.1136/bjsm.2008.047282

Struyf, F., Tate, A., Kuppens, K., Feijen, S., and Michener, L. A. (2017). Musculoskeletal dysfunctions associated with swimmers' shoulder. *Br. J. Sports Med.* 51, 775–780. doi: 10.1136/bjsports-2016-096847

Tak, I., Engelaar, L., Gouttebarge, V., Barendrecht, M., Van den Heuvel, S., Kerkhoffs, G., et al. (2017). Is lower hip range of motion a risk factor for groin pain in athletes? A systematic review with clinical applications. *Br. J. Sports Med.* 51, 1611–1621. doi: 10.1136/bjsports-2016-096619

Tate, A., Turner, G. N., Knab, S. E., Jorgensen, C., Strittmatter, A., and Michener, L. A. (2012). Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. *J. Athl. Train.* 47, 149–158. doi: 10.4085/1062-6050-47.2.149

Torres, E. M., Kraemer, W. J., Vingren, J. L., Volek, J. S., Hatfield, D. L., Spiering, B. A., et al. (2008). Effects of stretching on upper-body muscular performance. *J. Strength Cond. Res.* 22, 1279–1285. doi: 10.1519/jsc.0b013e31816eb501

Walker, H., Gabbe, B., Wajswelner, H., Blanch, P., and Bennell, K. (2012). Shoulder pain in swimmers: a 12-month prospective cohort study of incidence and risk factors. *Phys. Ther. Sport* 13, 243–249. doi: 10.1016/j.ptsp.2012.01.001

Wanivenhaus, F., Fox, A. J. S., Chaudhury, S., and Rodeo, S. A. (2012). Epidemiology of injuries and prevention strategies in competitive swimmers. *Sports Health* 4, 246–251. doi: 10.1177/1941738112442132

Witvrouw, E., Bellemans, J., Lysens, R., Danneels, L., and Cambier, D. (2001). Intrinsic risk factors for the development of patellar tendinitis in an athletic population a two-year prospective study. *Am. J. Sports Med.* 29, 190–195. doi: 10.1177/03635465010290021201

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Laboratory and Non-laboratory Assessment of Anaerobic Performance of Elite Male Wheelchair Basketball Athletes

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Wheelchair basketball is an adaptive Paralympic sport and wheelchair basketball players are under classification in sport. Coaches are looking for useful assessment tools (field-based tests) to evaluate players' anaerobic performance (anaerobic capacity). The aim of this study was to assess the validity of field-based tests for anaerobic performance evaluation for two functional categories of wheelchair basketball players and to create a calculator to predict mean or peak power on the basis of the selected field-based test results. Sixty-one elite male wheelchair basketball players performed the Wingate Anaerobic Test and the following field-based tests: 3 m sprint, 5 m sprint, 10 m sprint, 20 m sprint, basketball chest pass test, medicine ball (3 kg) chest pass test, bilateral handgrip, 3-6-9 m drill test, 30-s sprint test, agility drill test and 10 × 5 m sprint test. The participants were divided into two functional categories: A (classes from 1.0 to 2.5; $n = 29$) and B (classes from 3.0 to 4.5; $n = 32$) according to the International Wheelchair Basketball Federation rules. The large effect size (Cohen's $d > 0.5$) was found in four tests (3 m sprint, 5 m sprint, basketball chest pass test, medicine ball chest pass test; ES 0.90, 0.53, –0.96, –1.05). There were differences between category A and category B players regarding mean power, peak power and relative peak power. Peak power correlated with four tests, while mean power correlated with eight out of eleven tests. The formulas for estimating peak power or mean power in category A and B players were created separately. All the analyses confirmed that 3 m sprint, 5 m sprint, 10 m sprint, 20 m sprint, agility drill test, bilateral handgrip, 3-6-9 m drill test, 30-s sprint test, basketball chest pass test and medicine ball chest pass test are valid for non-laboratory anaerobic performance evaluation. Using the four formulas as a tool to predict mean or peak power on the basis of the selected field-based test results and functional categories will be helpful and will allow coaches and players to prepare pre-season, post-season and in-season conditioning exercises in wheelchair basketball.

Keywords: Paralympic sport, anaerobic capacity, field-based testing, wheelchair basketball players, classification in sport, useful assessment tool, adaptive sports

INTRODUCTION

Wheelchair basketball is a high-profile Paralympic sport. Rules of wheelchair basketball are similar to those in "running" basketball and are described by the International Wheelchair Basketball Federation (IWBF), 2018). The players with different physical impairments are divided into functional classes (International Wheelchair Basketball Federation, 2014). There are five major functional classes: 1.0, 2.0, 3.0, 4.0 and 4.5 (a higher class denotes a higher level of functional abilities on the court). Furthermore, players with functional capabilities of two neighboring classes can be classified as 1.5, 2.5 or 3.5. The sum of points of five players in one team on the court cannot exceed 14 (International Wheelchair Basketball Federation (IWBF), 2018). Players can be classified to category A (1.0 to 2.5) or category B (3.0 to 4.5) (International Wheelchair Basketball Federation, 2014).

The assessment of physical fitness in wheelchair basketball players is important in order to evaluate their physical state. Previous studies have shown that wheelchair basketball players perform intermittent efforts in the game and indicated an important role of short-time maximal-intensity efforts (Coutts, 1992; Goosey-Tolfrey, 2005; Hutzler et al., 2000). Coutts (1992) suggested that wheelchair basketball players required aerobic as well as anaerobic performance (e.g., during an attack, in defense and playing with the ball). Hutzler et al. (2000) concluded that anaerobic performance depended on the efficiency of wheelchair basketball players on the court. Goosey-Tolfrey (2005) indicated that short-term efforts are very important for wheelchair basketball players and an improvement in anaerobic performance could affect players' abilities on the court. This author also underlined the fact that an improvement in anaerobic performance is significant particularly for low-category players due to their trunk instability. There are several studies which introduced and explained the specificity of wheelchair basketball intensity (Croft et al., 2010; Iturricastillo et al., 2016; Iturricastillo et al., 2018; Mason et al., 2018; Marszalek et al., 2019). For instance, Croft et al. (2010) underlined that the specificity of wheelchair basketball required high-intensity efforts, e.g., in shooting, dynamic maneuvering or rebounds, and training these skills with high intensity would be more beneficial for players. Mason et al. (2018) highlighted the fact that wheelchair basketball players should practice more 3 vs. 3 small-sided games on half a court to practice high-intensity technical skills like turnovers, rotations, rebounds and shots more efficiently. Iturricastillo et al. (2016) observed high maximum heart rate (HRpeak) in wheelchair basketball games, which means that wheelchair basketball is a demanding sport. They also noted that the rate of perceived exertion (RPE) is the most useful method of assessing match load. Iturricastillo et al. (2018) showed that playoff wheelchair basketball matches were more demanding than league matches. Marszalek et al. (2019) investigated the percentage time contribution of elite players in five heart rate zones during a basketball game. It turned out that players spent 65% of game time in three heart rate zones (60–69%, 70–79% and 80–89% HRpeak). Compared to players from category B, players from category A spent less time in the fifth heart rate zone (90–100% HRpeak; 15 vs. 21%). This study also confirmed intermittent efforts in wheelchair basketball.

Research has revealed certain relationships between classification levels and athletes' anaerobic performance (Hutzler et al., 1998; Molik et al., 2006, 2010a,b, 2013; de Lira et al., 2010). For instance, de Lira et al. (2010) observed correlations between functional classification of players and their level of anaerobic performance in terms of peak power (PP), relative peak power (rPP) and mean power (MP). The authors confirmed that the functional classification in wheelchair basketball depends on players' ability on the court and their levels of anaerobic performance. Taking into account PP in the Wingate Anaerobic Test (WAnT), Hutzler et al. (1998) divided male wheelchair basketball players into three groups: high-level paraplegia, low-level paraplegia (category A) and amputation of lower limbs (category B). Molik et al. (2010a,b) compared Polish and Lithuanian wheelchair basketball players' anaerobic performance (results in the WAnT and in six field-based tests) across all eight classification levels. The level of anaerobic performance demonstrated by athletes in classification category A (functional classes 1.0 to 2.5) was significantly lower compared to category B (3.0 to 4.5), whereas differences between neighboring classes were not found. Also, differences between categories A and B in the results of the WAnT have been found in other studies carried out on male Polish league players and elite female players (Canadian Wheelchair Basketball Team) (Molik et al., 2006, 2013). However, Yanci et al. (2015) did not report significant differences between category A and B in field-based tests such as sprint (5–20 m with and without ball), agility tests (*T*-test and pick-up) and strength tests (handgrip and maximal pass).

In the literature, the Wingate Anaerobic Test (WAnT) is the most popular high-intensity test used for athletes with physical impairments. Accordingly, this test has previously been used among wheelchair basketball players to determine anaerobic performance (PP, rPP, MP, rMP and the fatigue index – FI) (Hutzler et al., 1998; Vanlandewijck et al., 1999; Goosey-Tolfrey, 2005; Hutzler et al., 2000; Molik et al., 2006, 2010b, 2013; de Lira et al., 2010).

It would be useful for practitioners to assess players' anaerobic performance using easy and feasible field-based tests, not only laboratory tests. For instance, Vanlandewijck et al. (1999) showed correlations between anaerobic performance and field tests – layup, figure-eight + ball, 20 m sprint, zone-shot, figure-eight, pass for accuracy. The authors concluded that the field-based battery of tests is reliable and valid for male wheelchair basketball players with respect to the parameters of anaerobic performance and basketball skill proficiency. Moreover, the authors underlined a strong correlation between the distance covered in the anaerobic field test (30 s sprint) and the WAnT (r = 0.93). Molik et al. (2013) selected seven field-based tests: 5 m and 20 m sprint, basketball chest pass test, slalom with the ball, slalom without the ball, shooting accuracy test and bilateral handgrip. The strongest correlation between the WAnT and the field-based test was found for the two-handed chest pass test. This result indicated that the chest pass test can be used to assess anaerobic performance indirectly. De Groot et al. (2012) also confirmed the reliability and validity of selected field-based tests for wheelchair basketball players such as 20 m sprint with ball, picking up the ball, suite, lay-up, spot shot and pass for accuracy. Yanci et al. (2015) confirmed high reliability of the agility *T*-test for the measurements of physical fitness of wheelchair basketball players. Several other researchers used the 20 m sprint test (Traballesi et al., 2009; Chapman et al., 2010; Yanci et al., 2015) or repetitive 15 × 20 m sprints (total time noted) (Goosey-Tolfrey et al., 2010) to measure anaerobic performance of wheelchair basketball players.

In general, findings show inconclusive results regarding differences between two functional categories of wheelchair basketball players. Moreover, previous studies have not looked into the relationships between field and laboratory tests separately for each functional category (A and B). Finally, regression models that would eventually help to predict mean power (MP) or peak power (PP) on the basis of field-based test results have not been developed in previous studies. Therefore, the aim of this study was to assess the validity of field-based tests for anaerobic performance evaluation for two functional categories of wheelchair basketball players and to create a calculator to predict MP or PP on the basis of the selected field-based test results.

MATERIALS AND METHODS

Participants

Sixty-one elite male wheelchair basketball players (mean age 28.5 ± 6.7 years) representing national wheelchair basketball teams of Poland (n = 23), Latvia (n = 8), Lithuania (n = 11) and France (n = 19) volunteered to participate in this study. They were informed about the purpose and all testing procedures and were asked to sign the consent form. This study was carried out in accordance with the recommendations of 'Ethics and Bioethics Committee of the Cardinal Stefan Wyszynski University' (Komisja Etyki i Bioetyki Uniwersytetu Kardynała Stefana Wyszyńskiego; KEIB – 10/2016) and 'the Senate Ethics Commission of Jozef Pilsudski University of Physical Education in Warsaw' (Senacka komisji Etyki Akademii Wychowania Fizycznego Józefa Piłsudskiego w Warszawie; SKE 01-16/2017), with written informed consent from all subjects. All the procedures were approved by the local Bioethics Committees (KEIB – 10/2016, SKE 01-16/2017) and were completed in accordance with the ethical standards as described in the Declaration of Helsinki. Data collection was carried out between February 2017 and July 2018, during training camps of the national wheelchair basketball teams.

The participants were divided into two functional categories: A (classes from 1.0 to 2.5; n = 29) and B (classes from 3.0 to 4.5; n = 32) according to the IWBF rules (International Wheelchair Basketball Federation, 2014). All the players were evaluated by international classifiers. The health conditions of participating athletes were as follows: spinal cord injury (n = 28), spina bifida (n = 8), lower limb amputations (n = 13), poliomyelitis (n = 2), cerebral palsy (n = 1) and other physical impairments (n = 9).

All individuals were asked about their age and wheelchair basketball training experience. Body mass, upper limb reach in a seated position (in sports wheelchair) and range of upper limbs were measured. The characteristics of wheelchair basketball players are presented in **Table 1**.

Procedure

The Laboratory Test – The Wingate Anaerobic Test

The Wingate Anaerobic Test (the WAnT) was conducted on LODE ANGIO (Groningen, Netherlands) arm crank ergometer (ACE) using the Wingate Anaerobic Software Package – Wingate v.1.07b (Groningen, Netherlands). To maximize the players' trunk stability, the athletes used their own basketball wheelchairs and strapping. The ACE was firmly fixed to a wall-mounted gymnastic ladder. The axis of rotation of the ergometer was set at the level of the athlete's glenohumeral joints. To help minimize rotational movements while arm-cranking, the wheelchair itself was stabilized by two assistants.

Each athlete performed one WAnT protocol. The test protocol included a 2-min cranking warm-up at 60 rpm with 50 W resistance for 2 min. Then, resistance was automatically set at the predetermined testing level and the athlete was instructed to crank as fast as possible for 30 s. The software began the 30-s count down as soon as the level of 25 rpm was achieved. Verbal encouragement was given throughout the test. During the assessment of anaerobic performance, the resistance of the ergometer was set on the basis of an individual profile, i.e., 4% of body mass for participants of category A and 5.5% for players belonging to category B.

Four parameters were measured during the WAnT, i.e., peak power (PP) defined as the highest 5-s power output, mean power (MP) defined as the average power sustained throughout the 30-s period, relative peak power (rPP; scaled to individual body mass in kilograms) and relative mean power (rMP; scaled to individual body mass in kilograms).

TABLE 1 | Characteristics of wheelchair basketball athletes.

Category	Age [years]	Sports experience [years]	Body mass [kg]	Upper limb reach in a seated position [cm]	Range of upper limbs [cm]
Category A (class 1.0–2.5)	27.3 ± 6.6	6.9 ± 4.5	77.4 ± 27.5	179.0 ± 16.6	178.4 ± 36.7
Category B (class 3.0–4.5)	29.3 ± 6.9	8.7 ± 6.3	77.5 ± 14.2	197.7 ± 22.7	188.5 ± 9.3
Total	28.5 ± 6.7	7.2 ± 5.6	77.4 ± 21.2	185.7 ± 22.1	187.7 ± 22.4

The Non-laboratory Tests – Field-Based Tests

To assess short-term maximal-intensity efforts, the following eleven field-based tests were used: 3 m sprint, 5 m sprint, 10 m sprint, 20 m sprint, basketball chest pass test, medicine ball (3 kg) chest pass test, bilateral handgrip, 3-6-9 m drill test, 30-s sprint test, agility drill test and 10 × 5 m sprint test. Time in all sprint tests was measured with the use of Microgate® photocells (electronic time measurement system with an accuracy of 0.01 s; Bolzano, Italy) and Witty Manager software (version 1.4.1). The participant was seated with the rear wheel axle lined up with the starting line and the timer was activated automatically when the participant was ready to start. All the tests were performed within 1 day with long intervals. Before the testing, all players were asked to do a warm-up for 10 min by themselves (propelling the wheelchair around the court, dynamic stretching of upper limbs and trunk).

The field-based tests were performed according to the following procedure:

- 3 m sprint, 5 m sprint, 10 m sprint, 20 m sprint tests. The participants pushed as hard and as fast as they could over the 3, 5, 10 or 20 m course. The result was the time in seconds (the faster of the two attempts).
- Bilateral handgrip. The participants squeezed a manual handgrip dynamometer DR3 with tensometer WTP003 using software version 3.1. They performed the test seated in their wheelchairs with the tested arm fully extended and not touching the wheelchair. The result was the combination of the value for the right and left hand.
- Basketball chest pass test and medicine ball (3 kg) chest pass test. The participants were in their wheelchairs with their feet placed on the footrest. The rear wheel axle was lined up with the starting line. The participants were encouraged to perform the task using arms as symmetrically as possible. The result was the distance covered by the ball, the best out of three attempts, measured with a tape from the starting line to the place where the ball fell. The measurement error was ±5 cm.
- 30-s sprint test. The participants propelled their wheelchairs as fast as they could over the distance of 20 m, turned and propelled back for 30 s. The result was the achieved distance in meters. There was only one attempt.
- Agility drill test. The participants propelled as fast as they could over the 12-m course in a straight line, came back to start a slalom (four cons) and returned through the slalom. Then, they went straight over the 12-m course and came back (**Figure 1**). The result was the time in seconds (the faster of the two attempts).
- 3-6-9 m drill test. The participants propelled as fast as they could over the 3-m course and came back to the starting line, then they covered the distance of 6 m and came back to the starting line. Finally, they propelled for 9 m and returned to the starting line (**Figure 2**). The result was the time in seconds (the faster of the two attempts).
- 10 × 5 m sprint test. The participants propelled as fast as they could 10 times over the 5-m course. The result was the time in seconds (the faster of the two attempts).

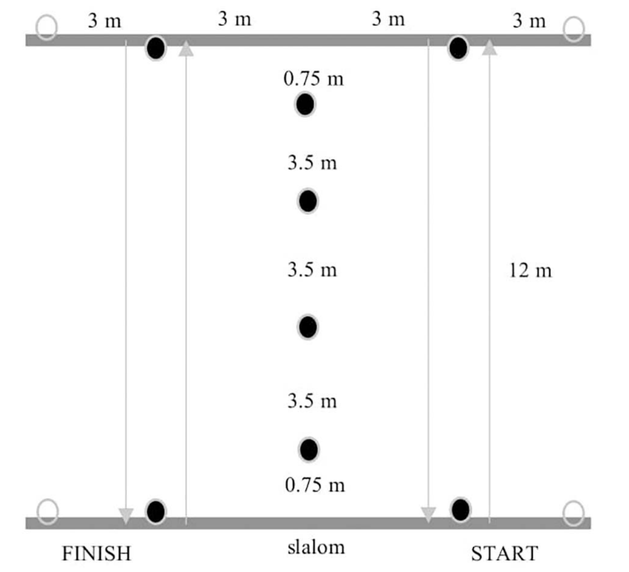

FIGURE 1 | The scheme of the agility drill test (authors' own interpretation).

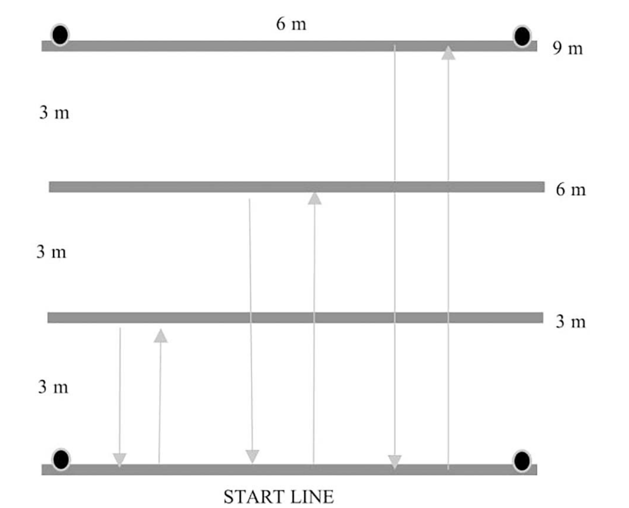

FIGURE 2 | The scheme of the 3-6-9 m drill test (authors' own interpretation).

Statistical Analysis

We first compared all the data collected (dependent variables) from categories A and B (factor) using the *t*-test for independent samples. When assumptions of normal distribution (Shapiro–Wilk test) or equal variances (Levene's test) were violated, the Mann–Whitney *U* test was performed instead. The effect size was displayed with Cohen's *d*, with 0.2, 0.5, and 0.8 values of d for small, medium and large effects, respectively (Cohen, 1988).

Afterward, we performed a correlation analysis between field and laboratory dependent variables using Pearson's *r* correlation test for each category (A and B). The level of significance was set at $p < 0.05$ and weak correlation at $r = 0.1–0.3$, moderate correlation at $r = 0.31–0.5$ and strong correlation at $r > 0.5$ (Cohen, 1988). Finally, we developed regression models to estimate the parameters of the WAnT (MP, PP, rMP and rPP) out of all field-test measures for each category separately. Collinearity and autocorrelation were controlled with Tolerance test and Durbin–Watson test, respectively, whereas further assumptions were controlled by means of Q-Q and residual scatterplots. Jamovi software (V.0.9.5.12 for Mac) was used to perform statistical analysis.

RESULTS

Table 2 presents information regarding the performance of the players and differences between categories in field tests. The large effect size (Cohen's $d > 0.5$) was found in four tests (3 m sprint, 5 m sprint, basketball chest pass test, medicine ball chest pass test) that showed differences between players from category A and B (**Table 2**).

Table 3 includes the participants' performance in WAnT with regard to each category. Differences between categories were found with a large effect size (Cohen's $d > 0.5$) for MP and PP and rPP (**Table 3**).

Table 4 shows the correlation matrix between field and WAnT measures for category A and B. For category A players, PP correlated with the results of three tests, i.e., 3 m sprint, 5 m sprint and medicine ball chest pass test, while MP correlated with the results of eight tests (**Table 4**). For category B players, PP correlated with the results of two tests, i.e., 20 m sprint and medicine ball chest pass test, while MP correlated with the results of seven tests. The results of all WAnT parameters correlated with the results of 3 m sprint and 5 m sprint tests for category A players and with the results of 20 m sprint for category B players (except rPP).

Table 5 shows the regression models used to estimate MP in the WAnT. For category A, the best tests to estimate MP in the WAnT are 3 m sprint test and medicine ball chest pass test:

MP in the WAnT of category A players = 367.46 – 142.06 × 3 m sprint test result + 18.81 × medicine ball chest pass test result.

For category B, the best tests to estimate MP in the WAnT are 10 m sprint test and bilateral handgrip test (**Table 5**):

MP in the WAnT of category B players = 461.42 – 97.47 × 10 m sprint test result + 1.81 handgrip test result.

Table 6 depicts the regression models used to estimate PP in the WAnT. For category A, the best test to estimate PP in the WAnT is 3 m sprint test:

PP in the WAnT of category A players = 1165.77 – 455.08 × 3 m sprint test result.

For category B, the best test to estimate PP in the WAnT is medicine ball chest pass test (**Table 6**):

PP in the WAnT of category B players = 325.10 + 46.65 × medicine ball chest pass test result.

TABLE 2 | Results and differences in the results of field-based tests performed by wheelchair basketball players from the functional category A and B.

Field-based tests	Category	Mean	Median	*SD*	*SE*	Test	*p*	*d*
3 m sprint [s]	A	1.37	1.36	0.12	0.02	*U*	0.004*	0.90^
	B	1.27	1.27	0.09	0.02			
5 m sprint [s]	A	2.14	1.96	0.73	0.16	*U*	0.004*	0.53^
	B	1.87	1.86	0.15	0.03			
10 m sprint [s]	A	3.28	3.21	0.27	0.05	*U*	0.250	0.19
	B	3.22	3.15	0.32	0.06			
20 m sprint [s]	A	5.57	5.48	0.47	0.10	*U*	0.06	0.37
	B	5.40	5.30	0.48	0.09			
Agility drill test [s]	A	29.26	29.06	2.59	0.57	*U*	0.178	0.20
	B	28.67	28.02	3.26	0.67			
Bilateral handgrip [N]	A	100.70	104.00	29.88	6.23	*U*	0.317	– 0.33
	B	109.17	110.00	21.15	4.32			
30-s sprint test [m]	A	99.12	100.00	7.98	1.60	*U*	0.272	– 0.30
	B	101.75	101.00	9.35	1.83			
10 × 5 m sprint test [s]	A	22.42	22.47	0.75	0.37	*T*	0.664	0.28
	B	22.13	21.77	1.15	0.43			
3-6-9 m drill test [s]	A	15.22	14.83	1.28	0.28	*U*	0.869	– 0.06
	B	15.31	14.92	1.91	0.38			
Basketball chest pass test [m]	A	10.21	10.10	1.47	0.29	*U*	0.001*	– 0.96^
	B	12.32	12.20	2.71	0.52			
Medicine ball chest pass test [m]	A	5.90	6.10	0.93	0.19	*T*	0.001*	– 1.05^
	B	7.08	7.30	1.27	0.24			

*Category A – class 1.0–2.5; category B – class 3.0–4.5; *statistically significant difference ($p < 0.05$);^ large effect size (Cohen's $d > 0.50$); SD – standard deviation; SE – standard error; T – T-test; U – Mann–Whitney U test.*

TABLE 3 | Results and differences in the results of the Wingate Anaerobic Test (the WAnT) performed by wheelchair basketball players from functional categories A and B.

WAnT parameters	Category	Mean	Median	*SD*	*SE*	Test	*p*	*d*
Mean power (MP) [W]	A	284.04	295.00	40.70	7.83	*U*	0.001*	– 0.99^
	B	344.00	314.00	74.95	14.42			
Peak power (PP) [W]	A	530.15	527.00	130.58	25.13	*T*	0.001*	– 1.07^
	B	657.04	682.00	104.85	20.18			
Relative mean power (rMP) [W/kg]	A	4.02	4.00	0.67	0.13	*U*	0.188	– 0.49
	B	4.47	4.40	1.11	0.21			
Relative peak power (rPP) [W/kg]	A	7.44	7.60	1.79	0.34	*T*	0.001*	– 1.07^
	B	8.50	8.20	1.61	0.31			
Fatigue index (FI) [W/s]	A	14.33	14.90	5.53	1.06	*T*	0.034*	– 0.59^
	B	17.38	17.40	4.74	0.91			

*Category A – class 1.0–2.5; category B – class 3.0–4.5; *statistically significant difference (p < 0.05);^ large effect size (Cohen's d > 0.50); SD – standard deviation; SE – standard error; T – T-test; U – Mann–Whitney U test.*

TABLE 4 | Correlations between the results of field-based tests and the Wingate Anaerobic Test (the WAnT) performed by wheelchair basketball players from functional categories A and B.

		WAnT parameters							
		Category A				Category B			
Field tests		MP	PP	rMP	rPP	MP	PP	rMP	rPP
3 m sprint [s]	*r*	– 0.69^	– 0.50	– 0.59^	– 0.52^	– 0.33	0.07	– 0.60^	– 0.39
	p	< 0.001*	0.021*	0.005*	0.015*	0.117	0.733	0.002*	0.057
5 m sprint [s]	*r*	– 0.68^	– 0.50	– 0.67^	– 0.58^	– 0.36	– 0.13	– 0.57^	– 0.47
	p	0.001*	0.025*	0.001*	0.008*	0.081	0.536	0.004*	0.021*
10 m sprint [s]	*r*	– 0.44	– 0.16	– 0.69^	– 0.33	– 0.46	– 0.14	– 0.57^	– 0.36
	p	0.036*	0.464	< 0.001*	0.125	0.018*	0.491	0.002*	0.068
20 m sprint [s]	*r*	– 0.40	– 0.22	– 0.66^	– 0.40	– 0.49	– 0.41	– 0.44	– 0.35
	p	0.056	0.302	< 0.001*	0.059	0.011*	0.039*	0.024*	0.081
Agility drill test [s]	*r*	– 0.53^	– 0.13	– 0.71^	– 0.35	– 0.57^	– 0.33	– 0.43	– 0.21
	p	0.015*	0.577	< 0.001*	0.125	0.004*	0.122	0.039*	0.337
Bilateral handgrip [N]	*r*	0.11	– 0.09	0.18	0.04	0.60^	0.35	0.29	– 0.00
	p	0.640	0.696	0.416	0.851	0.003*	0.100	0.178	0.984
30-s. sprint test [m]	*r*	0.44	0.16	0.57^	0.24	0.57^	0.29	0.51^	0.28
	p	0.032*	0.459	0.004*	0.249	0.003*	0.160	0.009*	0.170
10 × 5 m sprint [s]	*r*	0.36	0.57	– 0.09	0.08	– 0.25	– 0.19	– 0.76^	– 0.77^
	p	0.642	0.434	0.911	0.924	0.587	0.683	0.047*	0.042*
3-6-9 drill test [s]	*r*	– 0.49	0.05	– 0.16	0.19	– 0.54^	– 0.30	– 0.47	– 0.26
	p	0.029*	0.823	0.510	0.432	0.006*	0.147	0.019*	0.221
Basketball chest pass test [m]	*r*	0.61^	0.06	0.30	– 0.11	0.21	0.37	– 0.09	– 0.08
	p	0.001*	0.771	0.149	0.602	0.302	0.065	0.665	0.715
Medicine ball chest pass test [m]	*r*	0.74^	0.44	0.19	0.11	0.54^	0.57^	0.14	0.05
	p	< 0.001*	0.030*	0.383	0.621	0.005*	0.002*	0.493	0.794

*Category A – class 1.0–2.5; category B – class 3.0–4.5; *statistically significant Pearson's correlations (p < 0.05);^ strong Pearson's correlations. MP – mean power [W]; PP – peak power [W]; rMP – relative mean power [W/kg]; rPP – relative peak power [W/kg].*

DISCUSSION

The aim of this study was to assess the validity of field-based tests for anaerobic performance evaluation for two functional categories of wheelchair basketball players and to create a calculator to predict MP or PP on the basis of the selected field-based test results. In the first part of this study, the results of field-based tests of players from two functional categories (category A and category B) were compared. Four out of eleven tests, i.e., 3 m sprint, 5 m sprint, basketball chest pass test and medicine ball chest pass test confirmed statistically significant differences between low and high point category wheelchair basketball players.

TABLE 5 | Regression model predicting the influence of field-based tests on the Wingate Anaerobic Test (the WAnT) mean power for categories A and B.

	WAnT parameter – mean power (MP)					
	Category A			Category B		
	B	*SE*	*p*	*B*	*SE*	*p*
Intercept	367.46	62.63	0.001	461.42	132.52	0.002
3 m sprint	– 142.06	35.27	0.001			
Medicine ball chest pass test	18.81	4.54	0.001			
10 m sprint				– 97.47	33.98	0.009
Bilateral handgrip				1.81	0.52	0.003
p	0.001			0.001		
R^2	0.74			0.54		
Durbin–Watson	1.94			0.87		

$p < 0.05$; category A – class 1.0–2.5; category B – class 3.0–4.5.

TABLE 6 | Regression model predicting the influence of field-based tests on the Wingate Anaerobic Test (the WAnT) peak power for categories A and B.

	WAnT parameter – peak power (PP)					
	Category A			Category B		
	B	*SE*	*p*	*B*	*SE*	*p*
Intercept	1165.77	249.81	0.001	325.10	98.97	0.003
3 m sprint	– 455.08	182.00	0.021			
Medicine ball chest pass test				46.65	13.77	0.002
p	0.021			0.002		
R^2	0.26			0.32		
Durbin–Watson	1.31			1.31		

$p < 0.05$; category A – class 1.0–2.5; category B – class 3.0–4.5.

In the literature of the subject, there are few studies exploring the differences in field-based anaerobic performance between category A and B wheelchair basketball players (Molik et al., 2013). Those studies have some limitations as they do not systematically indicate in which tests players from category A had significantly different results compared to players from category B (e.g., different field-based tests, different number of participants). In our study, we partially confirmed the results presented by Yanci et al. (2015), who did not find differences in 20 m sprint test and handgrip test between players from category A and B. Yet, unlike previous results, in our study wheelchair basketball players showed different results in 5 m sprint test as a function of their category. Yanci et al. (2015) also compared agility test results (*T*-test and pick-up test) in different categories. In this case, the findings of the present experiment confirmed the lack of differences between two functional categories in agility tests (agility drill test, 10 × 5 m sprint test, 3-6-9 m drill test). In this sense, agility tests require very good wheelchair propulsion and maneuverability abilities. Even though our participants were elite athletes, we suggest that the results in agility tests could be more dependent on experience in wheelchair propulsion rather than on the players' functional capabilities or types of impairments. Therefore, agility tests should be used by coaches and players to develop wheelchair maneuverability skills on a basketball court.

Previous research showed that performance differences between players of category A and B were apparent in almost all tests (except shooting test) (Molik et al., 2013). Hence, while Molik et al. (2013) revealed differences between elite female players in six out of seven tests, results of the present experiment showed differences only in four out of eleven tests, i.e., in 3 m sprint, 5 m sprint, medicine ball chest pass test and basketball chest pass test. It is worth mentioning that in our experiment, the number of participants assessed was higher than in previous studies by Molik et al. (2013) and Yanci et al. (2015) (61 participants versus 16 and 23 participants, respectively).

de Witte et al. (2018) analyzed 15 different tests (activities) in the group of 46 players on a national and international level. Significant differences in the results of 12 m sprint test were confirmed. However, in the present study we did not find differences between the two categories in 10 m sprint test. Other significant differences underlined by de Witte et al. (2018) were found in 180° turn on the spot (left), 3-3-6 m sprint (sprint with two stops), 90°–90° turn on the spot with a stop (left), 90°–90° turn on the spot with a stop (left) and in combinations. The authors did not find differences in ball dribble and rotations test. These types of tests were not included in our analyses due to a strong influence of a wheeling technique and ball control. Our investigations focused more on relationships with power and anaerobic performance. Still, further research is needed to create the best field-based test battery for wheelchair basketball players.

In the second part of this study, the results of the Wingate Anaerobic Test (the WAnT) were analyzed. The findings of our study confirmed the analysis of Molik et al. (2010b) and showed significant differences between both categories (A and B) in anaerobic performance in the WAnT (except rMP). However, Molik et al. (2010b) did not analyze relative but only absolute parameters of MP and PP in the WAnT. The analysis of rMP and rPP could be discussed due to the specificity of impairments of each player, e.g., a player with lower limb amputation and lower limb muscle atrophy weighs less than a player with lower limb length differences. Therefore, the analysis of MP and PP could be more useful when comparing different athletes in Paralympic sports, especially in wheelchair basketball. Apart from this problem, personal periodic analysis of relative parameters could be useful for a coach and a player in pre-season, post-season and in-season conditioning exercises.

In the third part of this study, correlations between the results from field-based tests and the WAnT parameters were presented. The validity of some field-based tests was confirmed. The strong correlations ($r < 0.5$ for $p < 0.05$) were noted between MP in the WAnT and 3 m sprint test, 5 m sprint, agility drill test, basketball and medicine ball chest pass tests for players from category A and between MP and agility drill test, bilateral handgrip, 30-s sprint test, 3-6-9 drill test, and medicine ball chest pass test for players from category B. Moderate ($0.3 < r < 0.5$ for $p < 0.05$) correlations were documented between PP and 3 m sprint, 5 m sprint and medicine ball chest pass test. Our research confirmed moderate validity of 20 m sprint (category B) which was indicated by Vanlandewijck et al. (1999) and De Groot et al. (2012).

A strong correlation between chest pass tests and MP and PP were underlined in the analysis by Molik et al. (2013) ($r = 0.80$ and $r = 0.82$, respectively). Our research confirmed a strong correlation (with MP in the WAnT) for 3 m sprint and 5 m sprint tests (category A) and medicine ball chest pass test (category A and B). Moreover, 3 m sprint and 5 m sprint tests had stronger correlations with MP than any other sprint tests ($r = -0.69$ and $r = -0.68$) for category A players. Surprisingly, 3 m sprint and 5 m sprint did not correlate significantly with the WAnT for category B players, and 20 m sprint tests did not correlate significantly with the WAnT for category A players. It seems that tests measuring MP and short-term efforts that focus on wheelchair acceleration and explosive power are much more effective in wheelchair basketball game for players from category A, probably because trunk function of players from category A is weaker [according to the classification in wheelchair basketball (International Wheelchair Basketball Federation, 2014)].

It is worth highlighting the separate analysis of WAnT parameters by category performed in the present study so that validations of selected field-based tests can be done more accurately according to an impairment degree. In other studies, researchers only reported whether they found or did not find correlations between selected tests and the WAnT, so it is not possible for the reader to find out which WAnT parameters were correlated. In our study, we found that there are other relationships between MP and PP and selected tests (e.g., 3 m sprint and 5 m sprint correlated with PP more strongly 10 m sprint and 20 m sprint tests). It seems that in wheelchair basketball, all PP results could be more useful for coaches and training development because such actions as wheelchair acceleration, playing one-on-one, long-distance passing or shooting are strictly related with PP. Therefore, our approach to a separate analysis should be continued in the future studies.

In the last part of our study, we developed a calculator to predict MP and PP on the basis of the selected field-based test results. All analyses of regression allowed us to create four independent formulas to predict MP and PP for wheelchair basketball players representing two different functional categories (category A and B). The calculation of MP was based on 3 m sprint test, 10 m sprint test, medicine ball chest pass test and bilateral handgrip test. PP prediction was based on 3 m sprint test for category A, and medicine ball chest pass test for category B. These formulas are easy predictors to assess (estimate) anaerobic performance of wheelchair basketball players in the WAnT. Although all formulas significantly predicted the parameters of WAnT (MP and PP), it has to be highlighted that models for category A players were more precise (more variance explained as depicted by R2 values) than for category B players. Thus, it seems that the accuracy of the estimation of the WAnT values depends on the degree of impairment. This is a good question for further research. In any case, the construction of regression models signifies a step forward in literature, as we did not find these types of predictions or ideas (i.e., WAnT estimators on the basis of field-tests) in previous research.

Study Limitations

There are no reference values for all the tests to compare players, their physical fitness and anaerobic performance level. In wheelchair basketball classification there are eight functional levels of players (classes). We divided our participants into two categories and we could not compare differences between all classes because of a small number of subjects.

CONCLUSION

The present study confirmed the validity of field-based tests for anaerobic performance evaluation in the Wingate Anaerobic Test (WAnT). Within category A, the analysis revealed that field tests like 3 m sprint, 5 m sprint, 10 m sprint, agility drill test, 30-s sprint test, 3-6-9 drill test, basketball chest pass test and medicine ball chest pass test are valid for non-laboratory anaerobic performance evaluation of players from category A. Also, 10 m sprint, 20 m sprint, agility drill test, bilateral handgrip, 30-s sprint test, 3-6-9 drill test and medicine ball chest pass test appeared to be effective for non-laboratory anaerobic performance evaluation of players from category B.

Moreover, four formulas to estimate mean power (MP) or peak power (PP) on the basis of the selected field-based test results have been presented. In general, present findings will be helpful and will allow coaches and players to prepare pre-season, post-season and in-season conditioning exercises in wheelchair basketball.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available because of the entry in the agreement of the local Bioethics Committees (KEIB – 10/2016 and SKE 01-16/2017).

AUTHOR CONTRIBUTIONS

JM devised the structure of the paper, drafted the manuscript, collected and analyzed the data, and commented on the final version. AKo collected and analyzed the data, and commented on the final version. NM-A, AM, KG, AKl, and KS collected and analyzed the data. JN supported statistical analyses and reporting, and commented on the final version. BM devised the structure of the paper, drafted the manuscript, oversaw the whole research process, collected and analyzed the data, and commented on the final version.

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REFERENCES

Chapman, D., Fulton, S., and Gough, C. (2010). Anthropometric and physical performance characteristics of elite male wheelchair basketball athletes. *J. Strength Cond. Res.* 24:1. doi: 10.1097/01.JSC.0000367081.53188.ba

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences*. New York, NY: Lawrence Erlbaum Associates.

Coutts, K. D. (1992). Dynamics of wheelchair basketball. *Med. Sci. Sports Exerc.* 24, 231–234. doi: 10.1249/00005768-199202000-00012

Croft, L., Dybrus, S., Lenton, J., and Goosey-Tolfrey, V. (2010). A comparison of the physiological demands of wheelchair basketball and wheelchair tennis. *Int. J. Sports Physiol. Perform.* 5, 301–315. doi: 10.1123/ijspp.5.3.301

De Groot, S., Balvers, I. J., Kouwenhoven, S. M., and Janssen, T. W. (2012). Validity and reliability of tests determining performance-related components of wheelchair basketball. *J. Sports Sci.* 30, 879–887. doi: 10.1080/02640414.2012.675082

de Lira, C. A., Vancini, R. L., Minozzo, F. C., Sousa, B. S., Dubas, J. P., Andrade, M. S., et al. (2010). Relationship between aerobic and anaerobic parameters and functional classification in wheelchair basketball players. *Scand. J. Med. Sci. Sports* 20, 638–643. doi: 10.1111/j.1600-0838.2009.00934.x

de Witte, A. M. H., Hoozemans, M. J. M., Berger, M. A. M., van der Slikke, R. M. A., van der Woude, L. H. V., and Veeger, D. (2018). Development, construct validity and test-retest reliability of a field-based wheelchair mobility performance test for wheelchair basketball. *J. Sports Sci.* 36, 23–32. doi: 10.1080/02640414.2016.1276613

Goosey-Tolfrey, V., Foden, E., Perret, C., and Degens, H. (2010). Effects of inspiratory muscle training on respiratory function and repetitive sprint performance in wheelchair basketball players. *Br. J. Sports Med.* 44, 665–668. doi: 10.1136/bjsm.2008.049486

Goosey-Tolfrey, V. L. (2005). Physiological profiles of elite wheelchair basketball players in preparation for the 2000 paralympic games. *Adapt. Phys. Activ. Q.* 22, 57–66. doi: 10.1123/apaq.22.1.57

Hutzler, Y., Ochana, S., Bolotin, R., and Kalina, E. (1998). Aerobic and anaerobic arm-cranking power outputs of males with lower limb impairments: relationship with sport participation intensity, age, impairment and functional classification. *Spinal Cord* 36, 205–212. doi: 10.1038/sj.sc.3100627

Hutzler, Y., Vanlandewijck, Y. C., and Van Vlierberghe, M. (2000). Anaerobic performance of older female and male wheelchair basketball players on a mobile wheelchair ergometer. *Adapt. Phys. Activ. Q.* 17, 450–465. doi: 10.1123/apaq.17.4.450

International Wheelchair Basketball Federation (2014). *Official Player Classification Manual*. Winnipeg, MB: International Wheelchair Basketball Federation.

International Wheelchair Basketball Federation (2018). *Official Wheelchair Basketball Rules & Wheelchair Basketball Equipment*. Mies: International Wheelchair Basketball Federation.

Iturricastillo, A., Granados, C., Camara, J., Reina, R., Castillo, D., Barrenetxea, I., et al. (2018). Differences in physiological responses during wheelchair basketball matches according to playing time and competition. *Res. Q. Exerc. Sport.* 89, 474–481. doi: 10.1080/02701367.2018.1511044

Iturricastillo, A., Yanci, J., Granados, C., and Goosey-Tolfrey, V. (2016). Quantifying wheelchair basketball match load: a comparison of heart rate and perceived exertion methods. *Int. J. Sports Physiol. Perform.* 11, 508–514. doi: 10.1123/ijspp.2015-0257

Marszalek, J., Gryko, K., Prokopowicz, P., Kosmol, A., Mróz, A., Morgulec-Adamowicz, N., et al. (2019). The physiological response of athletes with impairments in wheelchair basketball game. *Hum. Mov.* (in press).

Mason, B. S., van der Slikke, R. M. A., Hutchinson, M. J., Berger, M. A. M., and Goosey-Tolfrey, V. L. (2018). The effect of small-sided game formats on physical and technical performance in wheelchair basketball. *Int. J. Sports Physiol. Perform.* 13, 891–896. doi: 10.1123/ijspp.2017-0500

Molik, B., Kosmol, A., Laskin, J. J., Morgulec-Adamowicz, N., Skučas, K., Dąbrowska, A., et al. (2010a). Wheelchair basketball skill tests: differences between athletes' functional classification level and disability type. *Fizyoter. Rehabil.* 21, 11–19.

Molik, B., Laskin, J. J., Kosmol, A., Skucas, K., and Bida, U. (2010b). Relationship between functional classification levels and anaerobic performance of wheelchair basketball athletes. *Res. Q. Exerc. Sport.* 81, 69–73.

Molik, B., Kosmol, A., Morgulec-Adamowicz, N., Hübner-Woźniak, E., and Rutkowska, I. (2006). Anaerobic performance in polish first league team of wheelchair basketball players. *Res. Yearb.* 12, 199–202.

Molik, B., Laskin, J. J., Kosmol, A., Marszalek, J., Morgulec-Adamowicz, N., and Frick, T. (2013). Relationships between anaerobic performance, field tests, and functional level of elite female wheelchair basketball athletes. *Hum. Mov.* 14, 366–371. doi: 10.2478/humo-2013-0045

Traballesi, M., Averna, T., Delussu, A. S., Polidori, L., Di Giusto, C., Di Carlo, C., et al. (2009). Improvement in metabolic parameters and specific skills in an elite wheelchair basketball team: a pilot study. *Med. Sport* 62, 1–16.

Vanlandewijck, Y. C., Daly, D. J., and Theisen, D. M. (1999). Field test evaluation of aerobic, anaerobic, and wheelchair basketball skill performances. *Int. J. Sports Med.* 20, 548–554. doi: 10.1055/s-1999-9465

Yanci, J., Granados, C., Otero, M., Badiola, A., Olasagasti, J., Bidaurrazaga-Letona, I., et al. (2015). Sprint, agility, strength and endurance capacity in wheelchair basketball players. *Biol. Sport* 32, 71–78. doi: 10.5604/20831862.1127285

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Player Migration and Soccer Performance

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The aim of this study is to examine the relationship between migrating soccer players and the annual ranking of the national teams according to the *World Football Elo Rating*. The sample includes annual data for 243 countries over the period 1994–2018. Migration is captured with the *number of migrating players by country* in the "big-five" leagues. The causal relationship between the two variables is examined by using Granger causality test. Four control variables are included: *the political regime, per capita income, population,* and *regional soccer confederations*. It was hypothesized that (i) the better the ranking of the national teams in the *Elo rating*, the higher the number of migrating players in the "big-five" leagues (shop-window hypotheses) and that (ii) while the shop-window effect takes place in the short-run, the annual *Elo rating* of a national team is positively affected by expatriate players in the medium or long-run, but not in the short-run (blending hypotheses). The results shed light on two crucial issues. First, causality mainly goes from national soccer performance to migrating soccer players rather than the other way around. Second, the timing of the two effects is quite different. While those players giving an outstanding performance when their national team is doing well are immediately bought by clubs from more highly ranked leagues (the shop-window effect), it takes at least 4 years for the additional skills acquired by migrated players to have a positive effect on the national soccer performance (the blending effect).

Keywords: football association, player migration, nation's soccer performance, endogeneity, globalization, performance analysis

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INTRODUCTION

Globalization —the process fueled by, and resulting in, increasing cross-border flows of goods, services, money, people, information, and culture (Held et al., 1999, p. 16)— has dramatically affected domestic societies over the last decades and stimulated an intense research in economics, sociology, political science or anthropology (Berger, 2000; Guillén, 2001; Steger, 2017).

Soccer is not isolated from globalization. Free circulation of players has substantially increased during the last 25 years, as limits on the number of foreign players in the European leagues have been lifted and clubs become more commercially minded (Milanovic, 2005). According to Gelade and Dobson (2007: 250), between 2000 and 2005 the 40.9% of the players representing their country in international competition played club soccer abroad, and the 86.2% of them played in a country with a higher FIFA ranking. More recently, as of May 1, 2017, 12,051 expatriate footballers were recorded in the 2,120 clubs competing in 137 leagues of 93 national associations worldwide. On average, a team has 5.7 expatriate footballers, meaning that foreign players represent 21.6% of the average squad (Poli et al., 2017). In 2018, the proportion of expatriate players in a sample of 31 top division leagues of UEFA members association has increased to a record level of 41.5% (Poli et al., 2018). In addition, they are increasingly important in their teams. According to the most recent available data (November 2018), the percentage of minutes played by foreign players is 64.7% in the English Premier League (EPL), 61% in the Italian Serie A, 51.5% in the German Bundesliga, 39% in the Spanish Liga and 37.3% in the French Ligue 1 (Poli et al., 2018).

Interestingly, existing research is overwhelmingly focused on the impact of soccer players' migration to foreign clubs on the international soccer performance of their country of origin (Gásquez and Royuela, 2016). Conventional (although not universal) wisdom establishes that soccer players' migration is positively correlated with countries' international soccer performance, particularly in poorer countries or countries with lower-quality soccer clubs. Clearly, the greater the number of good players formed in a country, the better the performance of the national soccer team. The mechanism accounting for this positive effect of soccer player migration is the additional skills acquired by migrating players in top foreign leagues (Berlinschi et al., 2013). More specifically, expatriate players bring additional resources of experience, skill, and fitness to their national teams (Gelade and Dobson, 2007). This is what we call the *blending* argument. However, in (rich) countries with high-quality domestic leagues, the expected effect of migration is not clear (Leeds and Leeds, 2009; Yamamura, 2009; Berlinschi et al., 2013; Allan and Moffat, 2014). For a less optimistic view about the effect of football player migration on national team performance, see Frick (2007) or Maguire (2008).

Surprisingly, how national team performance affects the migration of soccer players remains largely unexplored. Players' migration to foreign clubs should increase when national teams do well. Expatriate soccer players mainly move from countries with lower-quality domestic leagues to the major leagues in Europe, primarily the "big-five" European leagues (English Premier League, Italian Serie A. Spanish La Liga, French Ligue 1, and German Bundesliga) (Deloitte, 1997–2018). According to the data compiled by Poli (2010), in 1995–1996 there were 463 expatriate players in the "big-five" leagues or 20.2% of the total number of players in the "big-five" leagues, while in 2008–2009 there were 1,107 expatriates, accounting for 42.6% of players. The "big-five" leagues are conventionally studied separately from the rest of leagues due to the high aggregated market value of their teams (see, for instance, Frick, 2009; Poli, 2010; Kuper and Szymanski, 2014). Migration should be expected to increase when players from countries with lower-quality domestic leagues are in the spotlight – that is, immediately after a World Cup. In fact, it has been demonstrated that players who have recently participated in the World Cup appear to benefit from a double effect, both by raising player salaries paid by clubs and by helping players secure transitions to more highly – ranked teams (Simmons and Deutscher, 2012; Kuper and Szymanski, 2014). This is what we call the *shop-window* argument.

Despite the shop-window argument, reverse causality has been addressed very differently when testing the blending argument. Most existing empirical research simply ignores it. For instance, Gelade and Dobson (2007) rely on cross-section data for 201 countries and show that the percentage of expatriate players in the national teams positively affects the average country's FIFA rating over the 2000–2005 period. Similarly, using cross-sectional data for 170 countries in 2010, 2011, and 2012, Allan and Moffat (2014) found that player emigration has a positive impact on the performance of the national soccer team. On the contrary, when explaining the national team performance in 2010 in 202 countries, Berlinschi et al. (2013) take reverse causality into account. They find that migration of national team players improves international soccer performance. Reverse causality between national team performance and population and migration is addressed using population size as a proxy for each country's talent pool and performing instrumental variable estimations. Finally, the endogeneity problem is taken very seriously in the time-series analysis conducted by Vasilakis (2017). Using data from nine World Cup years (1978–2010) in 65 countries and Two-Stage Least Squares (2SLS), he shows that the total number of talented players weighted by the score of their employment league is a key determinant of national team performance.

In sum, the aim of this study is to examine the relationship between migrating soccer players and the annual ranking of the national teams according to the *World Football Elo Rating*. To the best of our knowledge, no studies have explored whether the causal relationship between migrating soccer players and national soccer performance is bidirectional. It was hypothesized that (i) the better the ranking of the national teams in the *Elo rating*, the higher the number of migrating players in the "big-five" leagues (shop-window hypotheses) and that (ii) while the shop-window effect takes place in the short-run, the annual *Elo rating* of a national team is positively affected by expatriate players in the medium or long-run, but not in the short-run (blending hypotheses).

MATERIALS AND METHODS

Sample

To examine the causal relationship between the annual ranking of the national teams according to the *World Football Elo Rating* and the migration of soccer players, data were collected from 243 countries for which annual data on the two variables are available over the period 1994–2018. The sources are www.eloratings.net and www.transfermarkt.com. In order to control for the impact of the Bosman transfer ruling, a sectorial liberalization shock to football labor markets that banned quotas on the number of foreigners playing for a club (Frick, 2009; Binder and Findlay, 2012), we start in 1994.

Variables

National soccer performance and migrating soccer players are measured using the *Elo rating* and the *number of migrating players* by country in the "big-five" leagues, respectively. First, the

World Football Elo Rating is a ranking system for men's national association soccer teams published by www.eloratings.net and increasingly used in the soccer literature (e.g., Binder and Findlay, 2012 or Gásquez and Royuela, 2016). *Elo Ratings* are based on the work of Arpad Elo. The Ratings were developed for chess but they have been adapted for other games, including soccer. In these Ratings, there is: a weighting for the kind of match played; an adjustment for home team advantage and an adjustment for goal difference in the match result. The formula used to calculate the *Elo Rating* is Rn = Ro + K × (W − We), in which: Rn is the new rating; Ro is the old (pre-match) rating; K is the weight constant for the tournament played; K is then adjusted for the goal difference in the game. It is increased by half if a game is won by two goals, by 3/4 if a game is won by three goals, and by 3/4+ (N−3)/8 if the game is won by four or more goals, where N is the goal difference; W is the result of the game (1 for a win, 0.5 for a draw, and 0 for a loss); We is the expected result from this formula. We = 1/[10(−dr/400)+ 1] in which dr equals the difference in ratings plus 100 points for a team playing at home.

As explained by Gásquez and Royuela (2016: 8), the *Elo rating* solves the methodological problems of the FIFA rating: the confederation effect, the high volatility among the rankings of the top 10 teams and the limited information it employs (i.e., exclusively whether the team wins, loses, or draws the match). The *Elo rating* uses a low volatility index (an index that has more memory present), does not depend on the confederation to which a national team belongs, and incorporates more information, in particular, the expected and goal difference in the game. Finally, the FIFA ranking underwent methodological changes in 1999 and 2006, while the *Elo rating* has not. Given that the period we are covering in our empirical analysis is 1994–2018, the *Elo rating* allows comparisons over time. The *Elo rating* in our sample ranges from a minimum rating of 354 points for Eastern Samoa in 2007, 2008, 2009, and 2010 to a maximum value of 2,182 points for Brazil in 1997. The mean value is 1,334 ± 365 for all the countries and years.

The number of migrating players has been calculated as the raw number of foreign players by country in the "big-five" leagues. The mechanism driving the relationship between a national team's performance and the migration of soccer players is that expatriate soccer players move from countries with lower-quality domestic leagues to countries with high-quality domestic leagues. However, an increasing number of players are moving in the opposition direction. In particular, Major Soccer League (MLS) in the United States and Canada has become a destination for many aging stars. When focusing on the migrating of players moving to the "big-five" leagues, the bottom-up movement in terms of the quality of domestic leagues is clear. National players in their domestic leagues do not count as migrating players. Our assumption is that is that if expatriate players are moving to higher-quality domestic leagues (i.e., expatriate players are better than the average player in their origin countries), all or most of them should play in their national teams. Additionally, as there is no available information for all expatriate players in all the domestic leagues in the world, it is not possible to determine in all cases whether a player is moving to a better or a worse domestic league. The source is www.transfermarkt.com. The *number of migrating players* in our sample goes from 0 in many countries and years to 157 in Brazil in 2008. The mean is 5.2 ± 12.8 for all the countries and years. The descriptive statistics of these two key variables are displayed in **Table 1**.

We also included some conventional controls when explaining soccer success (Gásquez and Royuela, 2016). In particular: (i) the *political regime* (i.e., whether the country is a democracy, 1, or a non-democracy, 0) using the regime classification by Cheibub et al. (2010); (ii) *per capita income* in constant dollars (data retrieved from https://data.worldbank.org/indicator/NY.GDP.PCAP.KD; (iii) *population* (data retrieved from https://data.worldbank.org/indicator/sp.pop.totl); and (iv) *regional football confederations* (AFC, CAF, CONCACAF, CONMEBOL, OFC or UEFA).

Statistical Analysis

The empirical analysis proceeds in three steps. The first step consists of examining the *Data Generator Process* (DGP) of *Elo rating* and *the number of migrating players* to determine whether the variables are stationary or integrated and, therefore, whether the empirical analysis has to be performed in levels or first differences. Two panel unit root tests, the Levin-Lin-Chu (Levin et al., 2002) and the Im-Pesaran-Shin (Im et al., 2003) tests have been employed. While the former assumes common slopes, the second computes individual slopes.

In the second step, the analysis is focused on the link between migrating soccer players and national soccer performance. Using the Granger causality test, we assess whether this link is unidirectional or bidirectional. Testing causality through the Granger (1969) approach involves determining whether lagged information on a variable Y provides any statistically significant information about a variable X in the presence of lagged values of X. If not, Y does not Granger-cause X. We test whether causality runs from the migration of soccer players to national soccer performance, as the blending hypothesis argues, or whether it runs from national soccer performance to the migration of soccer players, as the shop-window hypothesis argues. We have run the test using a number of lags, going from 2 (i.e., short-run) to 6 (i.e., long-run). We start from lag 2 instead of lag 1 in order to avoid a bias due to the omission of relevant independent variables. As the first two lags of the endogenous variable are statistically significant for the two dependent variables, using only one generates a bias in the analysis. The results do not change appreciably when increasing the number of lags, but reduces the number of observations.

TABLE 1 | Descriptive statistics.

	ELO rating	*The number of migrating players*
Mean	1334	5.2
Median	1368	0
Standard deviation	365	12.8
Maximum	2182	157
Minimum	354	0

5760 common observations.

Finally, the third step consists of quantifying the interplay between *Elo rating* and *the number of migrating players* using Vector Autoregression (VAR) models. In order to interpret the results intuitively, standard impulse-response figures are employed (Lütkepohl, 2008). When estimating the VAR models, we included the four controls in addition to the lags of *Elo rating* and *number of migrating players:* (1) whether the country is a *Democracy* or not, (2) *per capita GDP*, (3) *population,* and (4) *regional soccer confederations*. Only *Democracy* was statistically significant (at the 1% level) when explaining the number of expatriate players. All other things being equal, players' migration to foreign clubs increases when the country of origin is a democracy. Accordingly, *Democracy* has been included in the final specification when explaining *the number of migrating players*. The average of *Democracy* is 0.52. Individual fixed effects are excluded in order to avoid multicollinearity with *Democracy*. All statistical analyses were performed using Eviews for Windows, version 10.0.

RESULTS

The average number of migrating players per country in the "big-five" leagues in the period 1994–2018 is presented in **Figure 1**. Over the 25-year period, the number of expatriate footballers has multiplied by 3, from 2 in 1994 to more than 6 after 2012.

The results of the two panel unit root tests are displayed in **Table 2**. For both variables the hypothesis of unit roots is rejected at the 1 percent level using both the Levin-Lin-Chu and the Im-Pesaran-Shin tests. Accordingly, the variables are measured in levels.

As can be seen in **Table 3**, the results of the Granger causality tests strongly support the shop-window hypothesis. The null hypothesis that *Elo rating* does not cause the number of migrating players is rejected at the 1% level in all cases. However, the blending hypothesis is only supported when using four or more lags, at the $p < 0.05$ level or less. When considering 2 or 3 lags, the hypothesis is not supported. In other words, it takes at least 4 years before an improvement in national soccer performance, thanks to the additional skills acquired by migrated players in top foreign leagues, becomes evident.

TABLE 2 | Panel unit root tests.

	Elo rating	*Number of migrating players*
Levin-Lin-Chu test (*p*-value)	0.0006**	0.0028**
Im-Pesaran-Shin test (*p*-value)	0.0003**	0.00001**

*Tests include individual intercepts. **p < 0.01.*

Figures 2 and **3**, respectively, show the impulse-response of the *Elo rating* and the number of migrating players to shocks in the other variable. We have simulated the effect of two external shocks: an increase of 100 points in the *Elo rating* and an increase of 10 migrant players. As can be seen in **Figure 2**, the shock to the *Elo rating* has a positive and statistically significant effect on migrating players since the first year (the whole plus/minus two standard error bands about the impulse responses is in positive ground). There is evidence of a very steep curve, particularly in the first four years. For instance, an increase of 100 points in the *Elo rating* in a given year generates and average increase of 0.2 migrating players in the next year. However, the **Figure 3** shows that the effect of the number of migrating players on the *ELO rating* is only statistically significant in the third and following years, but not in the first two.

DISCUSSION

This article has examined the reverse causality between migrating soccer players and national soccer performance. The proportion of expatriate footballers has increased markedly in the last 25 years (Poli et al., 2017, 2018). Existing research is overwhelmingly focused on what we have labeled the blending

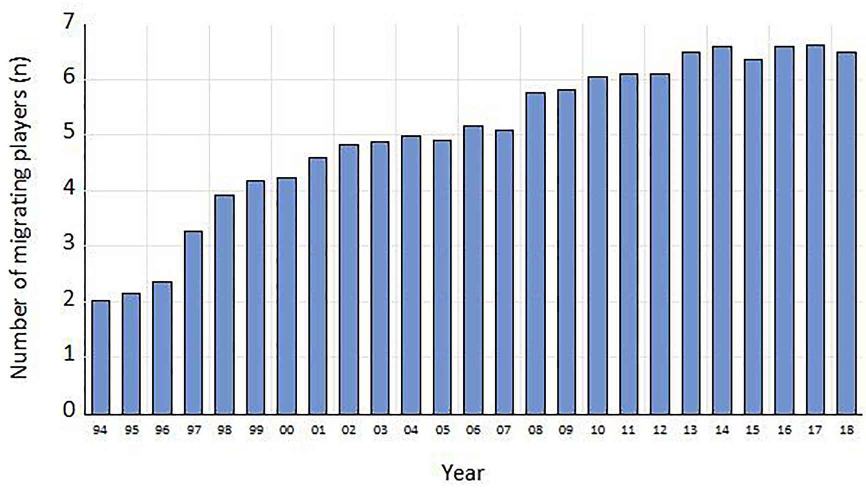

FIGURE 1 | Evolution of the average number of migrating players over time per country.

TABLE 3 | Causality tests for different lags structures (*p*-values are shown).

	2 lags	3 lags	4 lags	5 lags	6 lags
Elo rating does not cause the number of migrating players	0.0005**	0.0002**	0.0049**	0.0026**	0.0099**
The number of migrating players does not cause Elo rating	0.101	0.254	0.0357*	0.0211*	0.0067**

Tests include individual intercepts. According to the diagnostic tests, fixed effects are highly significant, while the time trend is not. Although autoregressive models with fixed effects lead to biased parameter estimates (Nickell, 1981), the bias is of order 1/T, where T is the number of time periods Accordingly, when T is equal or greater than 20, as in our case, the problem tends to fade out. Additionally, according to the Monte Carlo evidence provided by Beck and Katz (2011), the usual corrections for this bias do not perform better than the Least Squares Dummy Variables (LSDV) when T is greater than 20. $^{*}p < 0.05$; $^{**}p < 0.01$.

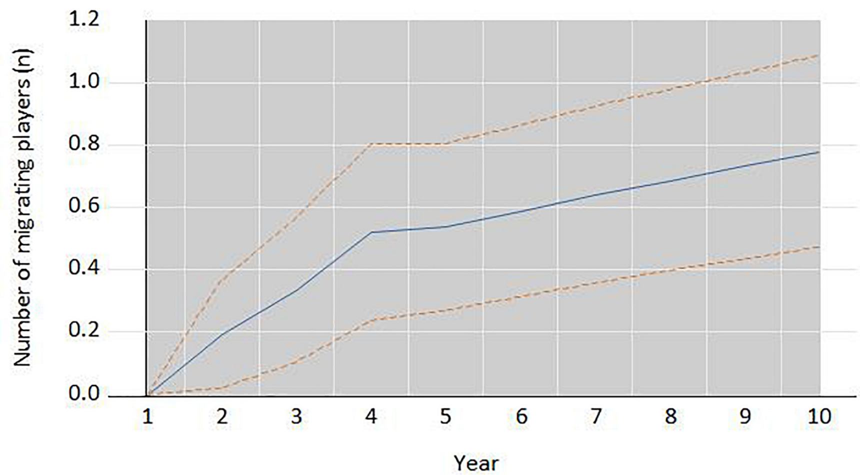

FIGURE 2 | Response of the number of migrating players per country to a shock of +100 points in the *ELO rating* in year 1. The dotes lines are the whole plus/minus two standard error bands about the impulse responses is in positive ground. The shaded area in gray indicates statistical significance at 5% or less.

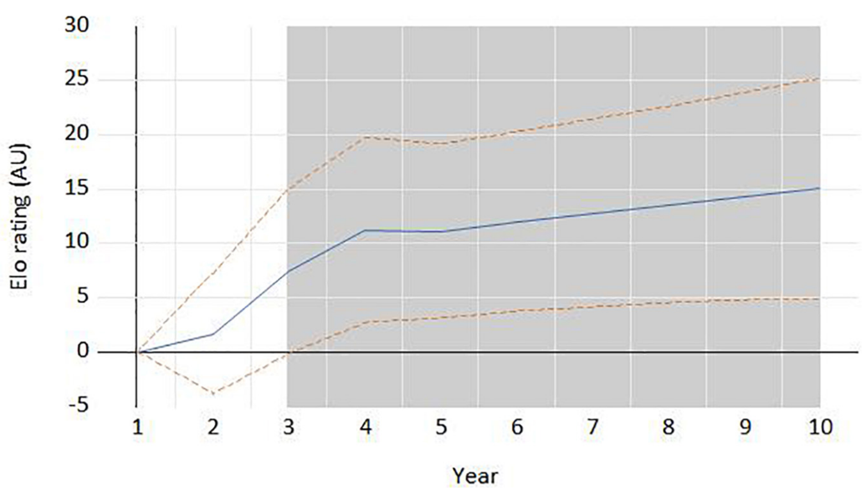

FIGURE 3 | Response of the *ELO rating* to an increase of 10 migrating players per country in year 1. The dotes lines are the whole plus/minus two standard error bands about the impulse responses is in positive ground. The shaded area in gray indicates statistical significance at 5% or less.

hypothesis, that is, that soccer players' migration is positively correlated with their nation's soccer performance in international competition, especially in poorer countries or countries with lower-quality soccer clubs. Interestingly, how a national team's performance affects the migration of soccer players (i.e., the shop-window hypothesis) has not been examined.

Our empirical analysis sheds light on two crucial issues. First, the causal relationship mainly goes from national team performance to migrating soccer players, rather than the other way around. Second, the timing of the two effects is quite different. While the shop-window effect – the better the ranking of the national teams in the *Elo rating*, the higher the number of migrating players in the "big-five" leagues – (Simmons and Deutscher, 2012; Kuper and Szymanski, 2014) takes place in the short-run, the blending effect – the annual *Elo rating* of a national team is positively affected by expatriate players – (Gelade and Dobson, 2007; Leeds and Leeds, 2009; Yamamura, 2009; Berlinschi et al., 2013; Allan and Moffat, 2014) is only observed in the medium or long-run. The mechanisms driving the diverging timing of the effects are as follows: on the one hand, when the *Elo rating* of a national team increases (which is particularly significant in World Cup years), their players are immediately bought by clubs from more highly ranked leagues (Simmons and Deutscher, 2012; Kuper and Szymanski, 2014). On the other hand, the performance of migrating players may require several years of experience to improve, especially for players from leagues of lower quality. As a result, it takes at least 4 year before the positive effect of the additional skills acquired by migrated players are visible in the national team's performance. Thus, the blending argument is partially confirmed.

This finding is in line with the empirical and anecdotal evidence provided by Kuper and Szymanski (2014). According to them, "the worst moment to buy a player is in the summer when he's just done well at a big tournament. Everyone in the transfer market has seen how good the player is, but he is also exhausted and quite likely sated with success. As Fergusson admitted after retiring from Manchester United: I was always wary of buying players on the back of good tournament performances. I did it at the 1996 European Championship, which prompted me to move for Jordi Cruyff and Karel Poborsky. Both had excellent runs in that tournament but I didn't receive the kind of value their countries did that summer. They weren't bad buys, but sometimes players get themselves motivated and prepared for World Cups and European Championships and after that there can be a leveling off [included in Kuper and Szymanski (2014)]."

The crucial implication of our analysis is that endogeneity is a serious problem when examining the relationship between migrating soccer players and national soccer performance. By ignoring the feedback effect, the correct inference plus a bias factor is estimated. When a national team's soccer performance is the dependent variable, endogeneity already emerges when using the values of migrating soccer players from the previous year. When migrating soccer players is the outcome, endogeneity is an issue when using lagged values of national team's performance. We urge researchers to take endogeneity very seriously in empirical analyses.

These findings may help coaches and managers to better understand how the success of national teams affects migration in elite soccer and may have the potential to assist in decisions such as, for example, when a new contract should be signed, the duration of the contract or when to replace or transfer a player depending on the moment of season. For example, the worst moment to buy a player is in summer when s/he's done well at an international tournament. On the other hand, the selling teams should not transfer a player before a big tournament if the market price is not high enough. The player can revalue after a good performance in a major national soccer event (i.e., World Cup or Continental Soccer Championship).

Concerning the limitations of the current study, some aspects should be highlighted. Future research should move from the nation/aggregated level to the player/individual one. Other variables such as the age of the players, their playing position, the quality of the receiving clubs or the number of played minutes should be included in future studies, given that they can affect their performance in the receiving countries' leagues and the additional skills they bring to their national teams. The number of migrating players in other leagues should also considered. In addition, the manager immigration variable should be also included in future studies (Allan and Moffat, 2014).

CONCLUSION

In conclusion, the results of the Granger causality tests support the shop-window hypothesis when examining the relationship between migrating soccer players and national soccer performance. Those players with an outstanding performance when the national team is doing well are immediately bought by top clubs. However, the blending hypothesis is only confirmed (on average) 4 years after players' migration: national team performance is positively affected by expatriate players in the medium or long-run, but not in the short-run.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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REFERENCES

Allan, G. J., and Moffat, J. (2014). Muscle drain versus brain gain in association football: technology transfer through player emigration and manager immigration. *Appl. Econ. Lett.* 21, 490–493. doi: 10.1080/13504851.2013.870641

Beck, N., and Katz, J. N. (2011). Modelling dynamics in time-series-cross-section political economy data. *Annu. Rev. Polit. Sci.* 14, 331–352. doi: 10.1146/annurev-polisci-071510-103222

Berger, S. (2000). Globalization and politics. *Annu. Rev. Polit. Sci.* 3, 43–62. doi: 10.1146/annurev.polisci.3.1.43

Berlinschi, R., Schokkaert, J., and Swinnen, J. (2013). When drains and grains coincide: migration and international football performance. *Labour Econ.* 21, 1–14. doi: 10.1016/j.labeco.2012.12.006

Binder, J. J., and Findlay, M. (2012). The effects of the bosman ruling on national and club teams in Europe. *J. Sports Econ.* 13, 107–129. doi: 10.1177/1527002511400278

Cheibub, J. A., Gandhi, J., and Vreeland, J. M. (2010). Democracy and dictatorship revisited. *Pub. Choice* 143, 67–101. doi: 10.1007/s11127-009-9491-2

Deloitte, (1997–2018). *Football Money League*. Manchester: Sports Business Group.

Frick, B. (2007). The football players' labor market: empirical evidence from the major European leagues. *Scot. J. Polit. Econ.* 54, 422–446. doi: 10.1111/j.1467-9485.2007.00423.x

Frick, B. (2009). Globalization and factor mobility: the impact of the 'Bosman ruling' on player migration in professional soccer. *J. Sports Econ.* 10, 88–106. doi: 10.1177/1527002508327399

Gásquez, R. G., and Royuela, V. (2016). The determinants of international football success: a panel data analysis of the elo rating. *Soc. Sci. Quart.* 97, 125–141. doi: 10.1111/ssqu.12262

Gelade, G. A., and Dobson, P. (2007). Predicting the comparative strengths of national football teams. *Soc. Sci. Quart.* 88, 244–258. doi: 10.1111/j.1540-6237.2007.00456.x

Granger, C. W. J. (1969). Investigating causal relations by econometric models and cross- spectral methods. *Econometrica* 37, 424–438. doi: 10.2307/1912791

Guillén, M. F. (2001). Is globalization civilizing, destructive or feeble? A critique of five key debates in the social science literature. *Annu. Rev. Sociol.* 27, 235–260. doi: 10.1146/annurev.soc.27.1.235

Held, D., McGrew, A., Goldblatt, D., and Perraton, J. (1999). *Global Transformations. Politics, Economics, and Culture*. Oxford: Polity Press.

Im, K. S., Pesaran, M. H., and Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *J Econometrics* 115, 53–74. doi: 10.1016/S0304-4076(03)00092-7

Kuper, S., and Szymanski, S. (2014). *Soccernomics: Why Spain, Germany and Brazil Win, and Why the USA, Japan, Australia -and Even Iraq- are Destined to Become the Kings of the World's Most Popular Sport*. New York, NY: Nations Books.

Leeds, M. A., and Leeds, F. M. (2009). International soccer success and national institutions. *J. Sport Econ.* 10, 369–390. doi: 10.1177/1527002508329864

Levin, A., Lin, C. F., and Chu, C. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *J. Econ.* 108, 1–24. doi: 10.1016/S0304-4076(01)00098-7

Lütkepohl, H. (2008). *Impulse Response Function. The New Palgrave Dictionary of Economics*, 2nd Edn. London: Palgrave Macmillan.

Maguire, J. (2008). 'Real politic' or 'ethnically based': sport, globalization, migration and nation-state policies. *Sport Soc.* 11, 443–458. doi: 10.1080/17430430802019375

Milanovic, B. (2005). Globalization and goals: does soccer show the way? *Rev. Int. Polit. Econ.* 12, 829–850. doi: 10.1080/09692290500339818

Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica* 49, 1417–1426. doi: 10.2307/1911408

Poli, R. (2010). Understanding globalization through football: the new international division of labour, migratory channels and transnational trade circuits. *Int. Rev. Sociol. Sport* 45, 491–506. doi: 10.1177/1012690210370640

Poli, R., Ravenel, L., and Besson, R. (2017). *World Expatriate Footballers*. Avaliable at: http://www.football-observatory.com/IMG/sites/mr/mr25/en/

Poli, R., Ravenel, L., and Besson, R. (2018). *Ten Years of Demographic Analysis of Football Players' Labor Market in Europe*. Avaliable at: http://www.football-observatory.com/IMG/sites/mr/mr39/en/

Simmons, R., and Deutscher, C. (2012). "The economics of the world cup," in *The Oxford Handbook of Sports Economics*, Vol. 1, eds L. Kahane and S. Shmanske (New York, NY: Oxford University Press), 449–469.

Steger, M. B. (2017). *Globalization: A Very Short Introduction*, 4th Edn. Oxford: Oxford University Press.

Vasilakis, C. (2017). Does talent migration increase inequality? A quantitative assessment in football labour market. *J. Econ. Dyn. Contro.* 85, 150–166. doi: 10.1016/j.jedc.2017.10.003

Yamamura, E. (2009). Technology transfer and convergence of performance: an economic study of FIFA football ranking. *Appl. Econ. Lett.* 16, 261–266. doi: 10.1080/13504850601018361

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Race Strategies of Open Water Swimmers in the 5-km, 10-km, and 25-km Races of the 2017 FINA World Swimming Championships

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Despite literature on the pacing strategies of endurance sports, there is an existing lack of knowledge about the swimmers' tactical decisions in the open water races. The aims of the present research were (1) to compare the pacing profiles and tactical strategies of successful elite open water swimmers (men and women) in the 5-km, 10-km, and 25-km races and (2) to relate these pacing strategies to the end race results. Intermediate split times, positions and gaps with leaders of the first ten swimmers classified in the 2017 FINA World Swimming Championships races were collected from the public domain and were related to the finishing positions. Overall swimming velocities of the 5-km races were faster than the 10-km (δ 0.03 $\pm$ 0.03 m/s) and the 25-km (δ 0.14 $\pm$ 0.01 m/s) events with male swimmers achieving relatively faster mean velocities than females in the 5-km (δ 0.12 $\pm$ 0.01 m/s) compared to the 25-km (δ 0.08 $\pm$ 0.01 m/s) events. Medallist swimmers achieved moderate faster overall velocities than finalists in the 25-km races (0.01 $\pm$ 0.01 m/s) only. Inter-level differences were detected in selected splits for each race distance. Pacing profiles presented lap to lap velocity improvements in the 5-km and men's 10-km races (from +0.02 $\pm$ 0.00 to +0.11 $\pm$ 0.01 m/s) but also mid-race decreases in the women's 10-km and on the 25-km races. Successful swimmers were located in the leading positions of the 5-km races but at mid-group in the first part of the 10-km and 25-km races, with time gaps with leaders of 15–20 s. Faster lap swimming velocities, mid-race leading positions and shorter time-gaps were only related to the finishing positions in the last lap of the 10-km and in the three last laps of the 25-km events, but also in the first lap of the women's 5-km race. Despite different mid-race positioning, successful open water swimmers typically presented negative pacing profiles, a consistent control of mid-race gaps with leaders (15–20 s maximum) and great spurts (4–6% faster than mean race velocities) at the end of races. Coaches and swimmers should be aware of the different race dynamics depending to the event distance in order to select optimal race strategies.

Keywords: pacing, tactics, competition, time-gap, end spurt

INTRODUCTION

The Federation Internationale de Natation (FINA) first included the 5-km, 10-km, and 25-km open water events in the 2000 edition of the World Swimming Championships held in Hawaii (United States). Since then, a great proportion of the open water elite competitors have taken part in two or three of these distances within the same competition, as races are usually separated a minimum of 48 or 72 h from each other. For example, in the 2015 World Championships held in Kazan (Russia), 19 out of 24 male swimming participants in the 25-km event had previously taken part in the 5-km or 10-km race of that edition[1]. Despite these data, there are few examples of competitors who achieved a successful position in two open water events within the same competition. If data from the 2015 edition are taken into consideration, only one out of nine male medallists was able to repeat the podium position (in the 5-km and 25-km). This could indicate that the race strategies at this elite standard differed according to the race distance and duration. The same pacing distribution or tactical positioning favorable for a successful performance on the 5-km or 10-km event might not necessarily be the most suitable for the 25-km event.

The pacing distribution in endurance sports has been a well-explored topic in the literature so far and it is widely acknowledged that the adoption of an optimal energy distribution in efforts with controlled conditions will have a clear impact on performance by delaying the onset of fatigue (Foster et al., 2005). From an individual athlete perspective, the optimal energy output will depend on the ability to understand their own metabolic capacities in relation to the task demand (Roelands et al., 2013), which may be assisted by prior experience (Micklewright et al., 2009) to anticipate the end-point of the exercise (Highton et al., 2017). Mainly, three general pacing strategies have been described for the duration of the effort (positive, negative or even pace profiles) depending on the athlete performing the first half of the task duration at a faster, slower or with no velocity variations than the second half. Depending on the task duration as well as the athlete competitive level, the adoption of one strategy will be indicated, being the positive pacing profile recommended for short-duration (<1 min) (Tucker et al., 2006), the even profile for ultra-endurance (>1 h) (Tan et al., 2016) and the negative profile more observed in the middle-duration efforts (≈4 min) (Abbiss and Laursen, 2008).

Beyond these general strategies, some pacing profiles (U-shaped, J-shaped or reversed J-shaped) have been described in endurance events as parabolic profiles (Garland, 2005) according to the variations in velocity in specific parts of the race, like the first or the last ≈10% of the race distance. These variations usually respond to the tactical decisions employed in head-to-head competitions (Corbett et al., 2011) where, depending on extrinsic factors like the opponent's behaviors (Smits et al., 2014) or the race configuration in packs (Hanley, 2015), competitors accelerate or decelerate to increase their chances of race success (Konings et al., 2016). Examples of these tactical decisions would be the fast speed naturally adopted by endurance competitors at the beginning of races before slowing down for most of the race distance (Tucker et al., 2006) or the velocity spurts observed at the end of races when athletes aim for the medal finishing positions (Thiel et al., 2012). Female athletes, in this aspect, have been reported to perform fewer pacing variations along races probably due to their physiological but also psychological specific features (Deaner et al., 2015).

In the open water swimming events, where the race duration ranges from 1 to 4 h, the tactical decisions of competitors seem to be of a critical importance because of the drag reduction when swimming behind or next to other competitors (Chatard and Wilson, 2003). Also, depending on the situation within the race, competitors interact in close contact with surrounding swimmers or can avoid collisions, which certainly influences their pacing decision-making throughout the race (Renfree et al., 2013). In 2017, Rodriguez and Veiga (2017) showed that successful competitors in the FINA World Swimming Championships 10-km event performed a conservative race strategy, with a delayed partial positioning and with swimming paces similar to those of non-successful swimmers for a great proportion of the race distance. With this strategy, they were able to save energy for an end spurt that was highly related to race success. However, it is unknown whether this same strategy would be effective for the remaining open water distances (5-km and 25-km). Despite the great increase in participants and races in the last years, there is a lack of information about the optimal race strategies for each open water event (Baldassarre et al., 2017).

Therefore, the aims of the present research were (1) to compare the pacing profiles and tactical strategies of successful elite open water swimmers (men and women) in the 5-km, 10-km, and 25-km races and (2) to relate these pacing strategies to the end race results. It was expected that swimming paces would be faster in the shorter races, with a more conservative strategy of successful swimmers (both in the swimming pace and the tactical positioning) in the longer events (25-km) compared to the shorter events (10-km and 5-km). Also, it was expected that female swimmers would demonstrate lower pacing variations within and between the race distances.

MATERIALS AND METHODS

Data from the 5-km, 10-km, and 25-km races of the FINA World Swimming Championships held in Budapest in July 2017 were freely available on the website (see footnote 1). The three races were held in a 7-day period with race circuits structured, as usual, in laps of 2.5 km: in this way, competitors had to perform 2, 4 or 10 laps, respectively, for the 5-km, 10-km, and 25-km events, to cover the total race distances. The FINA Organising Committee confirmed the official distances of each race according to the global positioning system coordinates of the official reference marks situated along the race circuits. All experimental procedures were carried out in accordance with the Declaration of Helsinki and were approved by the Technical University of Madrid's ethics committee.

From all the finishing competitors in the three distances (61, 65, and 25 swimmers for the men's and 57, 59, and

[1]http://www.omegatiming.com

19 for the women's 5-km, 10-km, and 25-km, respectively), the first ten swimmers classified in each race (top-10) were selected for further analysis and were considered as successful participants. This criterion was made according to previous research (Rodriguez and Veiga, 2017) and to the fact that the Olympic classification in the open water disciplines corresponds to the top-10 swimmers in the World Championships event. In total, 30 males and 30 females race results (10 per each race distance) were included into the present research and were subsequently divided in medallists (swimmers classified first to third) or finalists (swimmers classified fourth to tenth).

The race strategies in the 5-km, 10-km, and 25-km events were defined by registering the split and end race times, the mid-race and finishing positions (from first to tenth) and the gap-times (s) with the leading swimmers in each of the 2.5 km laps of the race circuit. Mean swimming velocities (m/s) in each lap as well as at the end of the race were calculated from official split and end times. These velocities were expressed as time per 100 m (s) for better interpretation purposes. Performance density (%) of each race was expressed as the difference between the mean swimming velocity of the first and tenth classified swimmers related to the velocity of the race winner (Baldassarre et al., 2017). In order to facilitate comparison between race distances, mid-race parameters were expressed in relation to the percentage of the total race distance covered at that point. Also, mid-race positions were indicated relative to the total participants in each race (**Figure 2**).

Statistical analyses were performed using IBM SPSS statistics for Windows, version 20.0 (IBM Corp, Armonk, NY, United States). Swimming paces of successful swimmers were compared with a repeated measures analysis of variance according to the race distance (5-km, 10-km, and 25-km), the race lap (first to second in the 5-km, first to fourth in the 10-km and first to tenth in the 25-km race), gender (male or female) and competitive level (medalist or finalist). Planned repeated contrast tests between successive laps were carried out. *Post hoc* tests were used to determine statistical effects ($p < 0.05$) between factors using Bonferroni corrections and were interpreted using effect sizes (partial η^2) with 0.2, 0.5, and 0.8 threshold values for small, medium and large effects (Cohen, 1992). The race tactical behaviors (mean velocity, mid-race positions and gap-times) were related to the end race results by using Pearson correlation coefficients, being 0.1, 0.3, 0.5, 0.7, and 0.9, the threshold values that represented small, moderate, large, very large, and nearly perfect correlations (Hopkins et al., 2009). Data variability was reported using standard deviations (SD) and intra-individual coefficient of variation (CV) and the uncertainty of estimates was indicated using 90% confidence intervals (CIs).

RESULTS

Overall Trends According to the Race Distance, Sex, and Competitive Level

The mean swimming pace in the open water 2017 FINA World Swimming Championships races (**Table 1**) showed meaningful differences according to the race distance (F_2 = 5043.75,

TABLE 1 | Swimming pace (per 100 m) of medallists and finalists' participants on the 5-km, 10-km, and 25-km events of the 2017 FINA World Swimming Championships.

Males		**Total**	**Split 1**	**Split 2**	**Split 3**	**Split 4**	**Split 5**	**Split 6**	**Split 7**	**Split 8**	**Split 9**	**Split 10**
5-km	Medal	65.50 ± 0.12	67.38 ± 0.07	62.61 ± 0.19								
	Final	65.75 ± 0.02	67.64 ± 0.31	62.83 ± 0.31								
10-km	Medal	67.19 ± 0.00	69.48 ± 0.56	68.31 ± 0.26	67.52 ± 0.32*	62.77 ± 0.19						
	Final	67.29 ± 0.08	69.04 ± 0.22	68.47 ± 0.10	67.83 ± 0.12	63.14 ± 0.28						
25-km	Medal	72.67 ± 0.01*	75.80 ± 0.05	74.95 ± 0.14	74.91 ± 0.33	71.61 ± 0.36	75.34 ± 0.04	73.16 ± 0.06	72.43 ± 0.13	70.86 ± 0.17	71.37 ± 0.03	66.72 ± 0.09*
	Final	73.07 ± 0.01	75.92 ± 0.33	74.81 ± 0.33	75.23 ± 0.39	71.31 ± 0.30	75.23 ± 0.29	73.33 ± 0.18	72.51 ± 0.31	71.18 ± 0.87	71.28 ± 1.15	70.23 ± 1.99
Females		Total	Split 1	Split 2	Split 3	Split 4	Split 5	Split 6	Split 7	Split 8	Split 9	Split 10
5-km	Medal	70.99 ± 0.05	72.97 ± 0.21	67.92 ± 0.18*								
	Final	71.30 ± 0.12	73.17 ± 0.19	68.33 ± 0.19								
10-km	Medal	72.16 ± 0.02	75.16 ± 0.92	71.89 ± 0.64*	72.73 ± 0.19	68.11 ± 0.36						
	Final	72.27 ± 0.08	74.86 ± 0.39	72.36 ± 0.30	72.78 ± 0.26	68.33 ± 0.36						
25-km	Medal	77.29 ± 0.02*	81.81 ± 0.15	80.79 ± 0.22	78.97 ± 0.20	75.84 ± 0.60	83.76 ± 1.01	79.67 ± 0.23	72.29 ± 0.23	71.34 ± 0.07*	75.32 ± 0.21**	73.55 ± 0.21
	Final	78.37 ± 0.61	81.51 ± 0.24	80.64 ± 0.27	78.75 ± 0.36	76.25 ± 0.48	83.81 ± 0.62	80.00 ± 0.29	72.51 ± 0.44	75.50 ± 3.31	79.19 ± 1.86	75.82 ± 2.21

Medallists are statistically faster ($p < 0.05$) than finalists with moderate or large** differences.*

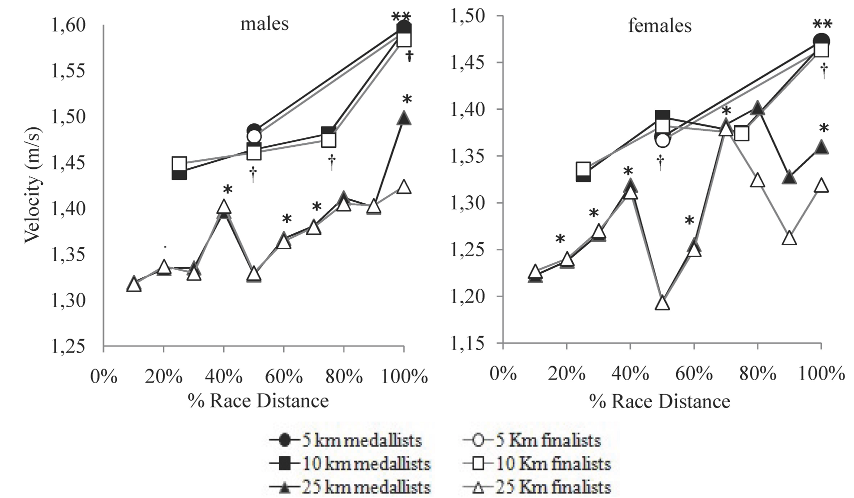

FIGURE 1 | Swimming velocity (m/s) evolution of the medallists (black) and finalists (white) on the 5-km, 10-km, and 25-km events of the 2017 FINA World Swimming Championships (error bars removed for clarity). Swimming lap velocity is statistically faster ($p < 0.05$) than the previous 5-km (**), 10-km (†) and 25-km (*) lap for the mean top-10 swimmers.

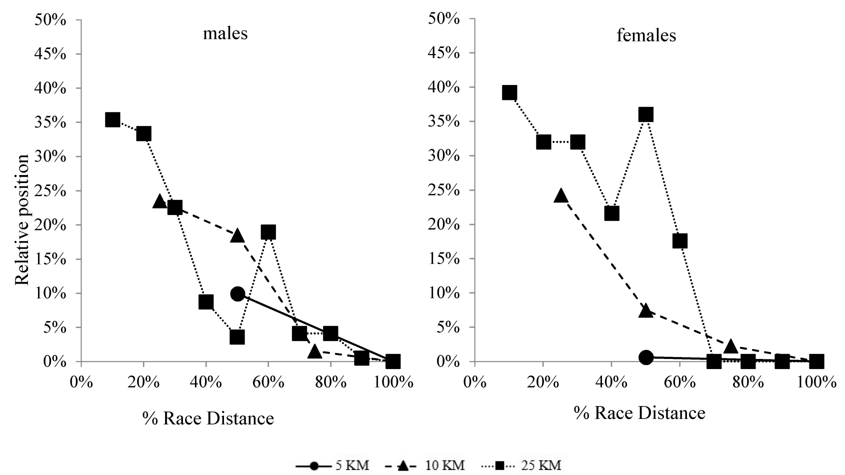

FIGURE 2 | Mean partial positioning (relative to the total participants) of the successful participants (top-10) on the 5-km, 10-km, and 25-km events of the 2017 FINA World Swimming Championships (error bars removed for clarity).

P = 0.001, η^2 = 0.99) being faster in the 5-km when compared to the 10-km (δ 0.03 m/s; 90% CI, 0.03–0.03 m/s, P = 0.001) and to the 25-km (δ 0.14 m/s; 0.13–0.14 m/s, P = 0.001) events. Male swimmers swam faster mean velocities than their female counterparts in all events (F_1 = 7759.08, P = 0.001, η^2 = 0.99) although relatively, gender differences in velocity were greater in the 5-km event (δ 0.12 m/s; 90% CI, 0.11–0.12 m/s, P = 0.001, η^2 = 0.98) than in the 10-km (δ 0.10 m/s; 0.10–0.11 m/s, P = 0.001, η^2 = 0.97) or the 25-km (δ 0.08 m/s; 0.08–0.09 m/s, P = 0.001; η^2 = 0.96) races. Also, medallists swam faster mean velocities than finalists swimmers (F_1 = 35.11, P = 0.001, η^2 = 0.42) although meaningful differences were only observed in the 25-km event (0.01 ± 0.01 m/s, P = 0.001, η^2 = 0.45). Performance density of the top-10 swimmers (indicating velocity differences between first and tenth classified swimmers) was 0.51% and 0.61% for the 5-km, 0.33% and 0.38% for the 10-km and 1.13% and 2.38% for the 25-km, respectively, men's and women's races.

Pacing Profiles of the Successful Competitors on the 5-km, 10-km, and 25-km Races

The evolution of the swimming pace throughout the open water races (**Figure 1**) showed meaningful changes both in the 5-km (F_1 = 1826.79, P = 0.001, η^2 = 0.99), the 10-km ($F_{2.07}$ = 1033.44, P = 0.001, η^2 = 0.98) and the 25-km events ($F_{4.21}$ = 139.92, P = 0.001, η^2 = 0.89). These changes depended on the gender (lap gender: η^2 = 0.32, 0.64 and 0.58, respectively, in the 5-km, 10-km, and 25-km events) although some small differences (lap level:

η^2 = 0.17 and 0.28 in the 10-km and 25-km races, respectively) were also observed between medallists and finalists.

In the 25-km event, the planned contrasts showed significant increases between successive laps ($p < 0.001$) except between the seventh and the eighth laps. *Post hoc* tests showed that the swimming velocity of male and female competitors showed large increases from lap to lap (at a maximum rate of +0.07 ± 0.01 m/s and +0.13 ± 0.01 m/s, for males and females) except in the fifth, eighth, and ninth laps. In these laps, the swimming pace was maintained (eighth lap) or even decreased (fifth lap: −0.07 ± 0.02 m/s and −0.12 ± 0.02 m/s, for males and females, both P = 0.001) (**Figure 1**). Finalists swam at similar paces than medallist swimmers except in the last lap (tenth lap differences = 0.08 m/s; 90% CI, 0.03–0.13 m/s, P = 0.01, η^2 = 0.39) of the male's race and on the eight (0.08 m/s; 0.02–0.13 m/s, P = 0.01, η^2 = 0.37) and ninth (0.07 m/s; 0.03–0.10 m/s, P = 0.001, η^2 = 0.51) laps of the females' race.

In the 10-km event, the planned contrasts showed a significant increase from the first to the second lap ($p < 0.001$) and from the third to the fourth laps ($p < 0.001$). *Post hoc* tests showed that the swimming pace also increased from lap to lap on the men's race (second lap: +0.02 ± 0.01 m/s, P = 0.01; third: +0.02 ± 0.00, P = 0.001 and fourth: +0.11 ± 0.01 m/s, P = 0.001) but it decreased on the third lap of the women's race (−0.01 ± 0.01 m/s, P = 0.001) before the spurt of the fourth lap (+0.09 ± 0.01 m/s, P = 0.001). This was observed in all the successful swimmers of the 10-km event, except the men finalists' group who did not increase swimming pace on the second lap (P = 0.23).

Finally, in the 5-km event, the planned contrasts showed a significant increases from the first to the second lap ($p < 0.001$) as well as the *post hoc* tests both for male (+0.11 ± 0.01 m/s, P = 0.001, η^2 = 0.99) and female (+0.10 ± 0.01 m/s, P = 0.001, η^2 = 0.98) swimmers, regardless of the competitive level. Medallists and finalists' swimmers in the 5-km and 10-km races did not show inter-level velocity differences at any race lap, except in the second lap of the 5-km (0.01 m/s; 0.00–0.02 m/s, P = 0.05, η^2 = 0.23) and 10-km (0.01 m/s; 90% CI, 0.00 to 0.02 m/s; P = 0.05, η^2 = 0.22) women's races and in the third lap on the 10-km men's race (0.01 m/s; 0.00 to 0.01 m/s; P = 0.04, η^2 = 0.24).

Changes in the swimming pace in relation to the mean race velocity reached maximum values in the last lap of races, with a magnitude of 6.71% and 5.81% (for male and female swimmers) in the 10-km event, 5.51% and 3.89% in the 25-km and 4.63% and 4.40% in the 5-km races. Intra-individual coefficient of variation in the lap velocity of the longest event (25-km) reached 6.48% and 9.65%, respectively, for the men's and women's race.

Tactical Positioning of the Successful Competitors on the 5-km, 10-km, and 25-km Races

In relation to the tactical positioning (**Figures 2–4**), successful swimmers of the 5-km events (males and females) were located at the 2.5-km split in the 20% front part of the group within a 10 s gap from the leading swimmers. Top-10 participants of the 10-km events, for their part, showed a more delayed positioning in the first half of the race (around the 40–50% front part of the main group) with a time gap of 15–20 s with the leaders. In the second half of the race, however, they reduced the time gap with leaders to 10–15 s and moved up to the 15% front part of the group. Finally, in the 25-km races, successful male swimmers showed a similar tactical positioning to the 10-km race swimmers by locating in the middle of the group during the first 60% of the race distance, 15–20 s beyond the leaders. However, in the second part of the race, their time gap with leaders decreased to less than 10 s and their partial positioning was within the top-10 swimmers. Successful female swimmers in this event, in turn, showed a more delayed positioning in the first half of the race by locating in the rear part of the group and more than 20 s behind leaders.

Relationships of Mid-Race Parameters With End Race Result

The relationships between the mid-race parameters and the end race result of the successful swimmers in the 2017 FINA World Swimming Championships (**Table 2**) indicated that the swimming pace in the first three and six laps of the 10-km and 25-km events (the 70% and 60% of the race distance), respectively, was not statistically related to the swimmer performance. Indeed, the swimming lap velocities of the 25-km race were only related to the race result in the men's last lap and in the women's last three laps of the races. In the 5-km race, however, the swimming velocity of the female swimmers in each race lap (first and second) was related to a better final race position. For the mid-race positions and time gaps with leaders, these parameters were not related to the 5-km or 10-km end race results, except for the females 5-km event. Tactical positioning, however, showed meaningful correlations with the race success in the last three laps of the 25-km race distance, both for male and female swimmers.

DISCUSSION

The present research aimed to compare the pacing profiles and tactical strategies of the open water swimmers (men and women) competing at the 5-km, 10-km, and 25-km races of the FINA 2017 World Swimming Championships. Successful swimmers in the three events performed a negative pacing profile with increasing swimming velocities at the end of races. However, the dynamic of pacing profiles as well as the tactical positioning of the competitors depended on the race distance and on gender.

Overall Trends According to the Race Distance, Sex, and Competitive Level

Mean swimming paces in the 5-km, 10-km, and 25-km races showed clear differences from race to race and represented different swimming intensities according to the lactate threshold velocities of elite freestylers (Pyne et al., 2001). A high level of competitiveness was demonstrated by the mean swimming velocity of the top-10 swimmers, similar to that of recent Olympic 10-km races (1.49 m/s for men and 1.39 m/s for women in the present research compared to 1.49 and 1.39 m/s in Beijing 2008, 1.51 and 1.41 m/s in London 2012 and 1.47 and 1.41 m/s in Rio 2016, respectively, for men and women) and faster than that reported in other international 10-km events

TABLE 2 | Relationships between lap swimming velocities, partial positions and intermediate gaps (from the first to the last lap) and the end race results for the top-10 competitors (males and females) of the 5-km, 10-km, and 25-km races of the 2017 FINA World Swimming Championships.

25-km		**Lap 1**	**Lap 2**	**Lap 3**	**Lap 4**	**Lap 5**	**Lap 6**	**Lap 7**	**Lap 8**	**Lap 9**	**Lap 10**
Velocity	Male	−0.19 (−0.68 to 0.39)	0.36 (−0.22 to 0.77)	−0.38 (−0.78 to 0.20)	0.27 (−0.31 to 0.73)	0.23 (−0.35 to 0.71)	−0.39 (−0.79 to 0.18)	−0.46 (−0.82 to 0.10)	0.11 (−0.47 to 0.63)	−0.33 (−0.76 to 0.25)	−0.97*** (−0.99 to −0.91)
	Female	0.21 (−0.37 to 0.69)	−0.07 (−0.61 to 0.49)	0.10 (−0.47 to 0.63)	−0.46 (−0.82 to 0.10)	0.34 (−0.23 to 0.76)	−0.53 (−0.85 to −0.01)	−0.30 (−0.74 to 0.29)	−0.87** (−0.96 to −0.64)	−0.88** (−0.97 to −0.68)	−0.82** (−0.95 to −0.54)
Position	Male	0.34 (−0.24 to 0.76)	−0.06 (−0.60 to 0.50)	0.21 (−0.38 to 0.69)	0.12 (−0.46 to 0.64)	−0.17 (−0.66 to 0.42)	0.57 (0.07 to 0.87)	0.74** (.36 to 0.92)	0.49 (−0.06 to 0.83)	0.84** (0.57 to 0.96)	
	Female	−0.24 (−0.71 to 0.34)	−0.06 (−0.60 to −0.51)	−0.15 (−0.65 to 0.43)	0.46 (−0.09 to 0.82)	−0.18 (−0.67 to 0.41)	0.31 (−0.28 to 0.74)	0.77** (0.43 to 0.94)	0.93*** (0.80 to 0.98)	0.94*** (0.83 to 0.98)	
Gap	Male	0.20 (−0.39 to 0.68)	−0.10 (−0.62 to 0.47)	0.22 (−0.37 to 0.70)	0.09 (−0.48 to 0.62)	−0.20 (−0.9 to 0.38)	0.16 (−0.42 to 0.66)	0.64* (0.18 to 0.89)	0.11 (−0.47 to 0.63)	0.68* (0.26 to 0.91)	
	Female	−0.21 (−0.69 to 0.37)	−0.08 (−0.61 to 0.49)	−0.10 (−0.62 to 0.47)	0.22 (−0.37 to 0.70)	−0.36 (−0.77 to 0.22)	0.27 (−0.31 to 0.73)	0.80** (0.48 to 0.94)	0.86** (0.63 to 0.96)	0.93*** (0.82 to 0.98)	
10-km		Lap 1	Lap 2	Lap 3	Lap 4						
Velocity	Male	0.35 (−0.23 to 0.77)	−0.25 (−0.71 to 0.34)	−0.62 (−0.88 to −0.15)	−0.83** (−0.95 to −0.56)						
	Female	0.14 (−0.44 to 0.65)	−0.32 (−0.75 to 0.26)	−0.11 (−0.63 to 0.46)	−0.63* (−0.89 to −0.16)						
Position	Male	−0.40 (−0.79 to 0.17)	−0.40 (−0.79 to 0.17)	0.31 (−0.28 to 0.74)							
	Female	−0.28 (−0.73 to 0.30)	0.07 (−0.50 to 0.60)	0.23 (−0.35 to 0.71)							
Gap	Male	−0.35 (−0.77 to 0.22)	−0.37 (−0.77 to 0.21)	0.29 (−0.29 to 0.74)							
	Female	−0.14 (−0.65 to 0.44)	0.22 (−0.36 to 0.70)	0.35 (−0.22 to 0.77)							
5-km		Lap 1	Lap 2								
Velocity	Male	−0.44 (−0.81 to 0.12)	−0.32 (−0.75 to 0.27)								
	Female	−0.74** (0.37 to 0.93)	−0.64* (−0.89 to −0.18)								
Position	Male	0.47 (−0.08 to 0.82)									
	Female	0.78** (0.45 to 0.94)									
Gap	Male	0.44 (−0.12 to 0.81)									
	Female	0.74** (0.37 to 0.93)									

*Magnitudes of correlations with P-values < 0.05: *large; **very large; ***nearly perfect.*

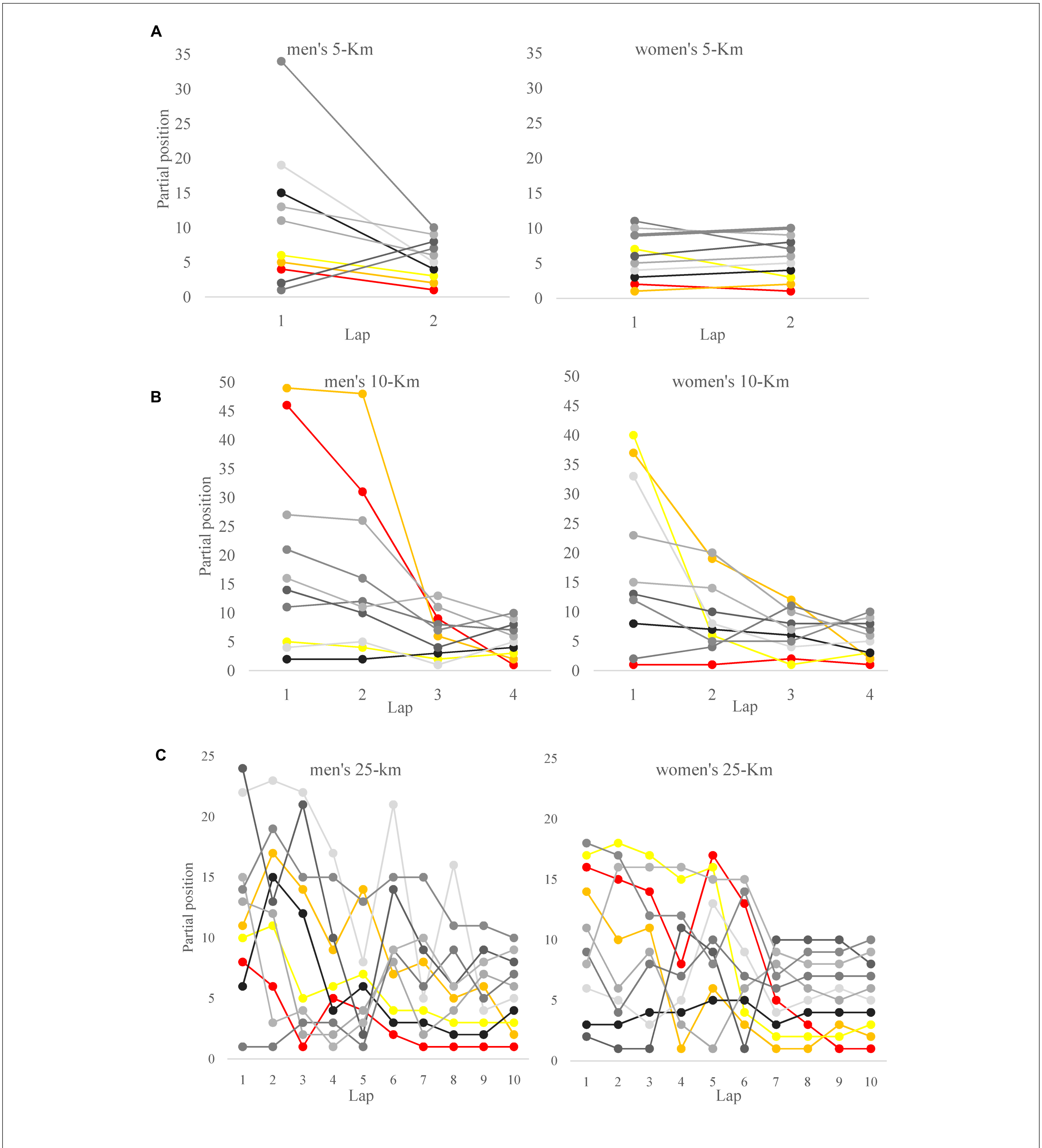

FIGURE 3 | Lap-to-lap positioning of the successful participants (top-10) on the **(A)** 5-km, **(B)** 10-km, and **(C)** 25-km events of the 2017 FINA World Swimming Championships.

(Vogt et al., 2013). The density of performances of the top-10 swimmers in Budapest was also greater than previous 5-km (1.83% for men and 1.95% for women), 10-km (1.5% and 2.3%) and 25-km (3.76% and 3.31%) official open water races (Vogt et al., 2013; Zingg et al., 2014). As expected, medallists and finalists' swimmers showed marginal velocity differences for the entire races, highlighting the tactical importance of major championships where athletes compete for the best finishing

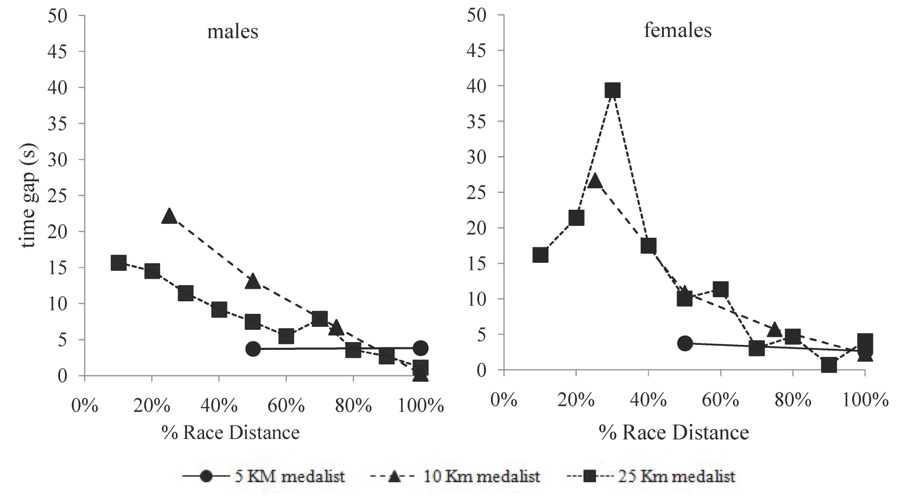

FIGURE 4 | Mean time gap (s) with leaders of the successful swimmers (top-10) in the 5-km, 10-km, and 25-km events of the 2017 FINA World Swimming Championships (error bars removed for clarity).

position but not the best possible time (Thiel et al., 2012; Casado and Renfree, 2018; Hanley and Hettinga, 2018).

Gender differences in the swimming velocity close to 7% were greater than previously reported (Vogt et al., 2013; Baldassarre et al., 2017) in the 10-km Olympic Games races in Beijing (6.3%), London (6.6%), and Rio (3.7%). These data disagree with previous results from non-conventional open water races such as the Manhattan Island Marathon Swim (Knechtle et al., 2014) and the "Maratona del Golfo Capri-Napoli" (Rüst et al., 2014), where the gender gap had continuously decreased over years. However, as previously observed (Knechtle et al., 2014), female swimmers in the present research presented a relatively better performance in the longer distances (9.30% gap between the 5-km and 25-km races for them compared to the 10.95% of male swimmers) with lower inter-gender differences in the 25-km (6.20%) than in the 5-km (7.80%) race times. The body composition of female athletes, with a more favorable percentage and distribution of fat tissue (Mclean and Hinrichs, 1998), would provide them with more buoyancy and less drag to perform better in the longer distances (Baldassarre et al., 2017). In relation to the pacing variations, female swimmers did not show lower changes in velocity than men as could be expected due to their physical features but also to their lower tendency to take risks in a race context (Deaner et al., 2015; Hanley, 2016). However, their end race spurts were of a lower magnitude than their male counterparts in line with the lower speed variations reported in the literature (Abbiss et al., 2013; Renfree and St Clair Gibson, 2013).

Pacing Profiles of the Successful Competitors on the 5-km, 10-km, and 25-km Races

In the 5-km event, successful competitors of the men's and women's races situated on the leading positions from the beginning of race and adopted a swimming pace faster (approximately 2 s per 100 m) than that of the 10-km race. From this fast but maintainable pace, medallist and finalists further increased their swimming pace by ≈7% in the second half of the race and maintained their leading positions to aim for the final top three positions. This strategy had been previously reported a successful approach by proficient Marathon runners who want to be in control of the race (Hanley, 2016), as it prevented less capable competitors to increase pacing in the second half of races.

10-km male and female swimmers, on the other hand, adopted slower paces for the first three race laps of the race and showed moderate pacing variations (first to third laps pace change lower than 3%). However, in the last lap of the race, they performed a dramatical end spurt (by increasing swimming velocity by 9.7% and 6.6%, respectively), which was largely related to their race success. This end race spurt was greater than that of 1.5–3% reported in the 2015 FINA World Swimming Championships (Rodriguez and Veiga, 2017) and it is a typical feature of highly trained endurance athletes with a great anaerobic reserve who speed up at the end of races to ensure they cross the finish line ahead of other competitors (Corbett et al., 2011; Renfree et al., 2013). Previous studies on endurance disciplines have reported end spurts of 1–2% for the successful competitors at the end of running marathons (Renfree and St Clair Gibson, 2013; Hanley, 2016) or 5–8% in shorter events like track running (Thiel et al., 2012). By maintaining a relative even pace profile for most of the race distance (in this case, 75% of the total race distance), successful swimmers in the 10-km race probably chose the best option to save glycogen reserves (Padilla et al., 2000) and this allowed them to subsequently perform an end spurt of a greater magnitude (de Koning et al., 2011).

Finally, in the 25-km races, competitors showed a more variable pacing profile than in the shorter events. Swimming paces in the first splits of the race were relatively slow (6–7 s slower per 100 m than the 10-km competitors) but then, progressively, they were increasing from lap to lap although not in a linear manner (**Figure 1**). In particular, the coefficient of variation between laps reached values between 6 and 9% that are considerably greater than those of Olympic track races (Thiel et al., 2012) or running Marathons (Renfree and St Clair Gibson, 2013). Probably, swimmers in this event (4-h long) organized their energy output according to external race conditionings and giving less weighting to their physiological status. This could respond to the so-called "herd behavior," where athletes follow the behavior of surrounding opponents regardless of their rational decision making (Tan et al., 2016).

When comparing the pacing profiles of finalists and medallists open water swimmers, results indicated similar swimming velocities and race dynamics for the most of race distance between them, but a greater ability of medallists to increase swimming pace at the end of races (**Figure 1**). This had been previously observed in Olympic track races (Thiel et al., 2012) and it was especially highlighted in the 25-km event, where medallists swam faster velocities than finalists in the last lap of the men's and in the eighth and ninth lap of the women's race only (**Table 1**). Probably, medallists presented similar aerobic capacities than finalists' swimmers at the World Championships level but a better ability to achieve swimming paces below 65 (men) or 70 (women) seconds per 100 m, which are typical paces at the end of elite open water races and indicate a greater anaerobic reserve for them (Corbett et al., 2011).

In general, the pacing strategies of successful swimmers in the 5-, 10-, and 25-km races showed clear differences with those of other endurance disciplines. Running competitors had been reported (1) to adopt initial paces considerably faster than the mean speed of the race (Tucker et al., 2006), (2) to present the lowest pacing decreases in the second half of races (March et al., 2011; Deaner et al., 2015), and (3) to perform an end spurt in the last ≈10% race distance (Thiel et al., 2012). However, elite open water swimmers in the present research (especially in the 10-km and 25-km races) did not adopt a fast pace approach at the beginning of the race but they performed the slowest pace in the first split (both men and women). Also, in all the 5-km, 10-km, and 25-km events, successful swimmers did not decrease pace in the second half of races, but they presented negative pacing profiles instead. Mean times of top-10 swimmers in the second part of races were approximately 2, 3 or 7 min shorter (for the 5-km, 10-km, and 25-km events) than in the first half. In relation to the end spurts, open water swimmers seemed to speed up velocity over a greater proportion of race distance compared to other endurance disciplines, although this information should be confirmed by a greater temporal resolution of intermediate splits (Thiel et al., 2012). All these characteristics of open water pacing profiles probably responded to pre-planned race strategies related to the drag resistance of swimming, where competitors situated behind or at the side of other leading competitors could save up to 20% the energy cost (Chatard and Wilson, 2003). Open water swimmers may deliberately seek to save energy in the initial stages of races (by swimming slower than an ideal pace) and then regulate pace according to the race configuration in packs to avoid gaps that would decrease the drafting effect.

Tactical Positioning of the Successful Competitors in the 5-km, 10-km, and 25-km Races

When examining the tactical positioning of successful swimmers in the different race distances, the 5-km event showed a different profile from that of the 10-km and 25-km races. Swimmers in the shortest event situated in the leading part of the main group from the early stages of the race (**Figure 3**) and with a narrow gap from leaders (shorter than 5 s or approximately 5 m). This was especially evident of the women's race where the finalists were located in the top 11 positions for the entire race, with mid-race positions and short times gaps being largely related to the end race result. The early leading strategy was probably less dependent on the opponent's behavior and, according to the shorter duration of the 5-km race, highlighted the ability of open water swimmers to deliver the best possible energy output for the duration of the race (Foster et al., 2005).

In the longer events (10-km and 25-km), successful competitors adopted a more conservative positioning in the first half of the race by locating in the mid-part of the main group. The time-gap with leading swimmers, in these events, did not exceed 15–20 s which represented (according to the swimming velocities) a maximum distance of 30–35 m. This had been previously observed in the 10-km race of the 2015 World Swimming Championships (Rodriguez and Veiga, 2017), but it had not been ever reported with time gaps in order to fully understand race dynamics. From the half of the race, both 10-km and 25-km successful competitors of the present study improved their relative positions and decreased the time gaps from leaders but, interestingly, 25-km male swimmers progressed to a more advance situation in the main group (within 10 s of leaders and in the 5% front positions of the main group) which was largely related to their race success (**Table 2**). The successful 10-km swimmers, on their behalf, did not achieve the leading positions until the last lap of the race [as previously observed during the 2015 World Championships (Rodriguez and Veiga, 2017)] assisted by their greater end spurt compared to the 5-km or 25-km events. Differences in the tactical positioning between events probably depended also on the different performance densities of races, as the greatest density of the 10-km was contrary to the lowest density observed in the 25-km race.

Regardless of the event distance, it was noticeable the ability of medallists across all distance events to maintain time gaps with leaders no longer than 10–15 s in the second half of races. These time-gaps (which would represent distance-gaps no longer than 20 m) allowed medallist to be in control of the race as they were able to cut them down within the 25–30 min duration (2.5 km) of the last race lap. It was also noticeable the influence of the mid-race positioning of medallist's swimmers (and especially of winners) in the race pacing variations. For example, a relative backward movement of medallists within the main group at the fifth lap of the 25-km race (losing from two to five positions, **Figure 4**) was accompanied, both in the men's and women's race, by a decrease in the swimming pace of the top-10 swimmers in that race lap (**Figure 1**). These race behaviors highlighted the influence of the extrinsic factors on the tactical decisions of elite open water swimmers (Renfree et al., 2013; Smits et al., 2014) and explained the greater pacing variations presented in the longest open water race (25-km), due to greater changes in the partial positioning. Other extrinsic factors that could also influence the race outcomes were specific aspects of the race venue like the structure of the course, currents, water temperature, . . .etc. (Abbiss and Laursen, 2008). These environmental constraints were probably beyond the conscious strategy of the open water swimmers, but they certainly also affected their pacing and tactical positioning.

Practical Applications

These results of the World Championships races highlight differences in the pacing profiles and tactical positioning of open water swimming compared to other endurance and ultra-endurance disciplines. Coaches and swimmers should be aware of the different race dynamics according to the event duration and should focus on the development a greater anaerobic reserve besides their great aerobic capacity. If properly handled through races, energy savings during the initial and mid stage of races due to drafting (especially in the longer distances) should be translated into great end spurts to leave behind adversaries and to access to the successful race positions. This could only be achieved if accompanied by an adequate control of time gaps with leaders within the main field, that would allow elite performers to reach the leading positions in the last lap of races.

CONCLUSION

Successful swimmers in the different events of the 2017 FINA World Swimming Championships (5, 10, and 25-km races) performed a negative pacing profile with an increase of their swimming velocity at the end of races. However, while doing so, they employed different tactical positioning strategies that depended on the race distance, their final positioning and gender. In the 5-km event, successful competitors presented an early quick pace with an advance mid-race positioning (20% part of the main group and 10 s maximum gap from leaders) that it was largely related to the women's end race result. 10-km competitors, on the other hand, adopted a slower than ideal pace with small pacing variations and a delayed partial positioning for most of the race distance. This allowed them to perform a dramatic end race spurt (between 6 and 9% velocity increase) in the last quarter of the race distance related to a better end race result. Finally, 25-km competitors performed a more variable pacing profile related to the greater changes on the mid-race positioning, but an aggressive strategy on the second half of the race with leading positions that allowed them to achieve race success. Regardless of the event distance, medallists swimmers showed a greater ability to control gap times with leaders around 10–15 s (≈15–20 m) for most of the race distance and to employ their greater anaerobic reserve to increase swimming pace at the end of races. Female swimmers, for their part, presented a relatively better performance in the longer events with more advance partial positioning that their male counterparts but a lower end race spurt.

AUTHOR CONTRIBUTIONS

SV, LR, PG-F, and AN contributed to the conception and design of the study. LR, PG-F, and SV organized the database. AN and SV performed the statistical analysis. SV and LR wrote the first draft of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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REFERENCES

Abbiss, C. R., and Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Med.* 38, 239–252. doi: 10.2165/00007256-200838030-00004

Abbiss, C., Ross, M., Garvican-Lewis, L., Ross, N., Pottgiesser, T., Gregory, J., et al. (2013). The distribution of pace adopted by cyclists during a cross-country mountain bike world championships. *J. Sports Sci.* 31, 787–794. doi: 10.1080/02640414.2012.751118

Baldassarre, R., Bonifazi, M., Zamparo, P., and Piacentini, M. F. (2017). Characteristics and challenges of open-water swimming performance: a review. *Int. J. Sports Physiol. Perform.* 12, 1275–1284. doi: 10.1123/ijspp.2017-0230

Casado, A., and Renfree, A. (2018). Fortune favors the brave: tactical behaviors in the middle-distance running events at the 2017 iaaf world championships. *Int. J. Sports Physiol. Perform.* 13, 1386–1391. doi: 10.1123/ijspp.2018-0055

Chatard, J. C., and Wilson, B. (2003). Drafting distance in swimming. *Med. Sci. Sports Exerc.* 35, 1176–1181. doi: 10.1249/01.MSS.0000074564.06106.1F

Cohen, J. A. (1992). Power primer. psychological bulletin. 112, 155–159. doi: 10.1037/0033-2909.112.1.155

Corbett, J., Barwood, M., Ouzounoglou, A., Thelwell, R., and Dicks, M. (2011). Influence of competition on performance and pacing during cycling exercise. medicine and science in sports and exercise. 44, 509–515.

Deaner, R., Carter, R., Joyner, M., and Hunter, S. (2015). Men are more likely than women to slow in the marathon. *Med. Sci. Sports Exerc.* 47, 607–616. doi: 10.1249/MSS.0000000000000432

de Koning, J. J., Foster, C., Bakkum, A., Kloppenburg, S., Thiel, C., Joseph, T., et al. (2011). Regulation of pacing strategy during athletic competition. *PLoS One* 6:e15863. doi: 10.1371/journal.pone.0015863

Foster, C., Hoyos, J., Earnest, C., and Lucia, A. (2005). Regulation of energy expenditure during prolonged athletic competition. *Med. Sci. Sports Exerc.* 37, 670–675. doi: 10.1249/01.MSS.0000158183.64465.BF

Garland, S. W. (2005). An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing. *Br. J. Sports Med.* 39, 39–42. doi: 10.1136/bjsm.2003.010801

Hanley, B. (2015). Pacing profiles and pack running at the iaaf world half marathon championships. *J. Sports Sci.* 33, 1189–1195. doi: 10.1080/02640414.2014.988742

Hanley, B. (2016). Pacing, packing and sex-based differences in olympic and iaaf world championship marathons. *J. Sports Sci.* 34, 1675–1681. doi: 10.1080/02640414.2015.1132841

Hanley, B., and Hettinga, F. J. (2018). Champions are racers, not pacers: an analysis of qualification patterns of olympic and iaaf world championship middle distance runners. J. *Sports Sci.* 36, 2614–2620. doi: 10.1080/02640414.2018.1472200

Highton, J., Mullen, T., and Twist, C. (2017). Influence of knowledge of task endpoint on pacing and performance during simulated rugby league match play. *Int. J. Sports Physiol. Perform.* 12, 1192–1198. doi: 10.1123/ijspp.2016-0603

Hopkins, W., Marshall, S., Batterham, A., and Hanin, Y. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–13. doi: 10.1249/MSS.0b013e31818cb278

Knechtle, B., Rosemann, T., Lepers, R., and Rüst, C. (2014). Women outperform men in ultra-distance swimming - the 'manhattan island marathon swim' from 1983 to 2013. *Int. J. Sports Physiol. Perform.* 9, 913–924. doi: 10.1123/ijspp.2013-0375

Konings, M., Noorbergen, O., Parry, D., and Hettinga, F. (2016). Pacing behavior and tactical positioning in 1500 m short-track speed skating. *Int. J. Sports Physiol. Perform.* 11, 122–129. doi: 10.1123/ijspp.2015-0137

March, D., Vanderburgh, P., Titlebaum, P., and Mackenzie, P. (2011). Age, sex, and finish time as determinants of pacing in the marathon. *J. Strength Cond. Res.* 25, 386–91. doi: 10.1519/JSC.0b013e3181bffd0f

Mclean, S., and Hinrichs, R. (1998). Sex difference in the center of buoyancy location of competitive swimmers. *J. Sports Sci.* 16, 373–383. doi: 10.1080/02640419808559365

Micklewright, D., Papadopoulou, E., Swart, J., and Noakes, T. (2009). Previous experience influences pacing during 20 km time trial cycling. *Br. J. Sports Med.* 44, 952–960. doi: 10.1136/bjsm.2009.057315

Padilla, S., Mujika, I., Orbañanos, J., and Angulo, F. (2000). Exercise Intensity during competition time trials in professional road cycling. *Med. Sci. Sports Exerc.* 32, 850–856. doi: 10.1097/00005768-200004000-00019

Pyne, D. B., Lee, H., and Swanwick, K. M. (2001). Monitoring the lactate threshold in world-ranked swimmers. *Med. Sci. Sports Exerc.* 33, 291–297. doi: 10.1097/00005768-200102000-00019

Renfree, A., Martin, L., Micklewright, D., and Clair Gibson, A. (2013). Application of decision-making theory to the regulation of muscular work rate during self-paced competitive endurance activity. *Sports Med.* 44, 147–158. doi: 10.1007/s40279-013-0107-0

Renfree, A., and St Clair Gibson, A. (2013). Influence of different performance levels on pacing strategy during the women's world championship marathon race. *Int. J. Sports Physiol. Perform.* 8, 279–285. doi: 10.1123/ijspp.8.3.279

Roelands, B., de Koning, J., Foster, C., Hettinga, F., and Meeusen, R. (2013). Neurophysiological determinants of theoretical concepts and mechanisms involved in pacing. *Sports Med.* 43, 301–311. doi: 10.1007/s40279-013-0030-4

Rodriguez, L., and Veiga, S. (2017). Effect of the pacing strategies on the open water 10 km world swimming championships performances. *Int. J. Sports Physiol. Perform.* 13, 694–700. doi: 10.1123/ijspp.2017-0274

Rüst, C. A., Lepers, R., Rosemann, T., and Knechtle, B. (2014). Will women soon outperform men in open-water ultra-distance swimming in the "maratona del golfo capri-napoli"? *Springerplus* 3:86. doi: 10.1186/2193-1801-3-86

Smits, B. L. M., Pepping, G. J., and Hettinga, F. J. (2014). Pacing and decision making in sport and exercise: the roles of perception and action in the regulation of exercise intensity. *Sports Med.* 44, 763–775. doi: 10.1007/s40279-014-0163-0

Tan, P., Tan, F., and Bosch, A. (2016). Similarities and differences in pacing patterns in a 161 and 101 km ultra-distance road race. *J. Strength Cond. Res.* 30, 2145–2155. doi: 10.1519/JSC.0000000000001326

Thiel, C., Foster, C., Banzer, W., and de Koning, J. (2012). Pacing in Olympic track races: competitive tactics versus best performance strategy. *J. Sports Sci.* 30, 1107–1115. doi: 10.1080/02640414.2012.701759

Tucker, R., Lambert, M. I., and Noakes, T. D. (2006). An analysis of pacing strategies during men's world-record performances in track athletics. *Int. J. Sports Physiol. Perform.* 1, 233–245. doi: 10.1123/ijspp.1.3.233

Vogt, P., Rüst, C. A., Rosemann, T., Lepers, R., and Knechtle, B. (2013). Analysis of 10 km swimming performance of elite male and female open-water swimmers. *Springerplus* 2:603. doi: 10.1186/2193-1801-2-603

Zingg, M. A., Rüst, C. A., Rosemann, T., Lepers, R., and Knechtle, B. (2014). . *Extrem. Physiol. Med.* 3:2. doi: 10.1186/2046-7648-3-2

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Fat-Free Mass and Bone Mineral Density of Young Soccer Players: Proposal of Equations Based on Anthropometric Variables

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Background: The assessment of body composition may assist in optimizing competitive efficiency and monitoring the success of training regimes for young soccer players. The purpose of this study was to determine the predictors for Fat-Free Mass (FFM) and Bone Mineral Density (BMD) of young soccer players. Also, the goal was to propose regression equations to estimate FFM and BDM through anthropometric variables.

Methods: One hundred and sixty-seven young soccer players ages 10.0 to 19.9 years old were studied. Weight, height, trunk-cephalic length, right arm circumference, diameter of the humerus, and length of the foot were assessed. FFM and BDM were determined by using dual X-ray absorptiometry (DXA). Maturity status using Peak Height Velocity (PHV) was calculated.

Results: Maturity status, weight, and circumference of the relaxed arm positively related to the FFM (R^2 = 41–66%). Similarly, PHV, weight, diameter of the humerus, and length of the foot explained BDM in both groups of soccer players (goalkeepers and filed players) (R^2 = 45–82%). Six equations to predict FFM (R^2 = 62–69%) and six to predict BDM (R^2 = 69–90%) were created. Chronological age had a limited use for predicting FFM and BDM.

Conclusion: Results suggested the use and application of the regression equations as a non-invasive alternative for everyday use in soccer clubs.

Keywords: soccer, equations, bone mineral density, fat-free mass, young people

INTRODUCTION

The assessment of body composition can provide valuable information about the changes that arise during the stages of training (Wittich et al., 1998). On the other hand, monitoring bone health during physical growth is relevant because it allows identification of low accumulation of minerals or risk of osteoporosis in due to low bone mineral density (BMD) in youth (Zemel et al., 2011).

Therefore, The Mechanostat Theory (Rauch et al., 2004) can be used to explain the muscle-bone relationship where larger muscles exert greater traction on the connector bones. In this sense, bone strength can be affected by physical exercise in two ways: from high impact loads associated with exercise and through indirect osteogenic muscle development in a given area where greater stress is exerted on the bone (Rahnama et al., 2005; Vicente-Rodriguez, 2006).

Currently strong empirical evidence exists that demonstrates that physical exercise affects the normal development of muscles and bones (Daly, 2007; Krustrup et al., 2009; Helge et al., 2010). Thus, the evaluation of these parameters can help optimize competitive efficiency and monitor the success of the training regimes of young soccer players.

Essentially, the analyses of body composition and bone health are often carried through dual X-ray absorptiometry (DXA). This method is considered ideal for use in children due to its wide availability, fast scanning, low radiation exposure (Zemel et al., 2011). However, this methodology is considered costly and inaccessible to most soccer teams, especially for young athletes (Shim et al., 2014) belonging to sports clubs without laboratories and sophisticated equipment.

In this context, anthropometry emerges as an alternative that is applicable to everyday situations. In addition to being useful, it has numerous advantages, such as the ease of administration and low cost (Santi-Maria et al., 2015). Moreover, as far as it is known, no national and international studies have proposed regression equations based on anthropometric variables that allow estimating the Fat-Free Mass (FFM) and BMD of young soccer players. Adolescence is the best time to gain BDM as well as to modify the size of the skeleton and its structure in response to mechanical loads (Marcus, 2001).

The hypothesis for this study was the following: the arm and muscle circumferences may be strongly related to the FFM, and the length and diameter of the humerus bone may have a close relationship with BMD in young soccer players. These variables are routinely assessed in as part of the control for physical growth and body composition. Additionally, chronological age, maturity status, and body weight may be important predictors of the aforementioned variables.

Thus, this study had two objectives. First, (a) to determine the predictors of FFM and BMD of young soccer players. Second, (b) to propose regression equations to estimate FFM and BMD with anthropometric variables.

MATERIALS AND METHODS

Subjects

A descriptive correlational study was designed to study the FFM and BMD of 167 young soccer players from the Sociedade Esportiva Palmeiras Sports Club, in São Paulo, Brazil. The young athletes belonged to the Centro de Formação de Atletas (Centre for Training Athletes). They were selected by convenience non-probabilistically, agreeing to participate voluntarily. The age range fluctuated between 10.0 and 19.9 years old. Game positions for this study included: Goalkeepers (n = 22), full-backs (n = 27), defenders (n = 22), defensive midfielders (n = 63), midfielders (n = 29), and strikers (n = 29). The sample was divided into two groups: goalkeepers and field players.

Data Collection

Evaluations were carried out at the beginning of the competitive season. Study subjects aged less than 13.9 years trained 4 times a week for 60–90 min/day (a competition) and had 3 years of experience in the sport. Players aged between 14.0 and 16.9 years trained 5 times a week 90–120 min/day (a competition) and had 5 years of experience. Individuals aged over 17.0 years trained 6 times a week 90–120 min/day (a competition) and had 6 years of experience. All players of legal age signed the informed consent form. For players less than 17.9 years old, parents, and/or guardians signed the informed consent form. At the same time, the underage minors were asked to sign the consent form if they agreed to participate. All players signing the informed consent form and underage players between the ages of 10.0 to 19.9 years with parental or guardian consent were included in the study.

Players with out medical clearance on the day of the assessment were excluded. The study was conducted in accordance with the guidelines established by the Ethics Committee of the School of Medical Sciences of the University of Campinas (São Paulo, Brazil- #2015-088). Written informed consents were collected from all participants prior to their inclusion in the study.

Anthropometric evaluations and the DXA scan were carried out in the club facilities (laboratory) in February 2015 (Monday-Friday) from 8 a.m. to 10 a.m. Four trained professionals were in charge of the evaluation process (three in anthropometry and one in DXA). The professional in charge of the DXA evaluations had the necessary certification for using and operating the equipment.

Anthropometric variables were evaluated following the Protocol of the International Society for Advancement of Kinanthropometry [Society for Advancement of Kinanthropometry [ISAK], 2001]. Weight, height, sitting height, circumference, diameter of the elbow, and length of the foot were measured twice. The Technical Error of Measurement ranged from 2 to 3%. Reproducibility ranged from r = 0.95 to 0.98.

Body mass (kg) was evaluated with a balance (SECA, Hamburg) with precision of 0.1 kg. Height was measured with a stadiometer (SECA, Hamburg) with a precision of 0.1 cm. Sitting height was measured on a wooden bench (flat box 50 cm high). A stadiometer (SECA, Hamburg) with 0.1 cm precision was used. The circumference of the relaxed arm was evaluated on the right side of the body with a metal measuring tape of SECA brand and graduated in millimeters with a precision of 0.1 cm. The diameter of the humerus bone and length of the foot were evaluated with a Harpenden adipometer with a range of 0 to 2.00 m and with a precision of 1 mm. Both variables were measured on the right side of the body.

Maturity status was determined by the Peak Height Velocity (PHV) obtained from a regression equation proposed by Mirwald et al. (2002). This method included the standing height, sitting height, length of the legs (standing height – sitting height), decimal age, and its interactions. Maturity status was constructed using 1 year intervals, represented as −4, −3, −2, −1, 0, 1, 2, 3, and 4 PHV.

Fat-Free Mass and BMD analyses were measured by DXA. The model of the equipment used was iDXA (GE Healthcare Lunar, Madison, WI, United States) and the Encore^{TM} 2011 software, version 13.6. Before players were scanned, they were warned about the use of jewelry and the presence of some types of metal in the body. For scanning, players remained in the supine position with arms extended to the side of the body and with the knees and ankles fastened by a Velcro tape. This allowed ensuring the default position. Reference points were adjusted according to the lines showed by the software. The whole-body scan was held, and the values (%) of body fat, bone mass, fat mass, FFM, and BMD were obtained.

Every day, before starting each assessment, the two evaluators in charge calibrated the equipment according to the manufacturer's specifications. The evaluators were qualified for the professional and scientific use of the equipment according to the manufacturer's instructions. To verify reproducibility (test and re-test), scanning was repeated on 10 soccer players. The intra-rater Technical Error of Measurement was less than 1.5%.

Statistical Analysis

Study variables were described using descriptive statistics of the arithmetical mean (X) and the standard deviation (SD). Differences between the two groups of soccer players were verified through the *t*-test for independent samples. Relationships between variables were obtained through Pearson's correlation coefficient. To develop the regression equations, multiple regression analysis was carried out. The equations were analyzed using R^2, Standard Error of Estimation (SEE), and the Variation Inflation Factor (VIF). The Bland–Altman Plot (Bland and Altman, 1986) was used to verify the consistency between the reference values (DXA) and the equations developed. One-way ANOVA test were used to determine differences between the averages of the three predictive models. A significance level of 0.05 was adopted. Calculations were carried out with Excel worksheets and SPSS 16.0 software.

TABLE 1 | Variables that characterize the studied sample in goalkeepers and field players.

Variables	Goalkeepers (n = 22)		Field players (n = 145)		All (n = 167)	
	X	*SD*	*X*	*SD*	*X*	*SD*
Age (years)	14.7	2.4	15.2	2.4	14.9	2.4
Biological age (PHV)	13.80*	0.1	14.7	0.6	14.6	0.6
Weight (kg)	69.2*	15.1	60.5	13.1	61.7	14.1
Height (cm)	177.7*	12.9	167.2	16.5	168.7	16.6
Sitting height (cm)	90.5*	7.7	87.2	6.5	87.7	6.8
Length of the foot (cm)	26.8	1.5	25.3	1.59	25.5	1.7
Arm circumference (cm)	26.6*	3.3	24.4	3	24.8	3.2
D. Humerus (cm)	7.0	0.8	6.7	0.7	6.7	0.7
BMD (g/cm^2)	1.2	0.2	1.2	0.2	1.2	0.2
FFM (kg)	50.0*	16.1	47.6	11.9	47.4	13.3

*X, average; SD, standard deviation; PHV, peak height velocity; C, circumference; D, diameter; BMD, bone mineral density; FFM, fat free mass; *p < 0.05.*

RESULTS

Characteristics of Study Population

The anthropometric profile, FFM, and BMD values of the young soccer players are shown in **Table 1**. No significant differences occurred between both groups regarding chronological age, length of the foot, diameter of the humerus, and the BMD ($p > 0.05$). However, goalkeepers showed greater weight, stature, sitting height, arm circumference, and FFM in relation to field players ($p < 0.05$). In addition, presented the PHV first than the field players.

The Relationship Between the Variables of Fat-Free Mass and Bone Mineral Density With Age

The linear regression analysis for the dependent variables of FFM and BMD for both groups of soccer players is described in **Table 2**. A positive relationship occurred between chronological age and maturity status with the FFM and BMD in both groups. A positive relationship existed between chronological age and maturity status with the FFM and BMD in both groups of soccer players. In addition, weight and arm circumference strongly related to the FFM weight, length of the foot, diameter of the humerus, and the BMD in both groups. Maturity status explained the greater % of the FFM and the BMD in relation to chronological age.

Proposed Equations

The proposed equations for the FFM and the BMD for goalkeepers and field players are illustrated in **Tables 3**, **4**. In both groups, the equations that predict the FFM are based on maturity status, weight, and arm circumference. The R^2 values oscillate between 66 and 68% in goalkeepers and between 62 and 69% in field players.

The equations that predict the BMD in both groups (goalkeepers and players) are based on maturity status, weight, length of the foot, and diameter of the humerus. Values of R^2 fluctuated between 85 and 90% in goalkeepers and 83 and 86% in field players. No collinearity was observed in the FFM and BMD equations. In all cases, the values of the VIF were less than 10.0.

Figures 1, **2** illustrate the correlation between the DXA method reference and the equations generated to predict the FFM and BMD in goalkeepers and field players. Overall, the 12 equations developed demonstrated broad limits of agreement in relation to the reference method. The equations generated to predict the FFM in both groups of young soccer players varied between −2.1 and 2.0. For the BMD, they oscillated between −0.38 and 0.21. Furthermore, correlations in the 12 equations were significant ($p < 0.001$).

Figures 1, **2** show the correlation between the reference method of DXA and the equations generated to predict the

TABLE 2 | Multiple linear regression values of FFM and BMD as dependent variables.

Dependent variables	Independent variables	Goalkeepers				Field players				All			
		R	R^2	SEE	*p*	*R*	R^2	SEE	*p*	*R*	R^2	SEE	*p*
FFM (kg)													
	Chronological age (years)	0.78	0.60	1.09	0.00	0.63	0.40	1.00	0.00	0.64	0.41	1.04	0.00
	Biological age (PHV)	0.81	0.66	1.01	0.00	0.69	0.48	0.93	0.00	0.71	0.51	0.94	0.00
	Weight (kg)	0.78	0.60	1.08	0.00	0.79	0.62	0.79	0.00	0.78	0.61	0.84	0.00
	Arm circumference (cm)	0.66	0.43	1.29	0.00	0.72	0.52	0.89	0.00	0.70	0.50	0.94	0.00
BMD (g/cm^2)													
	Chronological age (years)	0.91	0.82	0.08	0.00	0.78	0.62	0.12	0.00	0.80	0.64	0.11	0.00
	Biological age (PHV)	0.92	0.85	0.08	0.00	0.81	0.66	0.11	0.00	0.83	0.69	0.11	0.00
	Weight (kg)	0.90	0.82	0.09	0.00	0.84	0.71	0.10	0.00	0.84	0.70	0.10	0.00
	Length of the foot (cm)	0.79	0.62	0.12	0.00	0.68	0.47	0.14	0.00	0.67	0.45	0.14	0.00
	D. Humerus (cm)	0.82	0.68	0.11	0.00	0.69	0.47	0.14	0.00	0.70	0.50	0.13	0.00

PHV, peak height velocity; C, circumference; D, diameter; BMD, bone mineral density; FFM, fat free mass; SEE, standard error of estimation.

TABLE 3 | Regression equations to predict the FFM of goalkeepers and field players.

Groups	Prediction equations	C	VIF	*R*	R^2	SEE	*p*
Goalkeepers							
1	FFM = −9462.85 + 859.08*Weight	–	–	0.78	0.66	1.00	0.000
2	FFM = 25632.194 + 4315.34*PHV + 321.951*Weight	–	–	0.82	0.68	1.00	0.000
	PHV	0.24	4.23				
	Weight	0.24	4.23				
3	FFM = 32827.029 + 4149.134*PHV + 474.071*Weight-664.695*AC	–	–	0.82	0.68	1.30	0.000
	PHV	0.23	4.38				
	Weight	0.10	10.00				
	Arm circumference	0.18	5.60				
Field player							
1	FFM = 2428.7 + 734.7*Weight	–	–	0.81	0.66	0.10	0.000
2	FFM = 1949.902−65.081*PHV + 742.903*Weight	–	–	0.79	0.62	0.70	0.000
	PHV	0.22	4.61				
	Weight	0.22	4.61				
3	FFM = 4033.066−16.121*PHV + 767.570*Weight-146.733*AC	–	–	0.83	0.69	0.10	0.000
	PHV	0.37	2.70				
	Weight	0.42	2.39				
	Arm circumference	0.40	2.48				

C, collinearity; VIF, variation inflation factor; SEE, standard error of estimate; PHV, peak height velocity; AC, arm circumference; FFM, fat free mass.

FFM and BMD in goalkeepers and field players. Overall, the 12 developed equations showed broad limits of agreement in relation to the reference method. The equations generated to predict the FFM in both groups oscillate between −2.1 and 2.0 and for the BMD, oscillate between −0.38 and 0.21. Furthermore, correlations in the 12 equations are significant ($p < 0.05$).

DISCUSSION

Predicting FFM and BDM

The objective of this study was to determine the predictors of the FFM and BMD for young soccer players. The results from this research suggest that maturity status predicts the FFM and BMD at a higher percentage than does chronological age. This pattern was observed in the two groups: goalkeepers and field players. In fact, the status maturity plays a major role during the adolescence stage: since the chronology, duration and Intensity of the puberty are specific for each adolescent and may considerably vary among them (Malina et al., 2004).

Essentially, the results obtained from this study confirmed that chronological age is of limited use to analyze and/or study the FFM and BMD of young soccer players at least in an age group between 10.0 and 19.9 years. Therefore, the control of maturity status in young soccer players is a priority, especially to avoid potential confusion between the adolescents of various categories and age groups. Several previous studies have shown its utility and importance in samples of young soccer players (Seabra et al., 2012; Lautaro and Cossio-Bolaños, 2014; Santi-Maria et al., 2015) with grouping strategies between the soccer players helping to maintain, protect

TABLE 4 | Regression equations to predict the BMD of goalkeepers and field players.

Groups	Prediction equations	C	VIF	*R*	R^2	SEE	*p*
Goalkeepers							
1	BMD = 0.802 + 0.030*PHV + 0.008*weight			0.92	0.85	0.08	0.000
	PHV	0.24	4.23				
	Weight	0.24	4.23				
2	BMD = 0.867 + 0.071*PHV + 0.002*L. Foot + 0.037*D. Humerus			0.93	0.86	0.08	0.000
	PHV	0.21	4.8				
	Length of the foot (cm)	0.28	3.57				
	Diameter of the humerus	0.27	3.72				
3	DMO = 1.088 + 0.052*PHV + 0.006*Weight-0.016*L. Foot + 0.017*D. Humerus			0.95	0.90	0.07	0.000
	PHV	0.17	5.97				
	Weight	0.19	5.20				
	Length of the foot (cm)	0.25	4.02				
	Diameter of the humerus	0.26	3.89				
Field player							
1	BMD = 0.712 + 0.030*PHV + 0.008*Weight			0.85	0.73	0.10	0.000
	PHV	0.22	4.61				
	Weight	0.22	4.61				
2	BMD = 0.495 + 0.057*PHV + 0,017*L. Foot + 0.036*D. Humerus			0.83	0.69	0.11	0.000
	PHV	0.37	2.7				
	Length of the foot (cm)	0.42	2.39				
	Diameter of the humerus	0.40	2.48				
3	BMD = 0.856 + 0,028*PHV + 0.009*Weight-0.011*L. Foot + 0.010*D. Humerus			0.86	0.73	0.10	0.000
	PHV	0.21	4.78				
	Weight	0.11	8.95				
	Length of the foot (cm)	0.27	3.77				
	Diameter of the humerus	0.37	2.71				

C, collinearity; VIF, variation inflation factor; SEE, standard error of estimate; PHV, peak height velocity; L. Foot, length of the foot; D. Humerus, diameter of the humerus; BMD, bone mineral density.

and/or promote players according to their actual state of maturation (Malina et al., 2005).

Regarding the anthropometrical variables that predict the FFM, the results demonstrated that body weight and arm circumference presented high predictive values. These results are consistent with studies carried out with adults (Lee et al., 2000; Kuriyan and Kurpad, 2004; Lyra et al., 2012) to the extent that they showed significant correlations with the FFM.

The predictors of the BMD, weight, length of the foot, and diameter of the humerus were the variables that showed high predictive values in goalkeepers and field players. These results are consistent with other studies conducted with non-athletic children and adolescents (Silva et al., 2006; Fonseca et al., 2008; Gómez-Campos et al., 2017). In addition, the results demonstrated that anthropometric variables that are routinely assessed in the field are necessary to use to analyze bone health in children and adolescents.

In this context, Henderson et al. (2002) pointed out that the BMD relates to growth and nutritional factors. This information indicates that proper nutrition may have a significant impact on body weight and a consequent increase in length and diameter of the bones (Molgaard et al., 1997). Therefore, the presence of short and narrow bones may lead to a reduction in BMD and Bone Mineral Content (BMC) and possibly to other consequences for overall health (Gómez-Campos et al., 2017).

Equations for Goalkeepers and Field Players

The second objective of this study sought proposed regression equations to estimate the FFM and BMD with anthropometric variables. For both groups (goalkeepers and field players) in this study, 12 equations were developed (six for the FFM and six for the BMD).

Values of R^2 for the FFM for the goalkeepers oscillated between 66 and 68% and between 62 and 69% in field players. For the BMD R^2, values varied between 85 and 90% in goalkeepers and between 69 and 73% in field players. However, in all cases no collinearity was observed in the equations developed, and the values of the VIF were within the limits established by the literature (Slinker and Glantz, 1985).

Essentially, the 12 proposed equations showed adequate values as the Bland–Altman plot with the DXA reference method reflected narrow limits and highly significant correlation coefficients (r = 0.78 to 0.94). This ensured a high precision in the equations proposed for both working groups. In addition, some previous studies have reported similar R^2 values and levels of agreement for

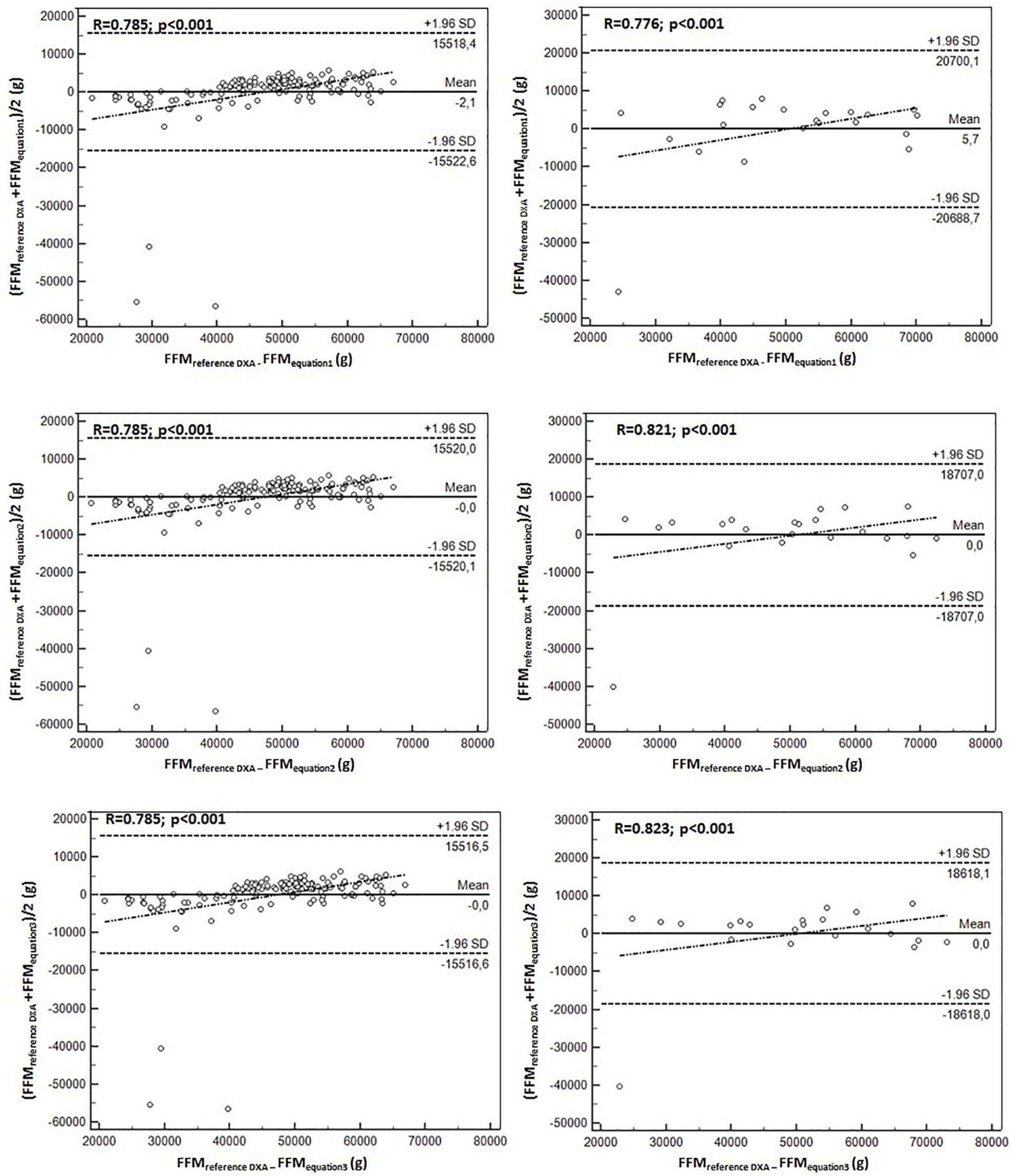

FIGURE 1 | Bland–Altman plot for the correlation between the FFM values determined by the reference method (DXA) and the three predictive equations for goalkeepers (left) and field players (right).

samples of children and adolescents (Cameron et al., 2004; Cossio-Bolaños et al., 2017; Gómez-Campos et al., 2017).

As a result, the equations developed are a non-invasive alternative to estimate the FFM and BMD of young soccer players. These results confirm that maturity status and anthropometric variables, such as weight, arm circumference, diameter of the humerus, and the length of the foot, need be introduced into anthropometric assessment of young soccer players. These variables are simple and easy to evaluate in laboratory conditions and require tools easy to access and of low cost. These factors facilitate using the independent variables for predicting FFM and BMD of young soccer players.

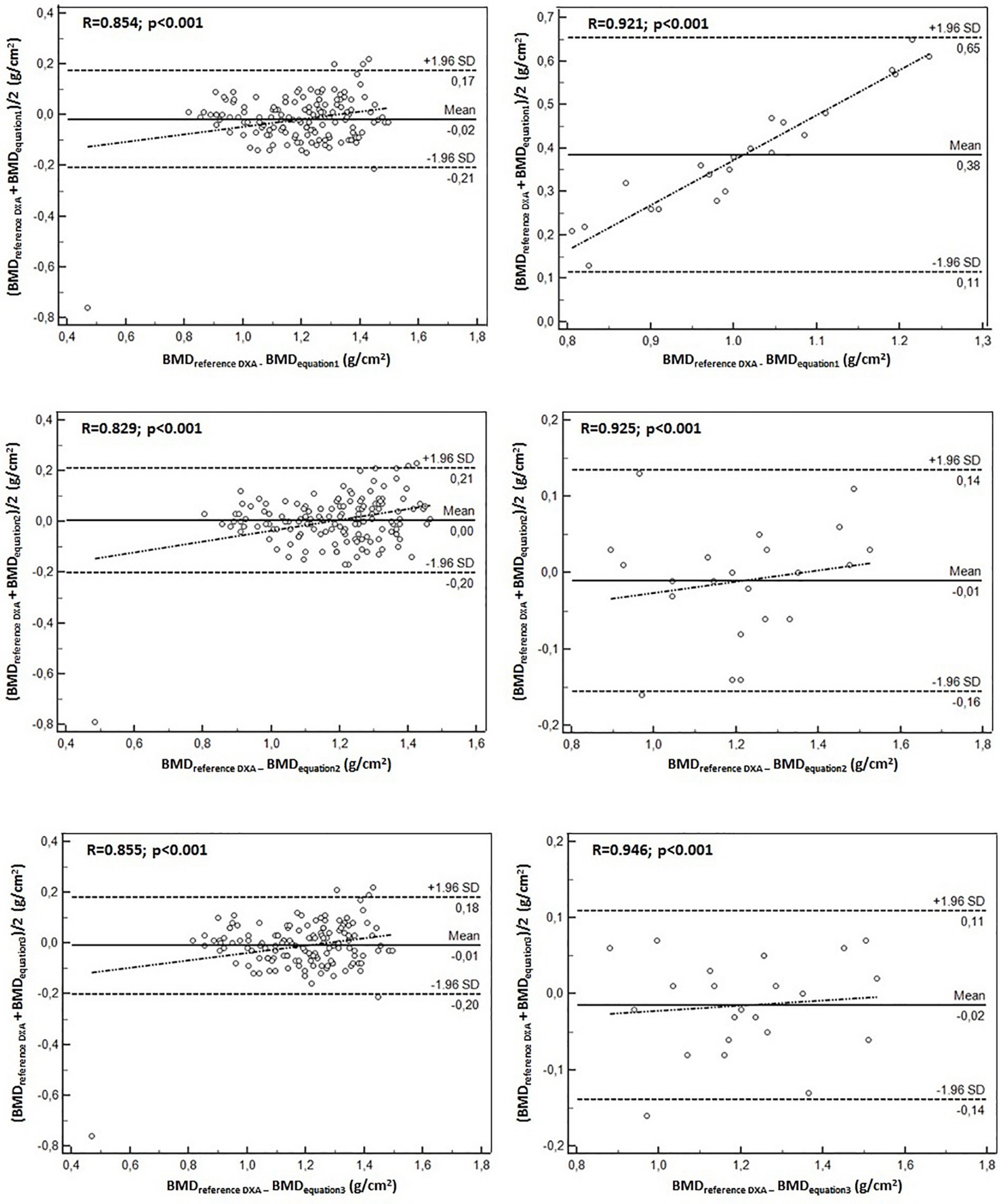

FIGURE 2 | Bland–Altman plot for the correlation between the BMD values determined by the reference method (DXA) and the three predictive equations for goalkeepers (left) and field players (right).

The equations created are subject to bias in the calculations. As a result, precision may be compromised when used with individuals with different anthropometric characteristics, particularly with samples from different geographical locations. Even though it was not possible to use an additional group to develop cross-validation, this does not invalidate the results. Validity was ensured with the measurement of the anthropometric variables by using a standardized protocol and the DXA reference method with a sample of young players from a different professional team from Brazil.

The results from this study need to be interpreted carefully. Consequently, as far as the equations are used, external validation will be achieved.

Limitations of the Study

Chronological age has a limited use for predicting FFM and BDM. However, the other anthropometric variables, such as weight, arm circumference, diameter of the humerus, and length of the foot, enabled generating regression equations to estimate the FFM and BDM of goalkeepers and field players.

CONCLUSION

The results from this study suggest broad agreement. Furthermore, they support reproducibility of the equations. In addition, the findings demonstrated the use and application of the regression equations as a non-invasive alternative for everyday use in soccer clubs.

DATA AVAILABILITY

Publicly available datasets were analyzed in this study. This data can be found here: https://figshare.com/s/fa5ff23c007cd6fa23a5.

AUTHOR CONTRIBUTIONS

MA, RG-C, and MC-B contributed to the conception and design of the current work, data analyses, data interpretation, and drafted the manuscript. TS-M, TM, AA, and MS coordinated NU-AGE data collection. All the authors contributed to interpretation of data, critically revised, and approved the final version of this manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00522/full#supplementary-material

REFERENCES

Bland, J. M., and Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 8, 307–310. doi: 10.1016/S0140-6736(86)90837-8

Cameron, N., Griffiths, P. L., Wright, M. M., Blencowe, C., Davis, N. C., Pettifor, J. M., et al. (2004). Regression equations to estimate percentage body fat in African prepubertal children aged 9 y. *Am. J. Clin. Nutr.* 80, 70–75. doi: 10.1093/ajcn/80.1.70

Cossio-Bolaños, M. A., Sulla-Torres, J., Urra-Albornoz, C., and Gómez-Campos, R. (2017). Development of equations and proposed reference values to estimate body fat mass among Chilean children and adolescents. *Arch. Argent Pediatr.* 115, 453–461. doi: 10.5546/aap.2017.eng.453

Daly, R. M. (2007). The effect of exercise on bone mass and structural geometry during growth. *Med. Sport Sci.* 51, 33–49. doi: 10.1159/0000103003

Fonseca, R. M. C., França, N. M., and Praagh, E. V. (2008). Relationship between indicators of fitness and bone density in adolescent brazilian children. *Pediatr. Exerc. Sci.* 20, 40–49. doi: 10.1123/pes.20.1.40

Gómez-Campos, R., Andruske, C. L., Arruda, M., Urra-Albornoz, C., and Cossio-Bolaños, M. (2017). Proposed equations and reference values for calculating bone health in children and adolescent based on age and sex. *PLoS One* 12:e0181918. doi: 10.1371/journal.pone.0181918

Helge, E. W., Aagaard, P., Jakobsen, M. D., Sundstrup, E., Randers, M. B., Karlsson, M. K., et al. (2010). Recreational football training decreases risk factors for bone fractures in untrained premenopausal women. *Scand. J. Med. Sci. Sports* 20, 31–39. doi: 10.1111/j.1600-0838.2010.01107.x

Henderson, R. C., Lark, R. K., Gurka, M. J., Worley, G., Fung, E. B., Conaway, M., et al. (2002). Bone density and metabolism in children and adolescents with moderate to severe cerebral palsy. *Pediatrics* 110:e5. doi: 10.1542/peds.110.1.e5

Krustrup, P., Nielsen, J. J., Krustrup, B. R., Christensen, J. F., Pedersen, H., Randers, M. B., et al. (2009). Recreational soccer is an effective health-promoting activity for untrained men. *Br. J. Sports Med.* 43, 825–831. doi: 10.1136/bjsm.2008.053124

Kuriyan, R., and Kurpad, A. V. (2004). Prediction of total body muscle mass from simple anthropometric measurement in young Indians males. *Indian Med. Res.* 119, 121–128.

Lautaro, M. G., and Cossio-Bolaños, M. A. (2014). Perfil antropométrico de jóvenes futbolistas en función de la maduración somática. *Rev. Peru Cienc. Act Fis. Deporte* 1, 47–52.

Lee, R. C., Wang, Z., Heo, M., Ross, R., Janssen, I., and Heymsfield, S. B. (2000). Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *Am. J. Clin. Nutr.* 72, 796–803. doi: 10.1093/ajcn/72.3.796

Lyra, C. O., Lima, S. C. V., Lima, K. C., Arrais, R., and Pedrosa, L. F. C. (2012). Prediction equations for fat and fat-free body mass in adolescents, based on body circumferences. *Ann. Hum. Biol.* 39, 275–280. doi: 10.3109/03014460.2012.685106

Malina, R. M., Bouchard, C., and Bar-Or, O. (2004). *Growth Maturation and Physical Activity*, 2nd Edn. Champaign, IL: Human Kinetics.

Malina, R. M., Cumming, S. P., Morano, P. J., Barron, M., and Miller, S. J. (2005). Maturity status of youth football players: a noninvasive estimate. *Med. Sci. Sports Exerc.* 37, 1044–1052.

Marcus, R. (2001). Role of exercise in preventing and treating osteoporosis. *Rheum Dis. Clin. North Am.* 27, 131–141. doi: 10.1016/S0889-857X(05)70190-3

Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., and Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Med. Sci. Sports Exerc.* 34, 689–694.

Molgaard, C. T. B., Prentice, A., and Cole, T. (1997). Whole body bone mineral content in healthy children and adolescents. *Arch. Dis. Childhood* 76, 9–15. doi: 10.1136/adc.76.1.9

Rahnama, N., Lees, A., and Bambaecichi, E. (2005). Comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. *Ergonomics* 48, 1568–1575. doi: 10.1080/00140130500101585

Rauch, F., Bailey, D. A., Baxter-Jones, A., Mirwald, R., and Faulkner, R. (2004). The "muscle-bone unit" during the pubertal growth spurt. *Bone* 34, 771–775. doi: 10.1016/j.bone.2004.01.022

Santi-Maria, T., Gomez-Campos, R., Andruske, C. L., Gamero, D. H., Luarte-Rocha, C., Arruda, M., et al. (2015). Percentage of body fat of young soccer players: comparison of proposed regression frequencies between goalkeepers and soccer camp players. *J. Exerc. Physiol.* 18, 70–80.

Seabra, A. M., Marquez, E., Brito, J., Krustrup, P., Abreu, S., Oliveira, J., et al. (2012). Muscle strength and soccer practice as major determinants of bone mineral density in adolescents. *Joint Bone Spine* 79, 403–408. doi: 10.1016/j.jbspin.2011.09.003

Shim, A., Cross, P., Norman, S., and Hauer, P. (2014). Assessing various body composition measurements as an appropriate tool for estimating body fat in national collegiate athletic association division I female collegiate athletes. *Am. J. Sports Sci. Med.* 2, 1–5.

Silva, C. G. T., Teixeira, A. S., and Dalmas, J. C. (2006). Análise Preditiva da Densidade Mineral Óssea em Adolescentes Brasileiros Eutróficos do Sexo Masculino. *Arq. Bras. Endocrinol. Metab.* 50, 105–113. doi: 10.1590/S0004-27302006000100015

Slinker, B. K., and Glantz, S. A. (1985). Multiple regression for physiological data analysis: the problem of multicollinearity. *Am. J. Physiol.* 249(1 Pt 2), R1–R12. doi: 10.1152/ajpregu.1985.249.1.R1

Society for Advancement of Kinanthropometry [ISAK] (2001). *Estándares Internacionales Para la Valoración Antropométrica*. San Juan: Universidad de Puerto Rico.

Vicente-Rodriguez, G. (2006). How does exercise affect bone development during growth? *Sports Med.* 36, 561–569.

Wittich, A., Mautalen, C. A., Oliveri, M. B., Bagur, A., Somoza, F., and Rotemberg, E. (1998). Professional football (soccer) players have a markedly greater skeletal mineral content, density and size than age- and BMI-matched controls. *Calcif. Tissue Int.* 63, 112–117. doi: 10.1007/s002239900499

Zemel, B. S., Kalkwarf, H. J., Gilsanz, V., Lappe, J. M., Oberfield, S., Shepherd, J. A., et al. (2011). Revised reference curves for bone mineral content and areal bone mineral density according to age and sex for black and non-black children: results of the bone mineral density in childhood study. *J. Clin. Endocrinol. Metab.* 96, 3160–3169. doi: 10.1210/jc.2011-1111

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Psychological Demands of International Rugby Sevens and Well-Being Needs of Elite South African Players

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Rugby sevens was included in the 2016 Olympic Games, with South Africa's Blitzboks winning bronze. They also won the 2016/2017 and 2017/2018 World Rugby Sevens Series. Whilst peak performance is paramount at the elite level there is a growing responsibility to address player well-being and off-the-field player needs. This study explored the psychological demands of international rugby sevens and the well-being needs of elite players. Twenty professional players (age range: 21–33 years) participated in semi-structured interviews. Qualitative content analysis yielded five categories of psychological demands: (1) tournament structure, (2) resilience, (3) cope with physicality, (4) perform when fatigued, and (5) perform under pressure. The prevailing team culture included: (1) team cohesion, (2) clear purpose, (3) work ethic, (4) team values, (5) happy environment, (6) relationships with coaching staff, and (7) faith. Various psychological skills [(1) goal-directed behavior, (2) compartmentalization, (3) deal with anxiety, (4) motivation, (5) imagery, and (6) self-confidence] and mental strategies [(1) coping, (2) "back-to-zero," (3) creativity, and (4) cognitive triggers] utilized by the players are discussed. Their general well-being and individual needs were: (1) physical needs, (2) financial concerns/needs, (3) preparation for life after rugby career, (4) support structures, and (5) mental (ill) health. This information could be useful to develop an integrated sport psychological and well-being program aimed at improving performance and facilitating psychological well-being both during and after retirement from elite sport.

Keywords: rugby sevens, performance, team culture, psychological skills, mental strategies, career termination, mental (ill) health, well-being

INTRODUCTION

Globally, the popularity of rugby sevens has increased, partly due to its inclusion in the 2016 Olympic Games (Higham et al., 2012; Lopez et al., 2012). This event has been a catalyst for research into this sport (Tucker, 2016). Higham et al. (2013) noted that players will begin to specialize in either fifteens or sevens. Due to its inclusion in the Olympics many 15-a-side players attempted the switch to sevens to take part in this global spectacle.

Sevens is played on the same field and has similar rules to fifteens (Higham et al., 2012, 2013). The main differences are fewer players (seven players on the field and five reserves), shorter matches (two seven-minute halves) and multiple matches during tournaments (Higham et al., 2012; Lopez et al., 2012; Suarez-Arrones et al., 2012). International 15-a-side (test) matches are typically separated by a week, allowing teams to recover and travel, adapt to the new conditions and prepare for the upcoming match. The annual HSBC World Rugby Sevens Series, consists of 10 tournaments over a six-month period, split into five continental tours, each consisting of two tournaments in different countries over consecutive weekends. Tournaments take place over a two or three-day period (World Rugby, 2016). Teams typically play three group stage matches on day one followed by one to three play-off matches on day two, with a waiting period of around 3 h between matches. Players need to adapt to traveling, different climates and time zones, as well as the frequency of games (Van Rooyen, 2015).

Sevens is played at a higher intensity than fifteens (Higham et al., 2012, 2013), with frequent accelerations and incomplete stops contributing to the accumulation of fatigue (Carreras et al., 2013). Sevens players should possess similar or superior physical abilities (e.g., acceleration, speed, power, aerobic and anaerobic capacity) to 15-a-side players (Higham et al., 2013). The body composition of sevens players are similar to 15-a-side backline players, with lower fat percentages enabling greater speed and anaerobic endurance. Teams tend to have multiple high intensity training sessions per day that consist of high running loads, frequent changes in speed and repeated maximal sprint efforts (Higham et al., 2012, 2013; Carreras et al., 2013). This has implications for the preparation of players switching between rugby formats.

Peak physical conditioning will allow players to recover faster between matches, from day one to two and from one tournament to the next (Higham et al., 2013). Injuries sustained during tournaments increase the workload of the remaining players making them more prone to experience fatigue and subsequently injuries (Van Rooyen, 2015). Recovery strategies is needed to reduce fatigue and ensure consistent performance over consecutive days (Higham et al., 2012, 2013).

Whilst mental preparation is key to sevens success (Van Rooyen, 2015), there appears to be a paucity of information on psychological factors in sevens. Osborne Finekaso and Treharne (2019) recently explored sources of stress (training camp, competition and organizational stressors) experienced by professional Fijian rugby sevens players and the detrimental effects thereof. Furthermore, they identified a broad range of coping strategies utilized by these players in these different settings to ameliorate these stressors. Psychological development is often neglected in talent development programs (MacNamara et al., 2010a). Psychological factors should be included in talent development programs as it influence the pathways players follow to reach the elite level (MacNamara et al., 2010b). Psychological skills become a determining factor of success when players possess similar skill levels and physical attributes (Hendricks, 2012). Competitiveness, commitment and self-belief contribute to the on-field performance of players and the development and use of these attributes should be a priority from an early age (MacNamara et al., 2010a).

To develop a psychological skills intervention for a specific sport or athlete the physical, technical, tactical, logistical and psychological demands, and individual player needs should be considered (Taylor, 1995). In light of this statement, the aim of the study was to explore the perceived psychological demands of the sport and off-the-field needs of professional rugby sevens players. In-depth and context rich information will be gained that could guide holistic player development within the existing talent development structures.

MATERIALS AND METHODS

The study was exploratory in nature, and utilized a purposive sample and qualitative approach to analyze participants' subjective views. This allows for a better understanding of the perspectives and experiences of participants (Hiatt, 1986).

Permission was granted by the South African Rugby Union's Internal Research Review Committee and the Research Ethics Committee of Stellenbosch University (SU-HSD-002671). Participation was voluntary and informed consent forms were signed in accordance with the Declaration of Helsinki.

Twenty of the 27 contracted South African rugby sevens players for the 2016/2017 season took part in the study, with their ages ranging from 21 to 33 years. The sample included nine Olympians, eight national sevens team players (Blitzboks) and three national sevens academy players. Seventeen participants previously represented the national team in the World Rugby Sevens Series ranging from two to 68 tournaments.

A semi-structured interview script was developed that consisted of open-ended questions relating to the perceived physical and psychological demands of international sevens and the off-the-field needs of elite players. NK first interviewed five coaching staff members, including the team's sport psychologist to refine the interview script. The final data analysis did not consider this information. Before interviewing commenced the participants were informed about the study's objectives and procedures, that they could withdraw at any time and without prejudice and that they did not have to answer all the questions. The interviews took place in a familiar room at the team's training facility and following a familiarization period with the interviewer, aimed at building rapport to enhance the trustworthiness of the data. NK conducted all the interviews with the players who were able to construct and voice their own experiences. The semi-structured nature of the interviews enabled probing for additional information from the participants to explore their experiences comprehensively. The interviews were recorded and lasted 40 min on average. All interviews were transcribed verbatim and the information was treated confidentially and reported anonymously.

DATA ANALYSIS

The interview transcripts were analyzed using qualitative content analysis. Data analysis commenced during the data collection phase already, by reading and rereading the scripts, in order to become familiar with the text (Braun and Clarke, 2006). Both authors individually extracted raw data themes from the first four completed interviews utilizing an inductive or bottoms-up approach. The unit of analysis was any single coherent idea (unit of meaning), which included single words, phrases, sentences or paragraphs. It was possible to code a single unit for multiple raw data themes. The authors met after the initial round of manual, open coding, to compare and critically discuss their initial coding and to reach negotiated agreement where discrepancies and confusion existed. The authors collectively grouped the various codes into sub-categories. NK conducted, transcribed and analyzed the remaining 16 interviews with the previously developed coding scheme in a short space of time to increase coding stability. The authors met on multiple occasions during this period, critically discussing NK's coding and categorization of the data and exploring alternative scenarios. The authors collectively grouped the sub-categories into categories and themes. Member checking and individual follow-ups ensured that the participant's responses were correctly interpreted and to establish trustworthiness. The final results were made available to the participants and a feedback session was held with the coaching staff. The participants and coaches were asked to corroborate these findings or provide alternate views.

RESULTS

Tables 1–4 contain the main findings. Quotes were used to explain certain themes and categories. **Table 1** contains five categories on the perceived psychological demands of elite rugby sevens. The players pointed to the tournament and match structure, extensive traveling, the high training load and the need to cope with the physicality of the sport as being psychologically very demanding.

The tournament structure of the international sevens series differs from fifteens:

> "…six games over one weekend, you have six warm-ups. After every match you cool down, you're a bit stiff. To pick yourself up after that first game, to do it all again the same day and go back and sleep. The next morning you feel like you ran in front of a train and you know there are three more games to come." – P19

> "If you are not mentally strong, you're not going to make it here. A lot of the current Springboks [South African national fifteens side], said they will never come play sevens again, cause it's just physically and psychologically too demanding." – P1

Players have to use the available scoring opportunities and limit their own mistakes:

> "The small decisions you have to make when you're tired…There aren't seconds in a sevens game; there are split seconds…You have to take every single opportunity the game throws at you. If you don't, you can lose a game." – P16

> "…speed of the game. The room for error is tiny. One mistake and you probably lose a game. If you play a good team and have the ball, you must score." – P12

Extensive economy class flights across multiple time zones pose challenges:

> "…going from different time zones can be tough on the body, especially sleep wise. Luckily we get there a little in advance, we have two or three days to get our bodies ready…to adapt to the new surroundings." – P17

TABLE 1 | Perceptions about the psychological demands of elite rugby sevens.

Perceived psychological demands	Tournament structure	Ten tournaments on five continents	Long season
			Traveling for 2.5 months/year
		Match structure	Use every opportunity
			Mistake are costly
			Three matches per day
			Turnaround between matches
			Day 2 opponents: short notice
		Travel	Economy class flights
			Time zones/jet lag
			Fatigue, sleep difficulties
			Adapt to climates and cultures
	Resilience	Growth mind-set	Exposure to adversity
			Positive reaction to adversity
			Bounce back after setbacks
		Raise own standards	Comparison and competition with opposition and teammates
		Injuries	High-collision, high risk sport
			Inherent part of the game
			Physical rehabilitation
			Psycho-social recovery
	Cope with physicality	High training load	3–5 high intensity sessions/day
			Quality over quantity
		Push physical barriers	
		Play through niggles	
		Monitor recovery	Daily rating on phone app
	Perform when fatigued	Reduce negative effect	Peak conditioning
			Use various recovery strategies
		Maintain concentration	
	Perform under pressure	High expectations and performance standards	Self (internal competition)
			From others
		Consistency	Thrive on pressure

Resilience is key to overcome injuries and other forms of adversity:

> "I've been battling with injuries over the last two years. Struggling just to find my feet, getting back to playing good rugby and then getting injured. And I have to start from the floor again." – P6

> "Coping during physical training …Coping with disappointments, like injury and not making the team, stuff like that. You don't only have to be tough for training, but also emotionally. Emotionally you have to be strong and tough, mentally tough, just to take everything as it comes." – P10

Physical and mental fatigue constantly challenge the players:

> "The recovery time between games is so short. You get a lot of bumps and bruises and you only have 2 h to recover. We do video

TABLE 2 | Perceptions about the Blitzboks' prevailing team culture.

Team culture	Team cohesion	Team comes before individuals (no superstars)	
		Brotherhood/family	
		Embrace cultural differences	
		Play for each other	
		Everybody on the "same page"	
	Clear purpose	Grow as people	
		Role-models to South African youth	
		Impact the lives of others	
	Work ethic	Team focused	Process driven
			Roles and responsibilities
		High work rate	
		Discipline	
		Feed of the energy of others	
	Team values	Respect, humility, loyalty, pride, passion, accountability, self-control, dedication, leadership	
	Happy environment	Relaxed environment	
		Enjoyment	
		Appreciative of each other	
	Relationship with coaching staff	Clear, open, honest communication	
		Aware of personality differences	
	Faith	God gave talents	
		Bible reading, prayer, listening to sermons	

analysis that is also draining mentally … you have to listen, your body is sore and you can lose focus quickly… it's really hard on the body … there's not a lot of time to recover before your next game … " – P14

Consistent performance necessitate that players develop across multiple domains:

"… I've dealt more with the mental side. I had two operations, so I'm definitely not physically at my best, but when I get my head right, I play well you know? I'm decisive and make smart decisions; the right ones at the right time." – P12

Team culture was identified as a key contributor to the team's performance, with seven categories outlined in **Table 2**.

A strong cohesiveness that embraced the rich diversity of the group was evident:

"… a family, we are really tight … we spend a lot time together, doing stuff together. Our team culture and dynamics is very important and really strong. We make sure that it does not go away regardless of what happens, win or lose, in good and bad times. The culture is big." – P3

"Different players from different backgrounds all aiming for one thing was pretty special." – P20

"To be understanding and respectful of different people's cultures; we really put a big emphasis on that. As much as we respect individual cultures, the players need to respect the team culture and the team identity." – P2

The team had clear objectives around personal growth and about being role-models:

"… we want to touch lives and continuously grow as people as well, not only as rugby players. When we strive toward those goals; touching people's lives and putting smiles on other people's faces, it really builds such a beautiful picture … it's phenomenal really." – P4

"Our motto is 'touching people's lives.' Everywhere we go we try to change or make a good impression on people's lives." – P2

Work ethic is essential to the team culture:

"… these guys are grafters, pure work horses. It is probably the back bone of our setup … If you're scared of work then sevens is not the game for you." – P1

"… discipline is the most important thing. If you don't have discipline you will just think of yourself and not care about the other guys around you. And the other thing is work ethic, you must work hard." – P18

A number of the participants highlighted the role of faith in their lives and rugby careers:

"I'm a believer … so I think those challenges [referring to injuries] are preparing me for greater things that lie ahead. I read my Bible. My Bible is like, it's not my stress reliever, but it calms me down and gives me hope that everything will be fine. That's a very big motivation for me." – P3

"… the talent is not yours; God gave you this talent. It depends what you do with it. You can touch other people's lives or you can just play around with it." – P18

"I don't allow stress to affect me that much, because I'm a believer. I believe the Lord will never put you in a situation that you can't handle. So, whenever I'm in a situation, I'm going to handle it, because I'm strengthened by the Lord." – P20

Table 3 contains the psychological skills and mental strategies used by elite rugby sevens players.

Staying focused over a prolonged duration is a prerequisite for success, but some players noted that they need to deliberately shift their focus away from rugby:

"… mentally, you want to try and be at your best every single time. You need to know yourself first of all, and need to know the tools you can use … Being consistent is the most important …, before a game, you have your routine and you're mentally ready every single time. Not just for games, also for training." – P17

"… to focus on the right stuff. My mental challenge is to stop thinking about the game. Sometimes I overthink the game. I really play the game over in my mind a lot in terms of how we are going to play; if the defense does this then we need to do that, we need to do this, you know? I think uh, I sometimes burn myself out. … that is mentally draining, you know?" – P14

Different coping strategies are needed to deal with external factors:

"Emotional issues will always be there. To cut out all the baggage and leave it at home. So when you hit the field you have a clear and open mind to focus on your job, focus on your performance.

TABLE 3 | Perceptions about the use of psychological skills and mental strategies by elite rugby sevens players.

Psychological skills	Goal-directed behavior	Goal-setting	Clearly defined big picture
		Goal achievement	Strive for excellence
	Compartmentalization (When and how to switch on/off)	Focused attention (switch on)	Focus/refocus
			Routines
		Failure to switch off	Leads to overthinking
			Emotionally draining
			High burnout risk
	Deal with anxiety	Anxiety reduction	Lower anxiety levels
		Anxiety management	Interpret anxiety positively
	Motivation	Utilize various resources	Internal: drive, passion
			External: social support
	Imagery	Simulate matches	
		Visualize scenarios	
		Repetition/ rehearsal	
	Self-confidence	Meticulous preparation	Marginal gains (1%'s)
		Positive self-talk	Affirmation
		Previous performances	
Mental strategies	Coping	Emotional, relational, personal problems	Approach behavior
			Address personal issues
		Refereeing decisions, outside interference, setbacks, non-selection	Problem-focused coping
			Emotion-focused coping
	"Back-to-zero"	Restart after every play, break, match, day, result	
	Creativity	Big-box, small-box	Think outside the small box, still within the big box
	Cognitive triggers		

Any emotional baggage that you carry is going to affect your performance on the field." – P11

"Off-field or on-field, your mental state is probably most important. You can't take personal stuff onto the field. . . . when you put your boots on next to the field, you switch on. You think about what's going to happen on the field. You can't let stuff that is bothering you at home, family, anything, mix with your rugby . . . You need to be in a good mental state to play the game." – P15

Sustained performance at this elite level requires a strong inner drive:

"It's a very demanding sport in terms of mental preparation and mental training, but if you're not up for the challenge from the get go and [don't have] that burning desire to want it more than the other guys, then you're not going to make it." – P1

". . . you need to motivate yourself, even though it is a team environment. You need to do what you do right, be the piece of the puzzle for the team." – P3

Imagery assists in preparing for various on-field scenarios:

". . . a product of how many times you see things on the field. If you are in a situation and you haven't seen it before, you start to get very nervous, cause you don't know how to handle it or how you're going to react to the situation. But if you've seen a situation a couple times before, you can be a lot calmer." – P12

The team employ a "big-box, small-box" philosophy referring to the creativity players are encouraged to produce within the bigger game plan:

". . . everyone's got this blueprint that we've been given for a tournament and within that blueprint we've got so much freedom to let your natural abilities come through, and to express yourself." – P4

Whilst peak performance is paramount at the elite level there is a growing responsibility to address player well-being and their off-the-field needs. **Table 4** contains four categories relating to the current and future well-being needs.

Most of the players acknowledged the importance of adequate financial planning and furthering their own education in preparation of the inevitable career change from professional rugby to a post-rugby career. Despite not mentioned frequently, the need to address various mental health issues and fostering general well-being is a high priority. A number of players require greater financial security and financial guidance:

". . . sevens players are not getting paid as much as the fifteens guys . . . What would make it better is to match what the fifteens

TABLE 4 | Well-being and individual needs of elite rugby sevens players.

Well-being and individual needs	Physical needs	Individualized training	Peak conditioning
			World-class facilities
			Weekly training plans
			Breaks in-between tournaments
		Individualized nutrition	Supplementation
			Hydration
			Top-up meals
		Access to expert medical team	Physicians, Physiotherapists, Biokineticists, massage therapy
	Financial concerns and needs	Earning less than fifteens	Code switching
		Earlier contracting	Security
			Stability
		Financial guidance	During and after career
	Preparation for life after rugby career	Shared responsibility between everyone	Players, agents, South African Rugby Union
		Furthering education	Certificates, coaching qualification
			More time to study
			Funding: Player or SA Rugby?
		Career guidance	Career termination exit strategy
			Networking
			Explore opportunities
			Start own business
		Holistic development (life – sport integration)	Develop sport identity in context
			Foster personal identity
	Support structures	Family/support system	Source of affirmation
			Explain team dynamics
			More family time
			Communication whilst traveling
		Mentorship needs	Mentor/life coach
			Act in the player's best interest
	Mental (ill) health	Human/athlete condition	(Competitive) anxiety
		Subclinical mental health disorders	Insomnia
			Burnout
		Clinical mental health disorders	Depression
			Suicide ideation

guys are getting . . . , so that money doesn't force a player to go to fifteens. I would've loved to have made enough money and to have found something that I want to do after rugby, because right now I have no clue. I'm still trying to figure it out. I would have loved to have things in place that's going to sustain me for the rest of my life." – P20

"…my concern is that 10 years down the line one of my teammates will be like 'Hey, do you have a job for me?' There's a lot of guys that come from nothing and unfortunately will go back to nothing, because [their] money is squandered. Then the opportunity for education has passed and you can't retire on a sevens salary. You should be smart and put yourself in a good position." – P12

The players are also aware that they need to start preparing early for life after rugby:

"A lot of guys don't study after school. But some of the guys do and it can add a lot of pressure, you know? Playing rugby and also study at the same time, so you're like a student-athlete sorta thing . . . , you need to have a backup plan . . . " – PP17

Mentorship within the team seems to have a positive effect of well-being:

"…there are very good leaders, because when I came here, they took me under their wing and they actually made something of me." – P7

Success on the world stage doesn't safeguard athletes from mental health challenges:

"I have these heavy anxiety feelings about …what if I got injured? The anxiety and fear literally want to lock you up and make you sit down in a dark corner. Just leave me please, don't let me play, I don't want to play. And there has been a lot of times in my career when I've been like uh, you know, pick somebody else. Like I don't want to be picked, you know? Because what if you mess up? …it gets hectic sometimes. It goes far deeper. Sometimes you even sit there and you're like 'Well, what if I wasn't even here? Then I wouldn't have to play rugby. Do you know what I mean when I say I'm not here? Like dead"'. – P12

DISCUSSION

Psychological Demands

The current results broaden our understanding of the demands of elite rugby sevens, the way in which this format of the game differs from fifteens and possible reasons why fifteens players may struggle with the transition to sevens. The tournament structure and schedule, multiple matches, short recovery periods and extensive traveling across multiple time zones is taxing and contribute to the experience and accumulation of both physical and mental fatigue (Waterhouse et al., 2000). Economy class flights caused further physical discomfort. To reduce the adverse effect of traveling, Meir (2012) suggest that players stay hydrated during flights, adapt their sleeping patterns and display a positive attitude. Set training routines and sleeping times could also minimize the negative after-effects (Waterhouse et al., 2000). Despite such efforts, sleep quality and quantity is often low (Fullagar et al., 2015). Training methods should focus on recovery to reduce injuries and fatigue (Higham et al., 2012, 2013; Lopez et al., 2012; Meir, 2012). Due to the short duration of matches, a single error could cost you a match or tournament (Meir, 2012) and players have to use every scoring and attacking opportunity (Barkell et al., 2016).

Toohey et al. (2019) reported an injury incident rate of 45.0 injuries per 1000 player-hours among 55 elite Australian male rugby sevens players over a 2-year period, with a high rate of subsequent injuries. The collisional nature of the sport coupled with fatigue taxes players physically, psychologically and socially. The high risk of injury and re-injury necessitates that players develop mental toughness and resilience to overcome these and other adverse stressors. Adverse experiences (e.g., non-selection, significant sporting failure, injuries, personal life challenges) plays a vital role in the psychological and performance development of elite athletes as it could result in adaptive behavioral responses and increased resilience (Sarkar et al., 2015). Sarkar and Fletcher (2017) continued that adversity-related experiences (including non-sport life experiences) combined with growth-related processes are essential for success at the elite level. The team's growth mind-set bodes well for turning possible adverse situations into learning opportunities. High performance expectations and standards are an innate part of elite sport. The current results point to multiple sources of pressure to perform consistently (e.g., self-imposed, team members, external pressure). Henriksen et al. (in press) noted that high performance demands coupled with high training loads places athletes at increased risk of developing mental health problems, requiring that psychological demands such as the ones identified in the current study be addressed to enhance mental health and well-being. In fact, they propose that mental health should be a core component of a culture of excellence.

Team Culture

The importance of strong team cohesion is well documented (see Carron et al., 2000; Kozub and Button, 2000). A positive team environment fosters strong team cohesion (McLaren et al., 2017), as the players play for each other rather than focusing on their personal accomplishments. The team's strong cohesiveness could also be due to their success, because of the reciprocal cohesion-performance relationship (Asamoah and Grobbelaar, 2017). The group embraced their diversity (e.g., different backgrounds, cultures, personalities), challenging conventional thinking that similarity among group members is necessary for strong cohesion. These differences appeared trivial in comparison to the squad members having the same work ethic (deemed crucial to the team's success) and an extensive list of shared team values. Sport is renowned as a vehicle for social change and empowerment, and plays an important role in the South African context, due to the country's history of racial and class segregation (Merrett, 2006). Embracing each other's differences and uniqueness is a distinctive feature of the team that contribute to their purpose of being role models who inspire the youth and influence the lives of all South Africans. Personal qualities, a facilitative environment and a challenge mind-set are prerequisites to develop psychological resilience for sustained success (Fletcher and Sarkar, 2016). The data showed that all three of these conditions were evident, potentially contributing to the team's successful defense of the 2016/2017 World Series title in 2017/2018.

The team culture is characterized by healthy player-coach relationships and creating an environment in which players can enjoy what they are doing, to the extent that smiles on the player's faces are indicative of an effective system. On the individual level, faith and religious beliefs also affected the team culture, whilst being cognizant of individual differences. Prayer has been noted to aid team cohesion (Murray et al., 2005), as it enhances a sense of unity among teammates (Turman, 2003). Many athletes use prayer and Bible reading as specific coping strategies (Park, 2000; Egli et al., 2014; Osborne Finekaso and Treharne, 2019).

Psychological Skills and Mental Strategies

The study did not yield any groundbreaking information, but pointed to an extensive use of a wide variety of psychological skills and mental strategies by these players in response to the perceived psychological and performance demands. Whereas the available resources allow for the service of a sport psychologist for the national team, the need exist to develop and implement a comprehensive sport psychological skills development program for players from grassroots level. Players should be exposed to skills such as self-talk, imagery and attentional focus to develop mental toughness from a young age (Di Corrado et al., 2014). A combination of psychological skills seems effective in lowering or managing competition anxiety (Neil et al., 2006; Sharp et al., 2013). Cognitive-general imagery (visualizing scenarios and rehearsing strategies) helps to prepare for upcoming matches as the next opponent is usually finalized around 2 h before kick-off. Disengaging from relational and personal issues whilst training and competing had a marked effect on attention. Likewise, they switch their attention away from the sport during off-periods, as failure to do so could increase chronic stress; a key contributor to burnout (Raedeke, 1997).

Individual coping mechanisms was utilized in response to personal and relational problems (emotional-focused coping), disappointments, setbacks, injuries, non-selection, handling negative feedback (problem and/or emotion-focused coping). Osborne Finekaso and Treharne (2019) observed a preference among Fijian sevens rugby players to deploy emotion-focused coping strategies to reduce stress.

Well-Being and Individual Needs

The players received limited financial and career guidance. Earlier contacting would also enable them to plan better (Stambulova et al., 2009). Whilst it is not clear who should pay for further education, there is consensus that players should be encouraged to study further. Failure to plan ahead and not having post-career financial and lifestyle provisions in order may exacerbate the transitional distress many players experience after terminating their playing careers (Henriksen et al., in press). A lack of work experience is often a major concern as retirement becomes eminent (Wylleman and Reints, 2010), and players should be granted opportunities to experience other workplace environments and to establish networks.

The effort needed to achieve success at the elite level restricts opportunities for identity development beyond the athletic role (Creswell and Eklund, 2005), and many athletes struggle to balance their personal lives and careers (Stambulova et al., 2009).

The development of a positive sporting identity is an important resource for a player at the peak of their playing career, but may become a barrier once they retire from elite sport (Hickey and Kelly, 2008). Personal development should be prioritized (Martindale and Mortimer, 2011) to foster personal and sport identity from the time a player starts to specialize in a specific sport (Wylleman et al., 2004). Support networks and family relationships should be nurtured as it influences athlete well-being (Sharp et al., 2013).

The player who discussed his ongoing challenge with depression and suicide ideation (and gave consent to write about it) should be commended as Henriksen et al. (in press), noted that such actions may promote others to open up about their mental health challenges, thereby normalizing these experiences and potentially reducing the stigmas attached to mental ill health. Identifying an elite player who experience common mental health disorder symptoms is not surprising, as elite athletes and non-athletes have similar prevalence rates. In fact, injuries, overtraining and career termination could increase the risk of athletes developing mental health disorders (Moesch et al., 2018). Mental health disorder symptoms are more prevalent among athletes who lack social support, suffered severe injuries or experienced difficult life events (Schinke et al., 2017). Gouttebarge et al. (2018) observed a high 12-month prevalence of common mental health disorder symptoms among 595 male professional rugby players: distress (11%), eating disorders (11%), sleep disturbance (12%), adverse alcohol use (22%), and anxiety/depression (28%). Ninety-five percent of the participants noted a detrimental effect on performance, whilst 46% noted that current rugby structures were inadequate to address mental health. Rugby governing bodies should increase awareness about common mental health disorders among current and retired players, and put preventive and support measures in place (Gouttebarge et al., 2016).

Leburn and Collins (2017) alluded to the possible ineffectiveness of current clinical screening methods, due to the additional performance stressors elite athletes' experience. The consensus statement on improving mental health of high performance athletes (Henriksen et al., in press), warns against pathologizing normal human experiences. They expressed the need to distinguish between clinical mental health disorders, subclinical mental ill health, the human condition (i.e., periodic and completely normal experiences of adversity, unpleasant thoughts and emotions in response to general life) and the athlete condition (e.g., performance anxiety in response to competition).

CONCLUSION AND RECOMMENDATIONS

The thick descriptive information pertaining to the perceived psychological demands of the game, the prevailing team culture, the implementation of psychological skills and mental strategies, as well as the well-being needs of elite players identified through this study could assist rugby governing bodies to support and attend to their player's needs more effectively. These findings should be integrated with evidence-based best practice regarding sport psychological skills and well-being development within a holistic framework aimed at improving performance as well as fostering well-being during and after retirement from elite sport. The effectiveness of such a program should be tested empirically.

AUTHOR CONTRIBUTIONS

NK explored the perceived demands of rugby sevens held by professional players and coaching staff, conducted, transcribed and coded all the semi-structured interviews, and wrote up the results and discussion as part of the original M.Sc. thesis. HG initially conceptualized the research problem, study design and methodology, contributed to the qualitative analysis, wrote the article from the thesis, and submitted the article.

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REFERENCES

Asamoah, B., and Grobbelaar, H. W. (2017). Team cohesion and performance during a university soccer championship: two sides of the coin. *SA J. Res. Sport Phys. Educ. Recr.* 39, 1–15.

Barkell, J. F., O'Connor, D., and Cotton, W. G. (2016). Characteristics of winning men's and women's sevens rugby teams throughout the knockout cup stages of international tournaments. *Int. J. Perf. Anal. Sport* 16, 633–651. doi: 10.1080/24748668.2016.11868914

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101. doi: 10.1191/1478088706qp063oa

Carreras, D., Kraak, W., Planas, A., Martin, I., and Vaz, L. (2013). Analysis of International rugby sevens matches during tournaments. *Int. J. Perf. Anal. Sport* 13, 833–847. doi: 10.1080/24748668.2013.11868692

Carron, A. V., Colman, M. M., Wheeler, J., and Stevens, D. (2000). Cohesion and performance in sport: a meta-analysis. *J. Sport Exerc. Psychol.* 24, 168–188. doi: 10.1123/jsep.24.2.168

Creswell, S. L., and Eklund, R. C. (2005). Changes in athlete burnout and motivation over a 12-week league tournament. *Med. Sci. Sport Exerc.* 37, 1957–1966. doi: 10.1249/01.mss.0000176304.14675.32

Di Corrado, D., Murgia, M., and Freda, A. (2014). Attentional focus and mental skills in senior and junior professional rugby union players. *Sport Sci. Health* 10, 79–83. doi: 10.1007/s11332-014-0177-x

Egli, T., Czech, D. R., Todd, S. Y., Shaver, G. W., Gentner, N., and Biber, D. D. (2014). The experience of Christian prayer in coaching: a qualitative investigation. *J. Psychol. Christ.* 33, 45–57.

Fletcher, D., and Sarkar, M. (2016). Mental fortitude training: an evidence-based approach to developing psychological resilience for sustained success. *J. Sport Psychol. Action* 7, 135–157. doi: 10.1080/21520704.2016.1255496

Fullagar, H. H. K., Duffield, R., Skorski, S., Coutts, A. J., Julian, R., and Meyer, T. (2015). Sleep and recovery in team sport: current sleep-related issues facing professional team-sport athletes. *Int. J. Sport Physiol.* 10, 950–957. doi: 10.1123/ijspp.2014-0565

Gouttebarge, V., Hopley, P., Kerkhoffs, G., Verhagen, E., Viljoen, W., Wylleman, P., et al. (2018). A 12-month prospective cohort study of symptoms of common mental disorders among professional rugby players. *Eur. J. Sport Sci.* 25, 1–9. doi: 10.1080/17461391.2018.1466914

Gouttebarge, V., Kerkhoffs, G., and Lambert, M. (2016). Prevalence and determinants of symptoms of common mental disorders in retired professional rugby union players. *Eur. J. Sport Sci.* 16, 595–602. doi: 10.1080/17461391.2015.1086819

Hendricks, S. (2012). Trainability of junior rugby union players. *S. Afr J. Sports Med.* 24, 122–126. doi: 10.17159/2078-516X/2012/v24i4a525

Hiatt, J. F. (1986). Spirituality, medicine, and healing. *S. Med. J.* 79, 736–743. doi: 10.1097/00007611-198606000-00022

Hickey, C., and Kelly, P. (2008). Preparing to not be a footballer: higher education and professional sport. *Sport Educ. Soc.* 13, 477–494. doi: 10.1080/13573320802445132

Higham, D. G., Pyne, D. B., Anson, J. M., and Eddy, A. (2012). Movement patterns in rugby sevens: effects of tournament level, fatigue and substitute players. *J. Sci. Med. Sport* 15, 277–282. doi: 10.1016/j.jsams.2011.11.256

Higham, D. G., Pyne, D. B., Anson, J. M., and Eddy, A. (2013). Physiological, anthropometric and performance characteristics of rugby sevens players. *Int. J. Sport Physiol.* 8, 19–27. doi: 10.1123/ijspp.8.1.19

Kozub, S. A., and Button, C. J. (2000). The influence of a competitive outcome on perceptions of cohesion in rugby and swimming teams. *Int. J. Sport Psychol.* 31, 82–95.

Leburn, F., and Collins, D. (2017). Is elite sport (really) bad for you? Can we answer the question? *Front. Psychol.* 8:324. doi: 10.3389/fpsyg.2017.00324

Lopez, V., Galano, G. J., Black, C. M., Gupta, A. T., James, D. E., Kelleher, K. M., et al. (2012). Profile of an American amateur rugby union sevens series. *Am. J. Sport Med.* 40, 179–184. doi: 10.1177/0363546511427124

MacNamara, A., Button, A., and Collins, D. (2010a). The role of psychological characteristics in facilitating the pathway to elite performance. Part 1: identifying mental skills and behaviours. *Sport Psychol.* 24, 52–73. doi: 10.1123/tsp.24.1.52

MacNamara, A., Button, A., and Collins, D. (2010b). The role of psychological characteristics in facilitating the pathway to elite performance. Part 2: examining environmental and stage-related differences in skills and behaviors. *Sport Psychol.* 24, 74–96. doi: 10.1123/tsp.24.1.74

Martindale, R., and Mortimer, P. (2011). "Talent development environments: key considerations foe effective practice," in *Performance Psychology: A Practitioner's Guide*, eds D. Collins, A. Button, and H. Richards (London: Elsevier), 65–84.

McLaren, C. D., Newland, A., Eys, M., and Newton, M. (2017). Peer-initiated motivational climate and group cohesion in youth sport. *J. Appl. Psychol.* 29, 88–100. doi: 10.1080/10413200.2016.1190423

Meir, R. A. (2012). Training for and competing in sevens rugby: practical considerations from experience in the international rugby board world series. *Strength Cond. J.* 34, 76–86. doi: 10.1519/SSC.0b013e31825105ed

Merrett, C. (2006). Sport, segregation and space: the historical geography of physical recreation in the South Africa. *Hist. Compass.* 5, 1–10. doi: 10.1111/j.1478-0542.2006.00368.x

Moesch, K., Kenttä, G., Kleinert, J., Quignon-Fleuret, C., Cecil, S., and Bertollo, M. (2018). FEPSAC position statement: mental health disorders in elite athletes and models of service provision. *Psychol. Sport Exerc.* 38, 61–71. doi: 10.1016/j.psychsport.2018.05.013

Murray, M. A., Joyner, A. B., Burke, K. L., Wilson, M. J., and Zwald, A. D. (2005). The relationship between prayer and team cohesion in collegiate softball teams. *J. Psychol. Christ.* 24, 233–239.

Neil, R., Mellalieu, D. S., and Hanton, S. (2006). Psychological skills usage and the competitive anxiety response as a function of a skill level in rugby union. *J. Sport Sci. Med.* 5, 415–423.

Osborne Finekaso, G., and Treharne, G. J. (2019). Stress and coping in Fijian rakavi (rugby) sevens players. *Sport Soc.* (in press). doi: 10.1080/17430437.2018.1487954

Park, J. (2000). Coping strategies used by Korean national athletes. *Sport Psychol.* 14, 63–80. doi: 10.1123/tsp.14.1.63

Raedeke, T. (1997). Is athlete burnout more than just stress? A sport commitment perspective. *J. Sport Exerc. Psychol.* 19, 396–417. doi: 10.1123/jsep.19.4.396

Sarkar, M., and Fletcher, D. (2017). Adversity-related experiences are essential for Olympic success: additional evidence and considerations. *Prog. Brain Res.* 232, 159–165. doi: 10.1016/bs.pbr.2016.11.009

Sarkar, M., Fletcher, D., and Brown, D. J. (2015). What doesn't kill me: adversity-related experiences are vital in the development of superior Olympic performance. *J. Sci. Med. Sport* 18, 475–479. doi: 10.1016/j.jsams.2014.06.010

Schinke, R. J., Stambulova, N. B., Si, G., and Moore, Z. (2017). International society of sport psychology position stand: athletes' mental health, performance, and development. *Int. J. Sport Exerc. Psychol.* 2, 1–18.

Sharp, L. A., Woodcock, C., Holland, M. J. G., Coming, J., and Duda, J. L. (2013). A qualitative evaluation of the effectiveness of a mental skills training program for youth athletes. *Sport Psychol.* 27, 219–232. doi: 10.1123/tsp.27.3.219

Stambulova, N., Alfermann, D., Statler, T., and Côté, J. (2009). ISSP position stand: career development and transitions of athletes. *Int. J. Sport Exerc. Psychol.* 7, 395–412. doi: 10.1080/1612197X.2009.9671916

Suarez-Arrones, L. J., Nuñez, F. J., Portillo, J., and Mendez-Villanueva, A. (2012). Running demands and heart rate responses in men rugby sevens. *J. Strength Cond. Res.* 26, 3155–3159. doi: 10.1519/JSC.0b013e318243fff7

Taylor, J. (1995). A conceptual model for integrating athletes' needs and sport demands in the development of competitive mental preparation strategies. *Sport Psychol.* 9, 339–357. doi: 10.1123/tsp.9.3.339

Toohey, L. A., Drew, M. K., Finch, C. F., Cook, J. L., and Fortington, L. V. (2019). A 2-year prospective study of injury epidemiology in elite Australian rugby sevens: exploration of incidence rates, severity, injury type, and subsequent injury in Men and Women. *Am. J. Sports Med.* doi: 10.1177/0363546518825380 [Epub ahead of print].

Tucker, R. (2016). Rugby sevens: Olympic debutante and research catalyst. *Br. J. Sport Med.* 50, 638–639. doi: 10.1136/bjsports-2016-096306

Turman, P. D. (2003). Coaches and cohesion: the impact of coaching techniques on team cohesion in the small group sport setting. *J. Sport Behav.* 26, 86–104.

Van Rooyen, M. (2015). Early success is key to winning an IRB sevens world series. *Int. J. Sports Sci. Coach.* 10, 1129–1138. doi: 10.1260/1747-9541.10.6.1129

Waterhouse, J., Reilly, T., and Atkinson, G. (2000). Chronobiological consequences of long haul flights, travel fatigue, and jet lag. *Int. Sportmed J.* 1, 1–9.

World Rugby (2016). *HSBC Sevens World Series Website*. Available at: https://www.world.rugby/sevens-series (accessed April 6, 2016).

Wylleman, P., Alfermann, D., and Lavallee, D. (2004). Career transitions in sport: European perspectives. *Psychol. Sport Exerc.* 5, 7–20. doi: 10.1016/S1469-0292(02)00049-3

Wylleman, P., and Reints, A. (2010). A lifespan perspective on the career of talented and elite athletes: perspectives on high-intensity sports. *Scand. J. Med. Sci. Sport* 20, 88–94. doi: 10.1111/j.1600-0838.2010.01194.x

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Statistical Differences in Set Analysis in Badminton at the RIO 2016 Olympic Games

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The aim of the present study was to determine statistical differences in a set of badminton competition matches in five different modalities with regard to competition level (Group Phase vs. Eliminatory Phase). Data from 453 sets (125 in men's singles; 108 sets in women's singles; 77 sets in men's doubles; 73 in women's doubles and 70 in mixed doubles) from the RIO 2016 Olympics Games were recorded and classified in two groups of variables to analyze variables related to match (5) and set (15). A descriptive analysis and univariate test (Mann–Whitney U) for non-parametric data were conducted. The results show in men's and women's singles all the variables related to match were higher in the Elimination Phase than in the Group Phase ($p < 0.01$). In Sets 1 and 3, the longest set duration, rally and average rally were found in the Elimination Phase than Group Stage ($p < 0.05$). In women's singles, these differences were also recorded in Set 2. For doubles, the results are more stable among groups. Men's doubles had a longer duration of the match and set (sets 1 and set 2) ($p < 0.01$), and also scored highest for average rally strokes (sets 1 3) ($p < 0.05$) and shuttles used in the Elimination Phase vs. the Group Phase along the match ($p < 0.01$). In women's doubles, more shuttles were used in a match in the Elimination than in the Group Phase. Moreover, the same results are established for Set 2, including for average rally. Mixed doubles saw no match going to three sets. However, the greatest differences showed a longer rally and average rally being registered in the Elimination than in the Group Phase. In conclusion, the timing factors of the badminton singles and doubles games were different in the Elimination and Group Phases. This information may help players and coaches prepare and administer different types of workouts or, more specifically, competition schedules adapted to the characteristics of modern badminton.

Keywords: notational analysis, match analysis, racket sports, performance indicators, performance analysis, badminton

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INTRODUCTION

Badminton has been an Olympic sport since the Barcelona Olympics Games of 1992. It includes five different modalities: men's singles, women's singles, men's doubles, women's doubles and mixed doubles (Gawin et al., 2015). In addition, in 2006 the rules were changed from playing 3 sets of 15 points to 3 sets of 21 points, with obvious differences being later revealed

(Chen and Chen, 2011) and triggering a rise in scientific research in this sport due to the modified technical/tactical, physical and physiological conditions (Phomsoupha and Laffaye, 2015). The main effect in the change of regulation has been a shortening of the times of game as far as the temporary structure (Phomsoupha and Laffaye, 2015). Accordingly, player characteristics in terms of somatotype are currently defined (Abián et al., 2012; Hussain, 2013) to include their physiological characteristics (Alcock and Cable, 2009; Jeyaraman et al., 2012), visual fitness (Williams et al., 2011; Di et al., 2012) or biomechanical aspects (Hussain et al., 2011; Li et al., 2017).

One area capturing most attention from researchers is notational analysis, fundamental in high-level competition such as world-class competition (Gawin et al., 2015) or badminton championships (Abdullahi and Coetzee, 2017). However, most investigations have involved the Olympics Games (Laffaye et al., 2015; Abián-Vicén et al., 2018; Chiminazzo et al., 2018). They have focused on aspects related to the temporal structure, where efforts have considered individual badminton aspects, inter alia establishing: a match duration of 48–65 min (Abian-Vicen et al., 2013; Phomsoupha and Laffaye, 2015; Chiminazzo et al., 2018), point duration of around 9 s (Abian-Vicen et al., 2013; Abián et al., 2014) or number of strokes per point at around 8–10 (Abian-Vicen et al., 2013; Abián et al., 2014). Recently, even differences have been established for game duration and types of stroke between the group phase and eliminatory phase in men's singles (Chiminazzo et al., 2018).

Yet studies on a modality like doubles are scarcer, noting one recent study that observed an development of time variables over the last three Olympic Games entailing a gradual rise in match duration or playing time, both in men's doubles (Abián-Vicén et al., 2018). However, there is much less literature concerning women's doubles and mixed doubles than for the other modalities.

Finally, we note that while the structure of a match has been analyzed (Abián-Vicén et al., 2018; Chiminazzo et al., 2018), only very rarely has the structure of a set (Abian-Vicen et al., 2013; Abián et al., 2014). In the Olympic Games they are classified by World Ranking in five events. The structure of the Olympic Games consists of a group phase, so that later the best of group goes to the elimination phase [Badminton World Federation (BWF), 2017]. To our knowledge, no research has previously considered with respect to the Olympic Games the structure of individual sets or the game phase at such a high level.

The aim of this study was therefore to analyze statistical differences in a set of competition badminton matches in five different modalities with regard to competition level (Group Phase vs. Eliminatory Phase) at the RIO 2016 Olympic Games.

MATERIALS AND METHODS

Sample

Data from 453 sets (125 sets in men's singles; 108 sets in women's singles; 77 sets in men's doubles; 73 in women's doubles and 70 in mixed doubles) from the RIO 2016 were analyzed. The unit of analysis was the set to prevent differences in comparing Group Phase (GP) (n = 344 sets) and Eliminatory Phase (EP) (n = 109) matches (**Table 1**).

TABLE 1 | Number of sets analyzed by phase and sex.

	Group phase	Eliminatory phase	Total
Men's singles	94	31	125
Women's singles	90	18	108
Men's doubles	54	23	77
Women's doubles	52	21	73
Mixed doubles	54	16	70
Total	344	109	453

All matches were played under the current badminton rules, where the person winning the best of 3 games of 21 points is the winner [Badminton World Federation (BWF), 2017]. The sample represents 100% of all matches played. The competition characteristics show the players were the best in the world at the time.

Procedure

Data were collected from the Olympic Games' official website[1] (accessed 10 September 2016) using the same methodology as previous studies (Ortega et al., 2009; Sánchez-Pay et al., 2015; Torres-Luque et al., 2017). The variables analyzed are shown in **Table 2**.

A specifically designed spreadsheet (Microsoft Excel) was used to collect all the statistics regarding the winning and losing players in the different modalities, which were then exported to the software IBM SPSS version 24.0 (IBM Corp. Armonk, New York, NY, United States). Intra reliability was calculated through observer registering the same values of play (one set) on two occasions separated by a 4 weeks period. Cohen's Kappa was used and 0.93 was obtained for observer. The value was considered as very good (>0.80) (Landis and Koch, 1977).

Statistical Analysis

The statistical program for analysis IBM SPSS version 24.0 (IBM Corp. Armonk, New York, NY, United States) was used. First, a descriptive analysis of the data (means and

[1] https://www.olympic.org/badminton

TABLE 2 | Variables studied in doubles badminton competition.

Group of variables	Game statistics
Variables related to match	Duration of match, longest rally (s), longest rally (strokes), average rally (s), average rally (strokes), shuttles used
Variables related to set	Match points, set points, duration of set, total points played, total points won, most consecutive points, longest rally (s), longest rally (strokes), average rally (s), average rally (strokes), shuttles used, points scored without service, points scored with service, biggest lead, biggest comeback to win the game

TABLE 3 | Descriptive statistics and different between level of competition (Group Stage vs. Elimination Phase) for men singles sets.

	Men singles						
	Group stage	**Eliminatory phase**	***P*-value**	***Z*-value**	***d***	**CV (Group stage)**	**CV (Elimnation phase)**
Variables related to match							
Duration of match	43.81 ± 12.10	58.76 ± 18.75	$p < 0.001$	−3.964	1.067	3.62	3.13
Longest rally (s)	43.11 ± 18.04	45.30 ± 10.24	0.10	−1.642	0.133	2.39	4.42
Longest rally (strokes)	39.20 ± 13.02	42.76 ± 9.04	0.02	−2.209	0.293	3.01	4.73
Average rally (s)	9.53 ± 2.58	10.23 ± 1.88	0.61	−0.505	0.288	3.69	5.44
Average rally (strokes)	7.95 ± 1.45	8.92 ± 1.57	0.01	−2.56	0.655	5.48	5.68
Shuttles used	15.18 ± 7.02	22.92 ± 11.38	0.00	−3.221	0.933	2.16	2.01
Set 1							
Match points	–	–	–	–		–	–
Set points	1.60 ± 1.00	1.92 ± 1.38	0.37	−0.897	0.29	1.6	1.39
Duration of set	18.13 ± 4.09	21.61 ± 5.37	$p < 0.001$	−2.823	0.784	4.43	4.02
Total points played	33.60 ± 4.50	34.92 ± 4.44	0.26	−1.111	0.294	7.47	7.86
Total point won	16.82 ± 5.27	17.46 ± 4.78	0.57	−0.558	0.124	3.19	3.65
Most consecutive points	3.79 ± 2.18	3.76 ± 2.42	0.73	−0.335	−0.013	1.74	1.55
Longest rally (s)	35.27 ± 13.02	42.30 ± 11.44	$p < 0.001$	−2.732	0.556	2.71	3.7
Longest rally (strokes)	33.11 ± 9.32	37.69 ± 10.44	0.04	−2.002	0.477	3.55	3.61
Average rally (s)	9.72 ± 2.65	10.30 ± 2.34	0.84	−0.196	0.225	3.67	4.4
Average rally (strokes)	8.18 ± 1.53	8.84 ± 2.11	0.16	−1.392	0.391	5.35	4.19
Shuttles used	6.97 ± 3.00	9.30 ± 3.76	$p < 0.001$	−2.95	0.728	2.32	2.47
Points scored without service	8.07 ± 2.44	8.46 ± 3.00	0.77	−0.287	0.151	3.31	2.82
Points scored with service	8.91 ± 4.63	9.00 ± 4.34	0.96	−0.048	0.02	1.92	2.07
Biggest lead	6.46 ± 4.75	5.65 ± 4.31	0.56	−0.581	−0.174	1.36	1.31
Biggest come back to win the game	2.56 ± 1.93	2.40 ± 1.64	0.90	−0.114	−0.086	1.33	1.46
Set 2							
Match points	1.80 ± 1.25	1.87 ± 0.64	0.25	−1.142	0.062	1.44	2.92
Set points	1.87 ± 0.83	1.60 ± 0.89	0.52	−0.629	−0.32	2.25	1.8
Duration of set	20.06 ± 4.27	23.84 ± 6.41	0.01	−2.441	0.775	4.7	3.72
Total points played	34.48 ± 4.69	35.53 ± 2.92	0.15	−1.411	0.243	7.35	12.17
Total point won	17.24 ± 5.01	17.76 ± 3.89	0.93	−0.088	0.109	3.44	4.57
Most consecutive points	3.96 ± 2.08	3.07 ± 1.49	0.07	−1.799	−0.456	1.9	2.06
Longest rally (s)	37.11 ± 19.10	37.30 ± 8.18	0.30	−1.021	0.011	1.94	4.56
Longest rally (strokes)	34.04 ± 14.45	36.53 ± 8.24	0.09	−1.683	0.189	2.36	4.43
Average rally (s)	9.90 ± 3.01	10.23 ± 1.60	0.86	−0.168	0.121	3.29	6.39
Average rally (strokes)	8.23 ± 1.76	9.00 ± 1.74	0.24	−1.171	0.439	4.68	5.17
Shuttles used	6.88 ± 3.20	8.53 ± 4.24	0.06	−1.846	0.474	2.15	2.01
Points scored without service	7.96 ± 2.13	9.57 ± 2.24	$p < 0.001$	−3.179	0.746	3.74	4.27
Points scored with service	9.45 ± 4.54	8.19 ± 3.76	0.14	−1.444	−0.289	2.08	2.18
Biggest lead	6.80 ± 4.18	5.70 ± 3.72	0.30	−1.022	−0.27	1.63	1.53
Biggest come back to win the game	3.13 ± 1.65	2.14 ± 0.89	0.15	−1.413	−0.66	1.9	2.4
Set 3							
Match points	1.77 ± 0.83	2.20 ± 1.09	0.47	−0.712	0.478	2.13	2.02
Set points	–	–	–	–		–	–
Duration of set	19.75 ± 4.61	29.40 ± 3.80	$p < 0.001$	−3.93	2.18	4.28	7.74
Total points played	31.87 ± 3.36	37.60 ± 4.43	0.30	−1.027	1.57	9.49	849
Total point won	15.93 ± 5.74	18.80 ± 3.39	0.30	−1.027	0.545	2.78	5.55
Most consecutive points	3.80 ± 2.78	3.20 ± 1.03	0.93	−0.085	−0.243	1.37	3.11
Longest rally (s)	33.00 ± 6.83	48.00 ± 7.74	$p < 0.001$	−3.607	2.124	4.83	6.20
Longest rally (strokes)	30.12 ± 8.18	47.00 ± 4.26	$p < 0.001$	−3.803	2.276	3.68	11.03
Average rally (s)	8.75 ± 1.77	12.20 ± 1.81	$p < 0.001$	−3.734	1.938	4.94	6.74

(Continued)

TABLE 3 | Continued

	Men singles						
	Group stage	**Eliminatory phase**	***P*-value**	***Z*-value**	***d***	**CV (Group stage)**	**CV (Elimnation phase)**
Average rally (strokes)	7.62 ± 1.54	10.80 ± 1.39	$p < 0.001$	−3.84	2.113	4.95	7.77
Shuttles used	7.12 ± 4.27	13.20 ± 6.94	0.01	−2.546	1.203	1.67	1.90
Points scored without service	7.87 ± 2.52	10.30 ± 2.35	0.03	−2.075	0.98	3.12	4.38
Points scored with service	8.60 ± 5.12	8.50 ± 2.92	0.88	−0.139	−0.021	1.68	2.91
Biggest lead	6.78 ± 4.91	4.11 ± 2.47	0.32	−0.985	−0.601	1.38	1.66
Biggest come back to win the game	2.00 ± 1.29	2.75 ± 0.95	0.28	−1.079	0.617	1.55	2.90

standard deviation) was performed. Second, a univariate (Mann–Whitney U) test (non-parametric) was conducted with the aim to analyze differences between competition level (Group Phase vs. Eliminatory Phase) in each modality because the assumptions of normality and homogeneity of variances were not satisfied. Unfinished matches were not included in the database. Significance was set at $p < 0.05$.

RESULTS

Tables 3, **4** shows differences between the Group Phase and Eliminatory Phase for both men's and women's doubles.

The results show that for men's and women's singles all the variables related to match were longer in the Eliminatory than in the Group Phase ($p < 0.05$). In Sets 1 and 3, the longest set duration ($p < 0.05$), rally ($p < 0.01$) and average rally ($p < 0.05$) were recorded in the Eliminatory Phase. In women's singles, these differences were also found in Set 2 ($p < 0.05$).

Tables 5, **6** presents differences between moments analyzed in the three doubles modalities.

In the doubles modality, the results are more stable among groups. Men's doubles had a longer duration of both match and Set (1, 2), as well as a longer average rally (Set 1, 3) and a higher number of shuttles used in the Eliminatory Phase vs. the Group Phase. Results for women's doubles also show the number of shuttles used was higher in the matches in the Elimination than in the Group Phase. Moreover, the same results are established in Set 2, including for the average rally. Mixed doubles saw no match go to three sets. However, the greatest differences were found in the variables longest rally and average rally, which were higher in the Eliminatory Phase than in the Group Phase.

DISCUSSION

The main findings of this study show the big differences in the individual badminton between group stage vs. elimination phase, highlighting the differences in the third set. Doubles modality shows more stable results, standing out the non-existence of the third set in the mixed doubles.

In relation to the modality of singles, the match duration is longer in the EP vs. GP for both men (43–58 min) and women (40–50 min). Several authors have established a badminton match duration of between 40 and 50 min in men (Abian-Vicen et al., 2013; Gawin et al., 2015) and 17 and 28 min in women (Cabello-Manrique and González-Badillo, 2003; Cabello et al., 2004). This denotes a key important difference among players since one must be better prepared to face the eliminatory phase. In fact, Laffaye et al. (2015) found a duration of 78 min in men's singles at the final of the London 2012 Olympics Games. Despite the importance of these results for player preparation, the data found in the set structure are more revealing. Results for men's singles show differences between the GP and EP in Sets 1 and 3, with a duration from 18 to 29 min. Different authors have established the duration of a set at around 18 min (Abian-Vicen et al., 2013; Abián et al., 2014), hence making it important to see what happens between tournament phases, since the data reach almost 30 min in the EP. The same trend occurs in women's singles, albeit as mentioned there are fewer values in the literature; in fact, data found for the Olympic Games are 12–13 min (Abian-Vicen et al., 2013), where higher values were recorded in Set 2. To our knowledge, this is the first study to show that Set 3 consumes the most time; with the figure for the EP even reaching 29 min, a fundamental consideration when planning training.

In addition to these data, some very interesting questions arise regarding the structure of shots. In men's singles, in GP vs. EP, rallies have an approximate duration of 9–10 s, with 7.5–9 strokes per point, which occurs as a match average and even in Set 1 and Set 2. These findings are similar to those reported by other authors who indicated that high-level badminton entails similar data (Abian-Vicen et al., 2013; Abián et al., 2014). However, the differences between the GP and EP are decisive in Set 3 where the values reach 12 s in the EP, and 10.8 strokes per point. Thus, it is observed that the duration of a set gradually rises between the GP and EP and that the points tend to be longer with more strokes per point. In fact, in all cases, the stroke by time ratio has a tendency of 1 stroke every 1 second or every 1.12 s, which is one of the longest times so far various authors have determined a stroke frequency of between 0.56 and 1.08 (Alcock and Cable, 2009; Abian-Vicen et al., 2013; Gawin et al., 2015). It is interesting to note how more shuttlecocks are used in the EP, around 23 shuttles. But Set 3 in the EP

TABLE 4 | Descriptive statistics and different between level of competition (Group Stage vs. Elimination Phase) for women singles sets.

	Women singles women						
	Group stage	**Eliminatory phase**	***P*-value**	***Z*-Value**	***d***	**CV (Group Stage)**	**CV (Elimnation Phase)**
Variables related to match							
Duration of match	40.11 ± 11.88	50.66 ± 13.75	$p < 0.001$	−3.759	0.865	3.38	3.68
Longest rally (s)	36.52 ± 15.05	38.50 ± 7.37	0.07	−1.776	0.14	2.43	5.22
Longest rally (strokes)	28.64 ± 8.35	34.16 ± 9.22	0.01	−2.532	0.65	3.43	3.7
Average rally (s)	9.35 ± 2.61	10.50 ± 1.74	0.02	−2.24	0.462	3.58	6.03
Average rally (strokes)	6.64 ± 1.40	7.58 ± 1.28	p < 0.001	−2.867	0.68	4.74	5.92
Shuttles used	9.59 ± 3.16	14.83 ± 6.22	p < 0.001	−3.978	1.372	3.03	2.38
Set 1							
Match points	–	–	–	–		–	–
Set points	1.59 ± 0.89	1.25 ± 0.62	0.15	−1.437	−0.399	1.79	2.02
Duration of set	17.76 ± 3.92	21.58 ± 4.32	p < 0.001	−3.41	0.958	4.53	5
Total points played	34.47 ± 4.07	35.58 ± 4.20	0.19	−1.306	0.271	8.47	8.47
Total point won	17.23 ± 4.76	17.79 ± 4.43	0.67	−0.414	0.119	3.62	4.02
Most consecutive points	3.54 ± 2.00	3.41 ± 1.93	0.96	−0.049	−0.065	1.77	1.77
Longest rally (s)	31.97 ± 14.43	33.83 ± 6.78	0.06	−1.865	0.138	2.22	4.99
Longest rally (strokes)	25.52 ± 7.26	31.00 ± 9.99	0.02	−2.294	0.706	3.52	3.1
Average rally (s)	9.64 ± 2.90	10.58 ± 1.93	0.16	−1.392	0.34	3.32	5.48
Average rally (strokes)	6.97 ± 1.51	7.83 ± 1.43	p < 0.001	−2.677	0.574	4.62	5.48
Shuttles used	4.66 ± 1.89	6.91 ± 2.48	p < 0.001	−3.868	1.127	2.47	2.79
Points scored without service	8.54 ± 2.09	9.04 ± 2.34	0.49	−0.688	0.235	4.09	3.86
Points scored with service	8.69 ± 4.31	8.75 ± 3.91	0.92	−0.093	0.014	2.02	2.24
Biggest lead	6.17 ± 4.40	5.35 ± 4.09	0.46	−0.73	−0.188	1.4	1.31
Biggest come back to win the game	2.25 ± 1.77	2.28 ± 1.97	0.80	−0.253	0.017	1.27	1.16
Set 2							
Match points	1.50 ± 0.73	1.90 ± 1.10	0.31	−1.014	0.499	2.05	1.73
Set points	1.33 ± 0.51	2.50 ± 2.12	0.44	−0.77	1.207	2.61	1.18
Duration of set	17.50 ± 4.33	22.83 ± 3.84	0.00	−5.186	1.253	4.04	5.95
Total points played	33.42 ± 4.12	35.41 ± 3.37	0.02	−2.285	0.496	8.11	10.51
Total point won	16.71 ± 5.20	17.70 ± 4.12	0.57	−0.559	0.196	3.21	4.3
Most consecutive points	3.57 ± 1.98	4.00 ± 2.43	0.54	−0.608	0.209	1.8	1.65
Longest rally (s)	30.57 ± 12.37	34.16 ± 6.98	0.03	−2.145	0.308	2.47	4.89
Longest rally (strokes)	25.26 ± 8.71	28.33 ± 6.57	0.01	−2.34	0.365	2.9	4.31
Average rally (s)	9.52 ± 2.57	10.66 ± 2.01	0.04	−2.028	0.458	3.7	5.30
Average rally (strokes)	6.78 ± 1.52	7.75 ± 1.56	0.01	−2.391	0.635	4.46	4.97
Shuttles used	4.45 ± 1.64	7.33 ± 3.57	p < 0.001	−4.079	1.388	2.71	2.05
Points scored without service	8.19 ± 2.18	8.58 ± 2.20	0.37	−0.895	0.179	3.76	3.9
Points scored with service	8.72 ± 4.80	9.12 ± 3.92	0.78	−0.268	0.086	1.82	2.33
Biggest lead	6.81 ± 4.39	5.75 ± 3.58	0.41	−0.822	−0.248	1.55	1.61
Biggest come back to win the game	2.43 ± 1.34	2.28 ± 1.11	0.91	−0.102	−0.115	1.81	2.05
Set 3							
Match points	1.50 ± 0.54	1.50 ± 0.70	1.00	0	0	2.78	2.14
Set points	–	–	–	–		–	–
Duration of set	20.00 ± 3.86	26.50 ± 5.19	0.05	−1.952	1.584	5.18	5.11
Total points played	36.50 ± 2.31	33.50 ± 2.88	0.08	−1.718	−1.011	15.8	11.63
Total point won	18.25 ± 3.30	16.75 ± 5.31	0.65	−0.454	−0.406	5.53	3.15
Most consecutive points	3.58 ± 1.97	3.00 ± 0.81	0.75	−0.311	−0.316	1.82	3.7
Longest rally (s)	30.16 ± 6.39	41.00 ± 6.92	0.01	−2.44	1.673	4.72	5.92
Longest rally (strokes)	26.16 ± 6.13	36.00 ± 5.77	0.02	−2.222	1.62	4.27	6.24
Average rally (s)	10.66 ± 2.93	13.00 ± 2.30	0.21	−1.235	0.824	3.64	5.65

(Continued)

TABLE 4 | Continued

	Women singles women						
	Group stage	**Eliminatory phase**	***P*-value**	***Z*-Value**	***d***	**CV (Group Stage)**	**CV (Elimnation Phase)**
Average rally (strokes)	7.83 ± 1.94	10.50 ± 1.73	0.02	−2.222	1.399	4.04	6.07
Shuttles used	3.33 ± 0.98	3.50 ± 1.73	1.00	0	0.15	3.4	2.02
Points scored without service	9.08 ± 1.44	8.00 ± 1.15	0.20	−1.26	-0.773	6.31	6.96
Points scored with service	9.16 ± 3.18	8.75 ± 5.12	0.85	−0.183	-0.115	2.88	1.71
Biggest lead	4.41 ± 2.46	8.50 ± 3.53	0.13	−1.49	1.537	1.79	2.41
Biggest come back to win the game	2.66 ± 0.81	–	–	–		3.28	–

stands out, reaching the highest values, with a value of 13 shuttles. Shuttlecock use relates to the force applied in execution of a stroke, mainly a smash, namely a common stroke in badminton (Abian-Vicen et al., 2013; Chiminazzo et al., 2018). This aspect was not evaluated in this study, but we showed that players entering the EP have at that stage already played longer sets, more strokes per point, and require more shuttlecocks. In addition, the longest rally is significantly higher in EP and more evident in Set 3 where it reaches a rally of 48 s with 47 strokes.

It is also interesting to note that the trend described in men's singles is similar to women's singles, except that the differences in average rally, duration, and strokes are greater in the EP, and increasing in all sets analyzed. Thus, the rally time is 9–10.50 s, with these figures exceeding those found in Olympic Games literature (Abian-Vicen et al., 2013; Abián et al., 2014) although similar for women's world-class badminton (Gawin et al., 2015). Strokes per point hover around 6.6–7.5, consistent with earlier findings (Abian-Vicen et al., 2013; Abián et al., 2014). Yet, differences between phases are most evident in Set 3 where in the EP the point duration averages up to 13 s, with up to 10.50 strokes per point. It is even observed in Set 3 where the longest point is seen in the EP of up to 41 s, involving 36 strokes. This implies that in all cases, including the longest points, the ratio of strokes per time is around 1.1–1.2, below findings of other studies in girls showing 0.5–0.9 (Abian-Vicen et al., 2013; Abián et al., 2014; Gawin et al., 2015). These data are very revealing since, as indicated by several authors, the intensity of badminton involves playing around 90% of the time at the maximum HR (Álvarez et al., 2016; Bisschoff et al., 2016) so it is observed that it is not only necessary to reach the competition in good fitness but, as the championship progresses, the execution times and stroke volume tend to be higher, mainly in the EP and at key moments such as Set 3. Therefore, this indicates a very important change in men's and women's singles at the quantitative level between the GP and the EP, where Set 3 is key to sports performance.

As far as the game of doubles is concerned, the findings are useful in specialties attracting less scientific research. In men's doubles, there is an increase in the match duration of 48 min in the GP compared to 68 min in the EP. Researchers have established an average of 40–45 min (Gawin et al., 2015), although longer lasting matches have been observed over the last three Olympics (Abián-Vicén et al., 2018). However, the fact the matches are longer in duration in the EP implies the need to better prepare for the final part of the tournament. To our knowledge, no specific data are available about the duration of a set, where in the present study some interesting questions arise. On one hand, the duration is significantly longer in Set 1 (18 vs. 23 min) and Set 2 (20 vs. 29 min) between the GP vs. EP. Albeit not significantly, statistically speaking, Set 3 has a longer duration in the GP vs. EP (25 vs. 22). Therefore, this seems to show a set duration of around 20 min, similar to a duration calculated based on others' findings (Gawin et al. (2015) and, over and above the data that exists in singles match (Abian-Vicen et al., 2013; Abián et al., 2014). The level of EP is similar, but in high-level men's doubles, it seems there were greater differences in superiority in the modality of partners and hence the Set time is lower.

The duration of a point, despite a tendency to rise between the GP vs. EP, is not significant in either a match or any analyzed set. Thus, the duration of a point is between 6 and 7 s, with 7–7.6 strokes per point. The duration of a point has grown over time, from 5 s established some time ago (Liddle and O'Donoghue, 1998; Alcock and Cable, 2009), until the interval established by other researchers (Gawin et al., 2015; Abián-Vicén et al., 2018). With regard to strokes per point, different authors have determined a range of 8–10 (Abián-Vicén et al., 2018). The highest values are found in Set 2, in the EP, with 8.58 strokes per point. This seems to be high since the first three strokes are decisive in men's doubles, where 80% of attack maneuvers begin with the service-return stroke (Gawin et al., 2013). These data give an approximate stroke-to-time ratio of 0.85–0.90, slightly higher than that found on a world-class level (Gawin et al., 2013). At the last three Olympics, a stable trend of around 1.5 is apparent (Abián-Vicén et al., 2018), which appears to be a high ratio given that the network game, is higher in doubles games is more evident (Zhang et al., 2013). Observing the structure by Set and by phase of competition may produce some results that can underpin modality-specific training.

There are almost no differences between the GP and EP in women's doubles. The longer match duration in the EP vs. the GP (68 vs. 47 min) stands out. Of the few studies that concern

TABLE 5 | Descriptive statistics and different between competition level (Group Stage vs. Eliminatory Phase) for men and women doubles sets.

	Men doubles							Women doubles						
	Group stage	Eliminatory phase	*P*-Value	*Z*-Value	*d*	CV *(GS)*	CV *(EP)*	Group stage	Eliminatory phase	*P*-value	*Z*-value	*d*	CV *(GS)*	CV *(EP)*
Variables related to match														
Duration of match	48.68 ± 17.87	68.94 ± 11.76*p*	< 0.001	−4.03	1.134	2.72	5.86	47.75 ± 13.00	68.62 ± 17.13*p*	< 0.001	−3.695	1.464	3.67	4.01
Longest rally (s)	42.30 ± 19.96	33.94 ± 10.20	0.10	−1.643	−0.473	2.12	3.33	54.33 ± 18.58	51.87 ± 13.77	1.00	−0.000	−0.141	2.92	3.77
Longest rally (strokes)	43.29 ± 10.11	42.41 ± 12.38	0.43	−0.777	−0.081	4.28	3.43	58.41 ± 15.10	56.37 ± 13.98	0.68	−0.404	−0.138	3.87	4.03
Average rally (s)	6.70 ± 2.16	7.23 ± 1.67	0.64	−0.463	0.261	3.1	4.33	10.33 ± 2.23	10.37 ± 1.99	0.87	−0.158	0.018	4.63	5.21
Average rally (strokes)	7.02 ± 1.11	7.76 ± 1.78	0.27	−1.086	0.552	6.32	4.36	9.91 ± 2.06	10.62 ± 1.70	0.18	−1.32	0.361	4.81	6.25
Shuttles used	15.74 ± 6.20	20.82 ± 6.75	0.01	−2.561	0.798	2.54	3.08	11.83 ± 5.06	16.50 ± 7.32	0.04	−2.022	0.81	2.34	2.25
Set 1														
Match points	–	–	–	–		–	–	–	–	–	–		–	–
Set points	2.04 ± 1.04	1.77 ± 0.97	0.44	−0.757	−0.265	1.96	1.82	1.56 ± 0.82	2.11 ± 1.96	0.65	−0.443	0.443	1.9	1.08
Duration of set	18.95 ± 4.57	23.00 ± 5.63	0.01	−2.548	0.826	4.15	4.09	20.20 ± 4.13	24.62 ± 6.08	0.01	−2.521	0.932	4.89	4.05
Total points played	35.89 ± 3.51	36.64 ± 2.66	0.37	−0.89	0.228	10.23	13.77	35.37 ± 3.83	37.37 ± 7.20	0.49	−0.686	0.401	9.23	5.19
Total point won	17.87 ± 3.97	18.52 ± 3.28	0.69	−0.39	0.172	4.5	5.65	17.68 ± 4.29	18.68 ± 5.19	0.55	−0.598	0.22	4.12	3.6
Most consecutive points	3.08 ± 1.39	3.17 ± 1.59	0.93	−0.079	0.062	2.22	1.99	3.41 ± 1.69	2.93 ± 1.52	0.25	−1.135	−0.292	2.02	1.93
Longest rally (s)	34.48 ± 18.00	29.58 ± 6.19	0.51	−0.654	−0.316	1.92	4.78	44.83 ± 16.09	43.50 ± 12.92	0.57	−0.559	−0.087	2.79	3.37
Longest rally (strokes)	38.23 ± 9.84	37.00 ± 7.70	0.93	−0.076	−0.133	3.89	4.81	50.45 ± 13.66	46.87 ± 10.09	0.70	−0.373	−0.28	3.69	4.65
Average rally (s)	7.04 ± 2.71	7.70 ± 1.31	0.68	−0.402	0.277	2.6	5.88	10.29 ± 2.74	11.00 ± 2.12	0.65	−0.443	0.275	3.76	5.19
Average rally (strokes)	7.44 ± 1.39	8.58 ± 1.54	0.01	−2.464	0.794	5.35	5.57	10.00 ± 2.25	11.50 ± 1.86	0.02	−2.304	0.698	4.44	6.18
Shuttles used	6.48 ± 2.19	7.58 ± 1.76	0.07	−1.765	0.531	2.96	4.31	5.79 ± 2.49	7.37 ± 2.87	0.03	−2.096	0.608	2.33	2.57
Points scored without service	9.78 ± 1.70	10.64 ± 2.08	0.18	−1.337	0.473	5.75	5.12	9.25 ± 1.75	10.06 ± 3.04	0.53	−0.621	0.371	5.29	3.31
Points scored with service	8.26 ± 3.62	7.88 ± 3.15	0.67	−0.42	−0.109	2.28	2.5	8.43 ± 3.91	8.62 ± 3.84	0.91	−0.109	0.049	2.16	2.24
Biggest lead	5.34 ± 3.43	4.60 ± 3.56	0.41	−0.814	−0.213	1.56	1.29	6.22 ± 3.43	4.86 ± 3.58	0.16	−1.394	−0.392	1.81	1.36
Biggest come back to win the game	2.42 ± 1.78	2.00 ± 1.29	0.61	−0.51	−0.254	1.36	1.55	3.00 ± 1.34	2.71 ± 1.88	0.63	−0.472	−0.192	2.24	1.44
Set 2														
Match points	1.50 ± 0.73	1.66 ± 0.57	0.52	−0.635	0.233	2.05	2.91	1.65 ± 0.87	2.50 ± 1.29	0.15	−1.429	0.848	1.9	1.94
Set points	2.75 ± 1.66	1.33 ± 0.51	0.05	−1.906	−0.998	1.66	2.61	2.00 ± 1.00	1.40 ± 0.54	0.30	−1.021	−0.668	2	2.59
Duration of set	20.23 ± 4.94	29.94 ± 11.36*p*	< 0.001	−2.608	1.308	4.1	2.64	21.54 ± 5.10	24.37 ± 3.93	0.06	−1.87	0.589	4.22	6.2
Total points played	36.44 ± 4.08	37.11 ± 2.80	0.17	−1.346	0.179	8.93	13.25	35.91 ± 4.09	36.75 ± 3.49	0.43	−0.781	0.213	8.78	10.53
Total point won	18.12 ± 3.98	18.70 ± 3.19	0.74	−0.321	0.154	4.55	5.86	17.95 ± 4.21	18.37 ± 3.68	0.89	−0.139	0.103	4.26	4.99

(Continued)

TABLE 5 | Continued

	Men doubles							Women doubles						
	Group stage	Eliminatory phase	*P*-Value	*Z*-Value	*d*	CV *(GS)*	CV *(EP)*	Group stage	Eliminatory phase	*P*-value	*Z*-value	*d*	CV *(GS)*	CV *(EP)*
Most consecutive points	3.08 ± 1.52	3.17 ± 1.07	0.53	−0.625	0.064	2.03	2.96	3.08 ± 1.74	2.68 ± 1.07	0.68	−0.404	−0.252	1.77	2.5
Longest rally (s)	31.72 ± 7.77	32.33 ± 1.02	0.55	−0.594	0.093	4.08	31.7	44.75 ± 20.17	46.50 ± 12.28	0.47	−0.714	0.095	2.22	3.79
Longest rally (strokes)	35.57 ± 11.34	35.17 ± 15.31	0.54	−0.609	−0.032	3.14	2.3	47.58 ± 18.69	48.37 ± 15.26	0.80	−0.248	0.044	2.55	3.17
Average rally (s)	6.72 ± 2.44	7.78 ± 17.92	0.35	−0.919	0.223	2.75	0.43	10.75 ± 2.72	10.25 ± 1.98	0.30	−1.034	−0.197	3.95	5.18
Average rally (strokes)	7.02 ± 1.37	7.52 ± 2.26	0.74	−0.328	0.298	5.12	3.33	10.12 ± 2.30	10.12 ± 2.21	0.63	−0.475	0	4.4	4.58
Shuttles used	7.17 ± 2.85	7.47 ± 2.06	0.53	−0.614	0.114	2.52	3.63	5.00 ± 2.14	4.87 ± 2.27	1.00	−0.00	−0.06	2.34	2.15
Points scored without service	10.19 ± 2.22	10.23 ± 1.52	0.96	−0.039	0.02	4.59	6.73	10.08 ± 1.96	10.31 ± 1.95	0.62	−0.495	0.118	5.14	5.29
Points scored with service	7.97 ± 3.68	8.47 ± 2.89	0.63	−0.474	0.114	2.17	2.93	8.21 ± 3.55	8.06 ± 3.21	0.86	−0.17	−0.043	2.31	2.51
Biggest lead	4.95 ± 3.29	4.20 ± 2.80	0.55	−0.591	−0.238	1.5	1.5	5.22 ± 3.56	4.06 ± 3.28	0.20	−1.266	−0.333	1.47	1.24
Biggest come back to win the game	2.56 ± 1.15	1.71 ± 1.49	0.05	−1.905	−0.675	2.23	1.15	2.37 ± 1.14	1.57 ± 1.13	0.08	−1.748	−0.703	2.08	1.39
Set 3														
Match points	2.28 ± 1.49	1.87 ± 1.12	0.62	−0.492	−0.295	1.53	1.67	2.50 ± 1.91	2.20 ± 1.64	0.89	−0.129	−0.163	1.31	1.34
Set points	–	–	–	–		–	–							
Duration of set	25.00 ± 4.86	22.33 ± 4.65	0.83	−0.207	−0.556	5.14	4.8	23.25 ± 3.15	26.60 ± 3.74	0.07	−1.8	1.008	7.38	7.11
Total points played	38.57 ± 2.70	39.33 ± 5.10	0.46	−0.731	0.213	14.29	7.71	36.25 ± 2.65	36.20 ± 3.91	1.00	−0.00	−0.016	13.68	9.26
Total point won	19.28 ± 2.61	19.66 ± 3.79	0.41	−0.814	0.126	7.39	5.19	18.12 ± 3.60	18.10 ± 4.12	1.00	−0.00	−0.005	5.03	4.39
Most consecutive points	3.00 ± 1.10	3.25 ± 1.21	0.42	−0.806	0.221	2.73	2.69	3.12 ± 1.24	3.22 ± 1.20	0.84	−0.2	0.081	2.52	2.68
Longest rally (s)	34.85 ± 11.62	15.22 ± 3.41	0.00	−3.299	−1.975	3	4.46	46.25 ± 3.05	41.80 ± 10.65	0.28	−1.08	−0.724	15.16	3.92
Longest rally (strokes)	34.85 ± 9.71	29.16 ± 6.78	0.07	−1.76	−0.636	3.59	4.3	52.50 ± 2.44	50.20 ± 14.35	0.47	−0.714	−0.295	21.52	3.5
Average rally (s)	6.07 ± 1.19	6.66 ± 0.98	0.24	−1.166	0.521	5.1	6.8	9.75 ± 1.38	15.50 ± 17.48	0.36	−0.911	0.623	7.07	0.89
Average rally (strokes)	7.71 ± 1.06	6.66 ± 1.15	0.03	−2.118	−0.966	7.27	5.79	10.00 ± 2.26	10.20 ± 1.81	0.85	−0.18	0.093	4.42	5.64
Shuttles used	7.00 ± 1.92	8.16 ± 2.44	0.07	−1.787	0.556	3.65	3.34	6.25 ± 2.76	6.80 ± 3.08	0.58	−0.54	0.193	2.26	2.21
Points scored without service	11.71 ± 1.85	11.08 ± 1.50	0.43	−0.785	−0.359	6.33	7.39	9.75 ± 1.03	9.80 ± 1.47	0.81	−0.231	0.043	9.47	6.67
Points scored with service	7.57 ± 2.65	8.58 ± 2.84	0.28	−1.069	0.373	2.86	3.02	8.37 ± 3.15	9.22 ± 2.38	0.66	−0.437	0.287	2.66	3.87
Biggest lead	4.50 ± 2.75	4.45 ± 2.97	0.85	−0.178	−0.018	1.64	1.5	4.37 ± 3.54	5.71 ± 3.63	0.34	−0.939	0.411	1.23	1.57
Biggest come back to win the game	2.33 ± 2.30	3.40 ± 2.88	0.63	−0.476	0.427	1.01	1.18	1.50 ± 0.57	2.50 ± 0.70	0.13	−1.5	1.644	2.63	3.57

GS, Group Stage; EP, Elimination Phase.

TABLE 6 | Descriptive statistics and different between competition level (Group Stage vs. Eliminatory Phase) for mixed doubles sets.

	Mixed doubles						
	Group stage	**Eliminatory phase**	***P*-value**	***Z*-value**	***D***	**CV (Group stage)**	**CV (Elimnation Phase)**
Variables related to match							
Duration of match	47.45 ± 16.36	44.25 ± 6.19	0.73	−0.342	−0.217	2.9	7.15
Longest rally (s)	32.66 ± 10.97	37.00 ± 6.96	0.08	−1.739	0.425	2.98	5.32
Longest rally (strokes)	36.83 ± 8.38	41.25 ± 6.96	0.03	−2.086	0.546	4.39	5.93
Average rally (s)	7.58 ± 1.79	7.87 ± 1.20	0.84	−0.19	0.173	4.23	6.56
Average rally (strokes)	7.04 ± 1.11	7.75 ± 1.34	0.05	−1.928	0.61	6.34	5.78
Shuttles used	11.08 ± 4.63	12.00 ± 4.44	0.51	−0.655	0.2	2.39	2.7
Set 1							
Match points	–	–	–	–		–	–
Set points	1.65 ± 0.74	1.62 ± 1.40	0.65	−0.443	−0.032	2.23	1.16
Duration of set	18.58 ± 4.71	20.62 ± 4.12	0.33	−0.964	0.445	3.94	5
Total points played	35.79 ± 4.86	35.12 ± 3.24	0.32	−0.976	−0.147	7.36	10.84
Total point won	17.89 ± 4.60	17.56 ± 4.22	0.68	−0.409	−0.073	3.89	4.16
Most consecutive points	3.21 ± 1.67	2.75 ± 1.39	0.37	−0.888	−0.285	1.92	1.98
Longest rally (s)	29.62 ± 11.26	32.75 ± 7.47	0.90	−0.124	0.297	2.63	4.38
Longest rally (strokes)	32.54 ± 9.76	34.00 ± 10.23	0.84	−0.193	0.148	3.33	3.32
Average rally (s)	7.95 ± 2.11	7.87 ± 1.31	0.09	−1.698	−0.041	3.77	6.01
Average rally (strokes)	7.29 ± 1.28	7.87 ± 1.50	0.04	−2.057	0.436	5.7	5.25
Shuttles used	4.54 ± 1.91	6.12 ± 2.75	0.37	−0.884	0.744	2.38	2.23
Points scored without service	9.77 ± 2.29	10.56 ± 1.89	0.53	−0.621	0.358	4.27	5.59
Points scored with service	8.12 ± 3.94	7.00 ± 3.84	0.91	−0.109	−0.286	2.06	1.82
Biggest lead	5.51 ± 3.98	5.81 ± 3.94	0.16	−1.394	0.076	1.38	1.47
Biggest come back to win the game	2.20 ± 1.65	1.33 ± 0.57	0.63	−0.472	−0.587	1.33	2.33
Set 2							
Match points	1.75 ± 0.91	1.37 ± 0.74	0.71	−0.366	−0.434	1.92	1.85
Set points	2.00 ± 1.73	–	–	–		1.16	–
Duration of set	20.75 ± 4.53	22.00 ± 3.34	0.15	−1.429	0.291	4.58	6.59
Total points played	37.37 ± 5.24	34.50 ± 3.30	0.11	−1.562	−0.588	7.13	10.45
Total point won	18.68 ± 4.25	17.25 ± 4.52	0.26	−1.124	−0.332	4.4	3.82
Most consecutive points	3.84 ± 1.92	3.06 ± 1.56	0.47	−0.718	−0.422	2	1.96
Longest rally (s)	25.95 ± 7.52	32.75 ± 9.23	0.00	−2.799	0.858	3.45	3.55
Longest rally (strokes)	30.33 ± 7.32	38.00 ± 9.53	0.04	−2.004	0.976	4.14	3.99
Average rally (s)	7.70 ± 1.71	8.25 ± 1.61	0.50	−0.66	0.326	4.5	5.12
Average rally (strokes)	7.20 ± 1.23	7.87 ± 1.66	0.74	−0.328	0.501	5.85	4.74
Shuttles used	5.41 ± 2.08	5.87 ± 1.82	0.13	−1.489	0.227	2.6	3.23
Points scored without service	9.33 ± 2.56	9.25 ± 1.91	0.62	−0.495	−0.033	3.64	4.84
Points scored with service	9.35 ± 3.55	8.80 ± 4.41	0.86	−0.17	−0.146	2.63	2
Biggest lead	5.31 ± 3.57	6.33 ± 3.84	0.20	−1.266	0.281	1.49	1.65
Biggest come back to win the game	3.29 ± 2.02	3.00 ± 1.15	0.08	−1.748	−0.156	1.63	2.61
Set 3							
Match points	1.66 ± 0.51	–	–	–	–	3.25	–
Set points		–	–	–	–	–	–
Duration of set	24.50 ± 4.12	–	–	–	–	5.95	–
Total points played	33.35 ± 7.73	–	–	–	–	4.31	–
Total point won	10.08 ± 3.80	–	–	–	–	2.65	–
Most consecutive points	2.58 ± 1.16	–	–	–	–	2.22	–
Longest rally (s)	30.16 ± 10.45	–	–	–	–	2.89	–
Longest rally (strokes)	32.33 ± 10.89	–	–	–	–	2.97	–
Average rally (s)	8.00 ± 1.59	–	–	–	–	5.03	–

(Continued)

TABLE 6 | Continued

	Mixed doubles						
	Group stage	**Eliminatory phase**	***P*-value**	***Z*-value**	***D***	**CV (Group stage)**	**CV (Elimnation Phase)**
Average rally (strokes)	7.33 ± 1.66	–	–	–	–	4.42	–
Shuttles used	4.50 ± 2.46	–	–	–	–	1.83	–
Points scored without service	10.83 ± 1.94	–	–	–	–	5.58	–
Points scored with service	7.25 ± 3.49	–	–	–	–	2.08	–
Biggest lead	5.37 ± 3.29	–	–	–	–	1.63	–
Biggest come back to win the game	2.00 ± 0.00	–	–	–	–	0	–

women's doubles, Gawin et al. (2015) found a duration of around 40 min. At the Beijing and London Olympic Games, durations of 42–47 min were observed similar to 47 min in the GP in this study, but away from the time in the EP. Abián-Vicén et al. (2018) note that, after the Hawk-eye appeared in badminton, observed rest times have increased, which may explain this increase when the other variables, as we will see below, do not show significant differences. An increase in the Set duration in the GP vs. the EP is shown, but it is not significant, placing it around 20–24 min, longer than what happens in women's singles (Abian-Vicen et al., 2013). Thus, in women's doubles there are no differences in the GP and EP, in the point duration, in strokes per point, in the longest points, or in the match duration in each of the sets analyzed. The average point is around 10–11.50 s with an average of 10–11.50 strokes per point, indicating an approximate ratio of 1:0. The duration of a point in women's doubles is established at around 7–10 s (Gawin et al., 2015; Abián-Vicén et al., 2018), showing progress made in the sport which a decade ago and, prior to the regulatory change, for this had values around 5 s (Liddle and O'Donoghue, 1998; Alcock and Cable, 2009). Strokes per point appears to have a value of approximately 12 (Abián-Vicén et al., 2018), slightly higher than our results, although it is true they are global data and the fact the present study was performed by competition phases and Set may explain the difference. If it is true, a stroke time ratio with a stable value of 1:2 is established (Alcock and Cable, 2009; Abián-Vicén et al., 2018), also above what is determined here. It calls for attention because, like in men's doubles, in women's, the first three strokes are vital, with 50% of attack actions being initiated after the return of service (Gawin et al., 2013). While some might say the level of experience in men players is very evident, this is not so much the case for women players (Gawin et al., 2013).

In badminton, doubles players are specific in that they do not participate in singles competitions as may happen in other sports like tennis (Torres Luque and Carrasco Páez, 2004). Along these lines, no great differences are observed between tournament phases, possibly indicating the level of competition is similar between partners in high-level competition, an aspect that deserves to be analyzed in more depth.

In mixed doubles, what is most striking is that at the Rio Olympic Games no match was played to three sets, revealing the constant superiority of certain partners compared to others. In fact, unlike in men's and women's doubles, mixed doubles show a difference between the GP vs. the EP. Particularly standing out is strokes per point at around 7.8, with the duration of a point impacting those values. The duration of a point in strokes at this level is already higher than about 5 and 5.6 found by other authors at lower levels of competition (Liddle and O'Donoghue, 1998; Gawin et al., 2015), although the stroke per point ratio extracted in this study exceeds 0.72 determined by Gawin et al. (2015). Considering the scarcity of scientific studies on this sport, it is necessary to regard these data as a reference for what is currently happening at high levels of the sport and to continue to investigate in the future.

A strength of this study is the analysis of competition statistics for five badminton modalities, where differences are observed in levels of competition and analyzed by set.

The applications of this study to specific training in a badminton sport, could be defined in two fundamentals: on the one hand, the differences in group phase vs. elimination phase, indicated that in high performance there are two competitive levels. This aspect, which is observed more in the singles badminton, so that, when planning competitive periods of high level, this must be considered. On the other hand, and we consider that more novel, is the analysis of these two phases and by set. So far, we only had analysis of set 1 and set 2, but few studies on set 3. This implies observing as set 3, which is determinant for the winner the match and therefore, to obtain medal in a competition such as JJOO, is substantially different between group stage vs. elimination phase. This study can contribute to a more specific preparation about being good or being the best.

CONCLUSION

The results show in men's and women's singles all the variables related to the match were higher in the Eliminatory Phase than in the Group Phase. Sets 1 and 3 registered the longest set duration, rally and average rally in the Eliminatory Phase. In women's singles, these differences were also established in set 2. In doubles, the results are more stable among groups. Men's doubles had a longer match duration and set (1, 2) duration, and scored higher for average rally (sets 1, 3) and shuttles used in the Eliminatory Phase vs. the Group Phase. In women's doubles, more shuttles were used in a match in the Eliminatory Phase than in the Group Phase. Moreover, the same results are found in set 2, including the average rally. Mixed doubles did not see any match go to three sets. However, the biggest differences were found in the variables longest rally and average rally which were higher in the Eliminatory than in the Group Phase. This information may help players and coaches prepare and administer different types of workouts or, more specifically, competition schedules adapted to the characteristics of modern badminton.

AUTHOR CONTRIBUTIONS

GT-L and MK conceived and designed the study. GT-L and ÁF-G analyzed the data. JB-T and GT-L drafted the manuscript. DC-M and MK advised on analysis and interpretation of the data and critically revised the manuscript. DC-M funding acquisition.

REFERENCES

Abdullahi, Y., and Coetzee, B. (2017). Notational singles match analysis of male badminton players who participated in the African badminton championships. *Int. J. Perf. Anal. Sport* 17, 1–16. doi: 10.1080/24748668.2017.1303955

Abián, P., Abian-Vicen, J., and Sampedro, J. (2012). Anthropometric analysis of body symmetry in badminton players. *Int. J. Morphol.* 30, 945–951. doi: 10.4067/S0717-95022012000300030

Abián, P., Castanedo, A., Feng, X. Q., Sampedro, J., and Abian-Vicen, J. (2014). Notational comparison of men's singles badminton matches between olympic games in Beijing and London. *Int. J. Perf. Anal. Sport* 14, 42–53. doi: 10.1080/24748668.2014.11868701

Abian-Vicen, J., Castanedo, A., Abian, P., and Sampedro, J. (2013). Temporal and notational comparison of badminton matches between men's singles and women's singles. *Int. J. Perf. Anal. Sport* 13, 310–320.

Abián-Vicén, J., Sánchez, L., and Abián, P. (2018). Performance structure analysis of the men's and women's badminton doubles matches in the olympic games from 2008 to 2016 during playoffs stage. *Int. J. Perf. Anal. Sport* 18, 633–644. doi: 10.1080/24748668.2018.1502975

Alcock, A., and Cable, N. T. (2009). A comparison of singles and doubles badminton: heart rate response, player profiles and game characteristics. *Int. J. Perf. Anal. Sport* 9, 228–237. doi: 10.1080/24748668.2009.11868479

Álvarez, J. R., Campos, M. D. C., Portes, C. P., Rey, M. R., and Martín, A. B. (2016). Analisis de parámetros fisiológicos en jugadores juveniles españoles de badminton/analysis of the physiological parameters of young spanish badminton players. *Rev. Int. Med. Cienc. AC* 16, 45–54. doi: 10.15366/rimcafd2016.61.004

Bisschoff, A. C., Coetzee, B., and Esco, R. M. (2016). Relationship between heart rate, heart rate variability, heart rate recovery and global positioning system determined match characteristics of male, elite, African badminton players. *Int. J. Perf. Anal. Sport* 16, 881–897. doi: 10.1080/24748668.2016.11868936

Badminton World Federation (BWF) (2017). *Rules of Badminton*. Available at: http://www.bwfbadminton.org/ (accessed June 15, 2017).

Cabello, D., Padial, P., Lees, A., and Rivas, F. (2004). Temporal and physiological characteristics of elite women's and men's singles badminton. *Int. J. Appl. Sport Sci.* 16, 1–12.

Cabello-Manrique, D. C., and González-Badillo, J. (2003). Analysis of the characteristics of competitive badminton. *Brit. J. Sport Med.* 37, 62–66. doi: 10.1136/bjsm.37.1.62

Chen, H. -L., and Chen, W. T. C. (2011). Physiological and notational comparison of new and old scoring systems of singles matches in men's badminton. *Asian J. Phys. Educ. Recreat.* 17, 6–17.

Chiminazzo, J. G. C., Barreira, J., Luz, L. S., Saraiva, W. C., and Cayres, J. T. (2018). Technical and timing characteristics of badminton men's single: comparison between groups and play-offs stages in 2016 rio olympic games. *Int. J. Perf. Anal. Sport* 18, 245–254. doi: 10.1080/24748668.2018.1463785

Di, X., Zhu, S., Jin, H., Wang, P., Ye, Z., Zhou, K., et al. (2012). Altered resting brain function and structure in professional badminton players. *Brain Connect.* 2, 225–233. doi: 10.1089/brain.2011.0050

Gawin, W., Beyer, C., Hasse, H., and Büsch, D. (2013). How to attack the service: an empirical contribution to rally opening in world-class badminton doubles. *Int. J. Perf. Anal. Sport* 13, 860–871. doi: 10.1080/24748668.2013.11868694

Gawin, W., Beyer, C., and Seidler, M. (2015). A competition analysis of the single and double disciplines in world-class badminton. *Int. J. Perf. Anal. Sport* 15, 997–1006. doi: 10.1080/24748668.2015.11868846.

Hussain, I., Paul, Y., and Bari, M. (2011). Videographical analysis of drop and cut shot in badminton: sport science. *Afr. J. Phys. Health Educ. Recreat. Dance* 17, 860–865.

Hussain, S. (2013). Somatotype and body composition of adolescent badminton players in Kerala. *Int. J. Adv. Sci. Tech. Res.* 6, 105–111.

Jeyaraman, R., District, E., and Nadu, T. (2012). Prediction of playing ability in badminton from selected anthropometrical physical and physiological characteristics among inter collegiate players. *Int. J. Adv. Innov. Res.* 2, 47–58.

Laffaye, G., Phomsoupha, M., and Dor, F. (2015). Changes in the game characteristics of a badminton match: a longitudinal study through the olympic game finals analysis in men's singles. *J. Sport Sci. Med.* 14, 584–590.

Landis, J. R., and Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics* 33, 159–174.

Li, S., Zhang, Z., Wan, B., Wilde, B., and Shan, G. (2017). The relevance of body positioning and its training effect on badminton smash. *J. Sport Sci.* 35, 310–316. doi: 10.1080/02640414.2016.1164332

Liddle, D., and O'Donoghue, P. (1998). "Notational analysis of rallies in European circuit badminton," in *Science and Racket Sports II*, eds A. Lees, I. Maynard, M. Hughes, and T. Reilly (London: E and FN Spon), 275–281.

Ortega, E., Villarejo, D., and Palao, J. M. (2009). Differences in game statistics between winning and losing rugby teams in the six nations tournament. *J. Sport Sci. Med.* 8, 523–527.

Phomsoupha, M., and Laffaye, G. (2015). The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports Med.* 45, 473–495. doi: 10.1007/s40279-014-0287-2

Sánchez-Pay, A., Palao, M. J., Torres-Luque, G., and Sanz-Rivas, D. (2015). Differences in set statistics between wheelchair and conventional tennis on different types of surfaces and by gender. *Int. J. Perf. Anal. Sport* 15, 1177–1188. doi: 10.1080/24748668.2015.11868860

Torres Luque, G., and Carrasco Páez, L. (2004). *Investigación en Deportes de Raqueta: Tenis y Bádminton.* Murcia: Universidad Catolica San Antonio de Murica.

Torres-Luque, G., Fernández-García, A., Sánchez-Pay, A., Ramírez, A., and Nikolaidis, P. (2017). Diferencias en las estadísticas de competición en tenis individual en función de la superficie de juego en jugadores junior masculinos de alto nivel. *SPORT TK Revista EuroAmericana de Ciencias del Deporte* 6, 75–80. doi: 10.6018/280431

Williams, A. M., Ford, P. R., Eccles, D. W., and Ward, P. (2011). Perceptual-cognitive expertise in sport and its acquisition: implications for applied cognitive psychology. *Appl. Cogn. Psychol.* 25, 432–442. doi: 10.1002/acp.1710

Zhang, B., Li, F., and Jiang, W. (2013). Mixed doubles match technical and tactical analysis of world badminton champion based on mathematical statistics. *Adv. Phys. Educ.* 3, 154–157. doi: 10.4236/ape.2013.34025

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Sanctioning of Illegal and Dangerous Ruck Cleanouts During the 2018 Super Rugby Competition

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Rugby is a high contact sport that results in many injuries. The majority of injuries at senior elite levels result from contact phases during match-play. It is estimated that 10% of all match injuries are associated with the ruck in professional and community rugby. Surveillance of legal and illegal ruck cleanouts and the sanctions imposed by the on-field referees will help identify whether referees are actually enforcing the law according to the laws of the game, which will consequently contribute to the creation and implementation of further injury prevention strategies. Players should play the game in accordance with the laws of the game and be mindful of their own safety and that of others. Coaches and trainers of the game have the responsibility to ensure that players are prepared in a manner that comply with the World Rugby (WR) laws of the game and safe practices. Laws and law amendments are fundamental to the development of sport and introduced for a variety of reasons. The aim of this study was to investigate the rate of sanctioning of illegal and dangerous ruck cleanouts during the 2018 Super Rugby competition by using Nacsport Basic+ video software; 120 round robin matches from the 2018 Super Rugby competition were coded and analyzed. The analysis of the intra reliability showed an almost perfect (>0.95) agreement between all the performance indicators. In total, 22,281 ruck cleanouts were coded of which 9% (n = 2111) were illegal ruck cleanouts and 93% were not sanctioned by the referees; 57% (1087 out of 1953) of the illegal ruck cleanouts not sanctioned by the referees were deemed dangerous. The majority of dangerous illegal ruck cleanouts not sanctioned by the referees were "*shoulder charge*" (88%, n = 280), "*neck roll*" (86%, n = 100), and "contact above the shoulder" (81%, n = 201). To aid injury prevention efforts in rugby, future research studies should investigate why on-field referees are not sanctioning all illegal and dangerous ruck cleanouts according to WR *Laws of the Game*.

Keywords: injury prevention, ruck cleanouts, sanctioning, dangerous play, referees, attack, defense

INTRODUCTION

Rugby union (rugby) is an invasion field-based team sport. At senior level matches last 80 min, which are characterized by short intermittent bouts of high intensity activity and multiple high impact contact situations between 30 players (Fuller et al., 2007). Rugby also has one of the highest incidences of injury, irrespective of the injury definition used in the investigation

(Fuller et al., 2010). The majority of injuries at senior and elite levels of rugby result from contact phases of play (Williams et al., 2013). More or less 10% of all match injuries are associated with the ruck in professional (Rugby Football Union, 2018) and community rugby (Roberts et al., 2015).

Any sport involving physical contact such as rugby has inherent risks toward its players. Players are required to play the game in accordance with the WR *Laws of the Game* and should be mindful of their own safety and that of their own and opposition players. It is the responsibility of the coaches and trainers to ensure that players are prepared in a manner that comply with the laws of the game and safe practices (Kraak et al., 2016, 2017). The on-field referees are responsible for interpreting and applying the laws of the game during the match, thereby protecting the players from potential injury risk. Apart from the maintenance of "fair play," the decisions of referees can affect the outcome of a game significantly (Mascarenhas et al., 2005; Spitz et al., 2016). Laws and law amendments are fundamental to the development of a sport and introduced for a variety of reasons (Kraak and Welman, 2014). Some of the reasons why law changes and experimental law variations are implemented in rugby are in response to player performance, to ensure safety of all role-players involve, increase participation and enjoyment, promote continuity of rugby, technological advancement, and commercial pressures, as well as to retain game integrity and development (Eaves et al., 2008). World Rugby (WR) replacing the International Rugby Board (IRB) in 2014 is responsible for delivering safe, enjoyable, and entertaining rugby tournaments and events. Therefore, WR *Laws of the Game* provide a framework by which WR ensures these aspects (Murray et al., 2014) are achieved.

Injury prevention programs such as WR's Rugby Ready, New Zealand's RugbySmart, Australia's Smart Rugby, and South Africa's BokSmart direct their interventions and programs toward coach and trainer (will hopefully be transferred to the player) and referee education, because these role-players have a large influence on player behavior during training and match play. These injury prevention programs are put in place by various governing bodies to assess and educate coaches (players through the coaches) and referees on the prevalence of injury and how to overcome them, in order to make rugby as safe as possible for its players (Viljoen and Patricios, 2012; Roberts et al., 2015). Specifically, coaches can reduce injury risk through coaching better techniques during training and referees by applying the WR *Laws of the Game* and in the context of this study, penalizing illegal ruck cleanouts during matches. A study by Kraak et al. (2016) indicates that because of law changes the number of ball carriers increased from 184 to 219 in the Super Rugby tournament between 2008 and 2013. Hendricks et al. (2018) indicate that 65% of all collisions (ball carrier and defender engaged in a tackle), resulted in rucks in professional rugby. Rucks are one of the most frequently occurring contact events in rugby during match play. The ruck is a contest between the attacking and defending team and players involved in the ruck need to be on their feet. A cleanout is an action by the arriving players to either retain (attacking team) or regain (defending team) possession. The ability to repeatedly engage and win rucks has been associated with team success. Ortega et al. (2009) and Kraak and Welman (2014) state that winning teams regained ball possession at rucks more frequently than losing teams in the Six Nations competition. For the attacking team to retain possession and for the defending team to try to regain possession at the ruck, the teams will have to utilize specific clean out techniques. Ruck clean out techniques used by players during matches could often be deemed illegal according to the WR *Laws of the Game*, and could be considered dangerous in many cases. Illegal ruck clean out types according to the 2018 WR *Laws of the Game* (Law 9.20 and 15.5-9), include: (a) neck roll; (b) shoulder charge; (c) contact above the shoulder of an opposition player; (d) side entry; (e) not grasping onto team mate when cleaning; (f) not supporting own body weight; (g) clean out a player not involved in the ruck; and (h) joining the ruck, while in an offside position. The minimum sanction for all of these infringements is a penalty kick for the opposition. It should be noted that not all illegal ruck clean out techniques are deemed dangerous with a potential injury risk.

According to Van Mechelen and Hlobil (1992), the first step in injury prevention process is the surveillance step. A recent study by Brown et al. (2018) investigated the sanctioning of illegal tackling in the South African under 18 Craven Week rugby tournament and revealed that 59% of illegal tackles were not penalized appropriately by the referees. A study by Fuller et al. (2010) on professional English rugby found that only a minority of illegal/dangerous tackles were penalized correctly by the on-field referee according to the laws of the game; 6% (14 out of 238) of the high tackles (to the head/neck region of ball carriers) were penalized by the on-field referees in the study of Fuller et al. (2010). Surveillance of legal and illegal (dangerous and not-dangerous) ruck clean outs and the sanctions imposed by referees will help identify whether the referees are actually enforcing the laws according to the WR law book. The findings of the current study can lead to the development and implementation of further injury prevention strategies in order to make the game safer for all the role-players involved. Therefore, the primary aim of this study was to investigate the rate of sanctioning of illegal and dangerous ruck cleanouts during the 2018 Super Rugby competition.

MATERIALS AND METHODS

Research Design

The study followed a descriptive and retrospective research design. Ethical approval (SU-HSD-001220) was obtained from the Research Ethics Committee: Human Research at Stellenbosch University.

Sample

Televised video recordings of (N = 120) round robin matches from the 2018 Super Rugby competition were used for this study. The Super Rugby competition is a professional men's rugby competition involving teams from Argentina, Australia, New Zealand, South Africa, and Japan. The Western Province Rugby Union (South Africa) video analysis department supplied the video recordings.

Data Collection Procedure

Coding

Nacsport software (version: Basic+, Spain, 2008) was used to code all ruck clean outs of the 120 round robin matches. Prior to coding, a "*gold standard*" was set by an international referee, using the 2018 WR *Laws of the Game* definitions and analyzing a match in conjunction with the coder that consisted of 180 legal and illegal clean-outs. The performance indicators displayed in **Table 1** were analyzed based on the aims of the study. The software allowed control over the speed at which each activity could be viewed, and the recording and saving of each coded event into a database thereafter, reflected as performance indicators.

Reliability

The reliability of the coded ruck cleanouts was tested using inter-rater reliability. The test and retest reliability of coded performance indicators were assessed using methods described by O'Donoghue (2010). In brief, performance indicators and operational definitions were developed based on published peer-reviewed literature specifically pertaining to the ruck area and clean outs and the 2018 WR *Laws of the Game*. After all the matches were coded by the primary researcher, an international referee and rugby injury specialist re-coded 25% (n = 30) of the matches which were randomly selected by the statistician in order to test for the inter-rater reliability. The inter-rater reliability of the coding was determined by using the intraclass correlation coefficient (ICC) of the test and retest data (Gratton and Jones, 2004). The inter-rater agreement data was interpreted as follows: poor (<0.20), fair (0.30–0.40); moderate (0.50–0.60); strong (0.70–0.95); and almost perfect (>0.95). The test and retest data showed that the agreement between all the performance indicators was almost perfect (**Table 2**), and thus considered as very reliable and were included in the study.

Statistical Analysis

Descriptive data of the performance indicators were reported as frequencies (number of observations), and percentages with an applied significance level of 5% ($p < 0.05$) was applied. Differences between categorical frequencies were determined by using chi-square. Some of the performance indicators were expressed as percentages, which according to Hughes and Bartlett (2002) provides a more accurate analysis of team performance during match-play. Six *a priori* proportions were decided upon as proxies of referee/player behavior, similar to that used by Brown et al. (2018). Referee behavior: proportion of (a) non-sanctioned illegal ruck clean outs out of all illegal ruck clean outs; (b) non-sanctioned illegal ruck clean outs out of all ruck clean outs (legal and illegal combined); (c) non-sanctioned dangerous ruck clean outs out of all illegal ruck clean outs; and (d) non-sanctioned dangerous illegal ruck clean outs out of all ruck clean outs (legal and illegal combined). Player behavior: proportion of

TABLE 1 | Performance indicators and operational definitions used in the study.

Performance indicators	Operational definition
Ruck World Rugby (2018)	The ruck is defined as a phase of play where one or more players from each team remain on their feet and are in physical contact close around the ball on the ground
Attacking team cleaning Hendricks et al. (2018)	Attackers are actively driving opponents off the ball in order to retain possession
Defending team cleaning Hendricks et al. (2018)	Defenders are actively attempting to regain possession
Match period Brown et al., 2018	Each match was divided into two halves of 40 min (first and second half) and four quarters of 20 min (first, second, third, and fourth quarter)
Arrival at the ruck: attacking and defending team Hendricks et al. (2018)	first, second, third, and fourth cleaner
Types of illegal ruck clean outs World Rugby (2018)	– *Neck roll*: A cleaner must not grasp an opposition player around the neck area to clean out – *Not supporting own body weight*: A player cleaning out a ruck must be on his feet – *Joining the ruck while in an offside position*: A player cleaning at the ruck may not do so while in an offside position. Non-participants at the breakdown must be behind the hindmost foot of the last player in their side of the ruck – *Shoulder charge*: A player must not charge into a ruck. Charging includes any contact made without use of the arms, or without grasping a player – *Side entry*: A cleaner must join alongside but not in front of the hindmost player – *Not grasping on teammate when cleaning*: A player joining a ruck must bind on a teammate or an opponent, using the whole arm. The bind must either precede, or be simultaneous with, contact with any other part of the body of the player joining the ruck – *Cleaning a player not involved in the ruck*: A cleaner must not take out opposition players who are not part of the ruck – *Contact above shoulder of opposition player*: A cleaner must not make contact with an opponent above the line of the shoulders
Sanctioning of illegal ruck clean outs World Rugby (2018)	Whether the illegal ruck cleanout was sanctioned (the first infringement) or not by the referee (s) according to the World Rugby *Laws of the Game*
Dangerous clean out	Dangerous clean out – action was deemed dangerous if the action of the player could lead to possible injury of (a) himself, (b) own players, and (c) opposition players

TABLE 2 | Inter-rater reliability of the coding test-retest using intraclass correlation coefficient (ICC).

Reliability	Ruck clean out	Illegal ruck clean out	Illegal ruck clean out sanctioned	Illegal ruck clean out not sanctioned	Dangerous illegal ruck clean out not sanctioned
Inter-reliability	1.00	0.98	1.00	0.97	0.96

(e) illegal ruck clean outs out of all ruck clean outs (legal and illegal combined); and (f) dangerous illegal clean outs out of all illegal ruck clean outs.

RESULTS

The current study revealed that 22,281 ruck clean outs occurred during the 2018 Super Rugby competition at an average of 186 cleanouts per match. The analysis revealed that 9% ($n = 2111$) of these ruck clean outs were deemed illegal according to the 2018 WR *Laws of the Game* at an average of 18 per match. The referees did not sanction 93% ($n = 1953$) of the illegal ruck clean outs at an average of 16 per match. Of the total illegal ruck cleanouts not sanctioned by the referees, 57% ($n = 1087$) were considered dangerous at an average of 10 per match.

The number of legal and illegal ruck clean outs coded is presented in **Figure 1**. The results reveal that the illegal ruck clean outs were consistently spread across the two halves and four quarters. The analysis revealed a statistically significant difference ($p < 0.001$) in the percentage of illegal clean outs between the first (11%, 1072 of 9436) and second (7%, 1038 of 10,707) halves of play. A statistically significant difference was also observed when comparing the percentage of illegal clean outs in quarter 2 (11%, 545 of 5118) and 3 (9%, 484 of 5583) ($p < 0.001$), as well as quarter 2 and 4 (9%, 555 of 6163) ($p < 0.001$). The attacking team accounted for 90% (1895 of 2111) of the total illegal ruck clean outs at an average of 16 per match. No statistically significant difference was found between the attacking and defending, or the number of cleaners, involved in the ruck cleanout. The first cleaner for both the attacking and defending team were responsible for 67% (1450 of 2111), of the illegal ruck clean outs.

Figure 2 shows the sanctioned and not-sanctioned illegal ruck clean outs in which the referees did not sanction 93% (1953 of 2111) of total illegal ruck clean outs, presenting 9% (1953 of 22,281) of the total ruck clean outs (legal and illegal combined). The non-sanctioned illegal rucks clean outs were evenly spread across the two halves, but revealed a statistical significant ($p < 0.05$) increase from quarter 3 ($n = 444$) to 4

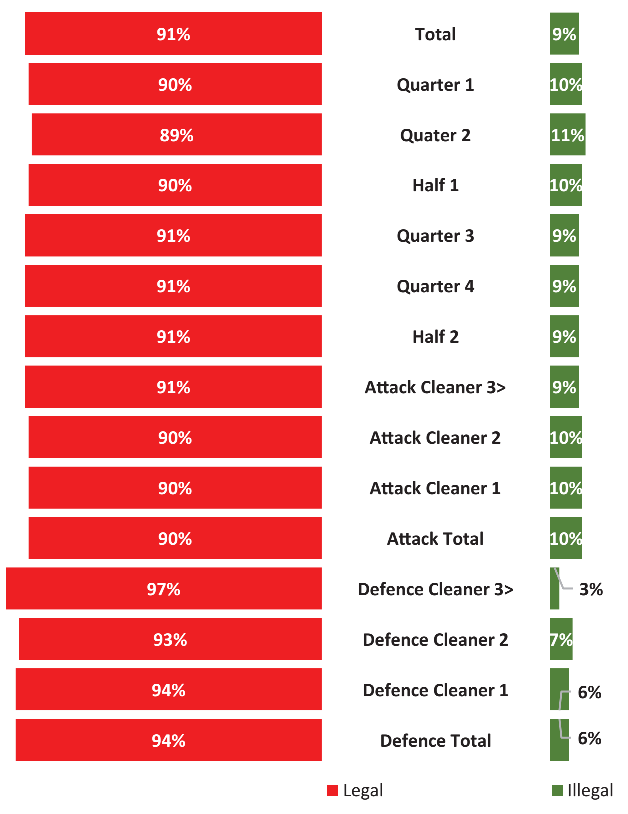

FIGURE 1 | The proportion of legal (red) versus illegal (green) ruck clean outs during the 2018 Super Rugby Tournament.

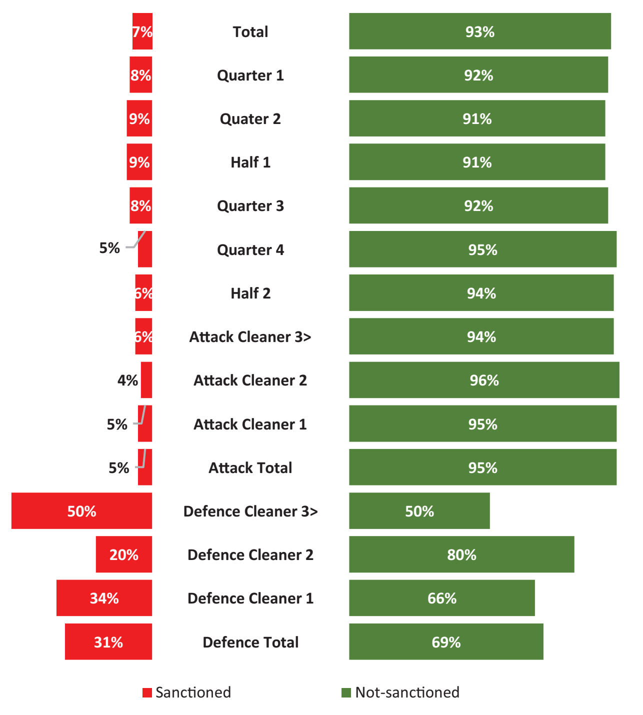

FIGURE 2 | The proportion of sanctioned (red) versus non-sanctioned (green) illegal ruck cleanouts coded during the 2018 Super Rugby Tournament.

($n = 529$) of the match. The referees did not sanction the attacking team for 90% (1804 out of 1953) of the illegal ruck clean outs not sanctioned. The first cleaner for both the attacking and defending team were not sanctioned for 68% (1333 of 1953) of the total illegal ruck clean outs.

Table 3 presents the non-sanctioned illegal ruck clean outs not sanctioned for both the attacking and defending team. The majority of illegal ruck clean outs not sanctioned by the referee were "*not supporting own body weight*" (32%; $n = 624$), followed by "*side entry*" (16%; $n = 318$), "*shoulder charge*" (16%; $n = 317$), and "*contact above the shoulder*" (13%; $n = 247$). The attacking team were not sanctioned when "*not supporting own body weight*" (96%; $n = 599$) and "*side entry*" (95%; $n = 303$) compared to the defending team for "*cleaning a player not involved in ruck*" (27%; $n = 12$) and "*joining the ruck from an offside position*" (12%; $n = 22$). The illegal ruck clean outs not sanctioned for the defending team were "*cleaning a player not involved in ruck*" (27%; $n = 12$), followed by "*joining the ruck from an offside position*" (12%; $n = 9$).

Figure 3 presents the dangerous and not-dangerous illegal ruck clean outs not sanctioned by the referee; 5% in terms of proportion (1087 of 22,281) of all the ruck clean outs and 51% (1087 of 2111), of the total illegal clean outs were deemed dangerous. The current study showed a statistical increase ($p < 0.001$) in dangerous non-sanctioned illegal ruck clean outs from the first ($n = 481$) to the second half ($n = 606$), as well as an increase from quarter 1 ($n = 215$) to 2 ($n = 266$). The same trend was observed for quarter 3 ($n = 210$) to 4 ($n = 396$). The referees did not sanction the attacking team for 95% (1037 of 1087) of the dangerous illegal ruck clean outs. The first cleaner for the attacking team was not sanctioned 77% (801 of 1037) of the dangerous illegal ruck clean outs.

Table 4 presents the dangerous and not dangerous illegal ruck cleanouts not sanctioned by the referees. The majority of dangerous illegal clean outs not sanctioned were "*shoulder charge*" (88%, $n = 280$), followed by "*neck roll*" (86%, $n = 100$) and "*contact above the shoulder*" (81%, $n = 201$).

TABLE 3 | Illegal ruck cleanouts not sanctioned for the attacking and defending team.

Type of illegal ruck cleanout	Attacking team 7% (n = 1804)	Defending team 93% (n = 149)
Not supporting own body weight	96% (n = 599)	4% (n = 25)
Side entry	95% (n = 303)	5% (n = 15)
Shoulder charge	90% (n = 285)	10% (n = 32)
Contact above the shoulder	91% (n = 224)	9% (n = 23)
Neck roll	91% (n = 105)	9% (n = 11)
Not grasping	90% (n = 188)	10% (n = 22)
Joining the ruck from an offside position	88% (n = 67)	12% (n = 9)
Cleaning a player not involved in ruck	73% (n = 33)	27% (n = 12)

n = number of observations and % = percentage.

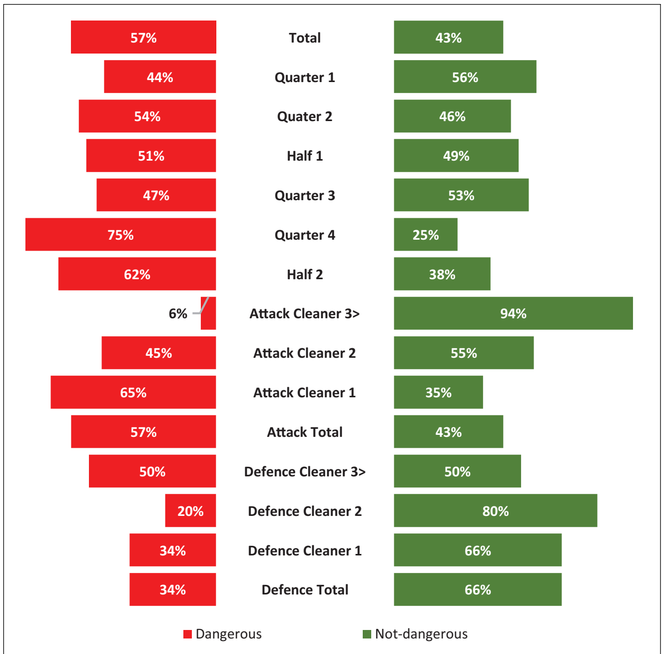

FIGURE 3 | The proportion of not sanctioned dangerous (red) versus not-dangerous (green) illegal ruck cleanouts coded during the 2018 Super Rugby Tournament.

DISCUSSION

The major findings of this study were that: (a) on average 57% ($n = 1\ 087$) of all the dangerous illegal ruck clean outs were not sanctioned by the on-field referees according to the 2018 WR *Laws of the Game*; (b) the on-field referees did not sanction the attacking team for 95% (1037 out of 1087) of all the dangerous illegal ruck clean outs; and (c) the majority of the dangerous illegal clean outs not sanctioned by the referees were "*shoulder charge*," "*neck roll*," and "*contact above the shoulder*." To the researchers' knowledge, this is the first study that investigated non-sanctioning of dangerous illegal clean outs at the ruck by on-field referees during match play. Other studies investigated the non-sanctioning of illegal tackles in professional (Fuller et al., 2010) and youth (Brown et al., 2018) rugby. The findings of the present study are a concern for rugby referee stakeholders from an error rate perspective as 1953 non-sanctioned illegal ruck clean outs were identified. A greater concern for rugby safety and rugby referee stakeholders should be that 1087 of these non-sanctioned ruck clean outs were deemed dangerous, which could pose an injury risk to the players involved in the ruck area.

The rate of illegal and dangerous illegal ruck clean outs were considered high: 9 and 5%, respectively, of the ruck clean outs, this finding does not bode well for player behavior at elite level. Furthermore, when the errors made by the on-field referees were contextualized in comparison to the total number of ruck clean outs, it will be difficult for referees to detect and sanction all illegal ruck clean outs due to the number of players involved. However, from an injury prevention perspective, referees can minimize the risk by focusing on "*shoulder charge*," "*neck roll*," and "*contact above the shoulder*," given the high proportion of these infringements that are deemed dangerous. While the rate of non-sanctioned illegal ruck and non-sanctioned dangerous illegal

TABLE 4 | Dangerous and not dangerous illegal ruck cleanouts not sanctioned.

Type of illegal ruck cleanout	Dangerous 57% (*n* = 1087)	Not dangerous 43% (*n* = 866)
Shoulder charge	88% (*n* = 280)	12% (*n* = 37)
Neck roll	86% (*n* = 100)	14% (*n* = 16)
Contact above the shoulder	81% (*n* = 201)	19% (*n* = 46)
Not supporting own body weight*	64% (*n* = 280)	36% (*n* = 344)
Side entry*	60% (*n* = 190)	40% (*n* = 128)
Cleaning a player not involved in ruck*	22% (*n* = 10)	78% (*n* = 35)
Not grasping*	10% (*n* = 20)	90% (*n* = 190)
Joining the ruck from an offside position*	8% (*n* = 6)	92% (*n* = 70)

**the first infringement by the cleaner was not deemed dangerous but the action by the cleaner that followed the initial cleanout was deemed dangerous; n – number of observations and % – percentage.*

ruck clean outs to all the ruck clean outs could be seen as a proxy for referee behavior, the rate of illegal and dangerous illegal ruck clean outs to all the ruck clean outs in turn can be seen as a metrics of player behavior during match-play.

The high error rate by the referees for illegal and dangerous illegal ruck clean outs (especially the first cleaner for both the attacking and defending team) in the current study could be due to the positioning of the referee at the ruck, which influences whether there is a clear view of the clean out for both the attacking and defending players. The study by Kraak et al. (2011) revealed that the on-field referees movement patterns varied per game due to (a) referee experience – during the study the experienced referees moved less because they anticipate subsequent play better than the novice referees; (b) the level or/and quality of the competition that are being observed; (c) the intensity and different match-play activities completed by the attacking and defending players; (d) the referees time of arrival at the ruck; and (e) application of the laws – Spitz et al. (2016) stated that perceptual and cognitive skills are required by on-field referees to make sure that the decision-making process results in accurate, consistent, and uniform decisions, (f) decision-making (application of the law) ability by the on-field referee. Wheeler et al. (2013) indicated that it is difficult for on-field referees to officiate and sanction the ruck area accurately due to the number of attacking and defending players involved in this phase of play. According to Souchon et al. (2010) on-field referees are faced with making complex decisions in limited time, research has shown that on-field referees rely on judgmental heuristics (i.e., quick and easy decision laws), to help them make their decisions. Research by Mascarenhas et al. (2005) in rugby and Hancock and Ste-Marie (2013) in ice hockey attempted to quantify referee decisions during match play. The rugby on-field referees were accurate in their sanctioning 50% of the time compared to the 75% accuracy of the ice hockey officials (Mascarenhas et al., 2005; Hancock and Ste-Marie, 2013). Although video-based assessments could provide valid examination of decision-making performance by on-field referees, they do not replicate the physical, physiological, and psychological aspects of the match (Emmonds et al., 2015). The lowest accuracy in sanctioning was observed during the last quarter of the match, advising that physical and psychological fatigue could occur during the final stage of the match (Emmonds et al., 2015). This is supported by the fact that the referees had higher error rates when players were going off their feet, joining from the side and charging into the ruck with the shoulder. The referee can easily miss these infringements because of poor positioning. The current study revealed that referees were not consistent with the application of the laws for the attacking and defending team because the referees favored the attacking team more. According to Kraak et al. (2016, 2017), a possible reason why referees tend to favor the attacking team, by penalizing the defending team more frequently, was to improve the continuity of the game. If more of these dangerous illegal ruck clean outs were picked up by referees and sanctioned accordingly, it might improve player behavior and subsequently reduce the number of dangerous illegal ruck clean outs. Therefore, the potential knock-on effect of stricter application of the laws and minimizing the sanctioning error rates of referees should not be ignored (Brown et al., 2018).

The findings of the current study showed that the attacking teams arriving players will engage in an illegal clean out in order to retain possession of the ball more frequently. A typical game situation on attack can be as follows: after the initial collision and placement by the ball carrier, the first attacking arriving player has to clear the first defender away from the ball carrier and then the second attacking arriving player secures the possession along with engaging the additional defenders as they arrive to support the first defender (Kraak and Welman, 2014). A possible reason for the high error rate by the attacking team could be because of: (a) the ball carrier is not dominating the collision and is not presenting the ball in an effective position (Hendricks et al., 2018), therefore, the arriving player must use an illegal technique to try and retain possession, (b) the attacking teams arriving players reaction time is poor from the prior activity, and thus, arrive late at the collision, (c) poor decision-making and assessment of the situation, (d) poor ruck cleaning techniques used in the latter period of the match due to fatigue (Burger et al., 2018), and (e) the defending team might be infringing already because the attacking team has no other option but to use illegal techniques in order to retain possession. Based on studies by Wheeler et al. (2010) and Kraak and Welman (2014), it is obvious that players have to execute specific actions and techniques to retain (attacking team) or regain (defending team) possession of the ball at the ruck.

The current study further identified a need for coaches and trainers to equip themselves with information pertaining to safe and effective techniques. The coaches and trainers should emphasize the importance of safe and effective techniques during training and matches and one of the few possible modes to reduce injuries, especially non-fatal catastrophic injuries toward the head, neck, brain, and spine (Posthumus and Viljoen, 2008; Brukner and Khan, 2012). The ruck is a dynamic situation, and therefore, coaches should not coach the ruck clean out in isolation because this limits the decision-making ability of the players. Ruck drills should include the initial tackle, fight for dominance by the ball carrier, placement of the ball, and clearing techniques in the same drill because this will assist players with adjustment and decision-making based on the situation. For example, after demonstrating the techniques to carry the ball effective into contact, the ball carrier should also be expected to fall sideward (away from the defending team cleaners), and present the ball (Hendricks et al., 2018), which is followed by the arriving player(s) who clean out the ruck based on the situation. These safe and effective techniques should be incorporated and emphasized during training in order to prepare players for matches. Coaches should also invite referees to training to officiate contact training sessions/drills according to the laws of the game, which will provide clarity to both players and coaches with input from the referees.

It, therefore, seems clear that referees, coaches and players play an integral part in cleaning up the ruck area and so additional strategies aimed at these role players might be beneficial to further reduce the risk of injury at this phase of play. This perspective is also consistent with the BokSmart's adopted goal of "Vision Zero" which try to eliminate all serious injuries from the game (Brown et al., 2017).

Practical Application

The findings of this study provide referees with an understanding of the importance of the decision-making process during match-play, especially at the rucks area. On-field referees should be firmer when it comes to discipline at the rucks because illegal dangerous ruck clean outs could result in serious injuries for players. Rugby stakeholders should also consider using two referees during a game as is currently being used by Rugby League and residence rugby union at Stellenbosch University, South Africa. The study further provides players, coaches, and rugby stakeholders with data that suggests that the ruck area needs to be more seriously recognized when it comes to injury prevention. Player behavior plays a large role regarding discipline and executing of safe and effective cleanout technique at the ruck. They must recognize their mistakes and illegalities and take responsibility for their actions. The ability of a player to engage and tolerate frequent contact events such as the ruck, whether as a ball-carrier, tackler, or attacking or defending cleaner influences the performance of the team and exposes the players to a high risk of injury. Furthermore, these safe techniques need to be added to coaching manuals for the ruck cleanout. Additional interventions need to be targeted at referees to improve identification according to the WR *Laws of the Game* and appropriate sanctioning of illegal ruck clean outs whether dangerous or not.

CONCLUSION

This study of referee sanctioning in the 2018 Super Rugby competition found that 91% of the ruck clean outs were legal and 9% illegal according to the 2018 WR *Laws of the Game*. Of the illegal ruck clean outs 93% (n = 1953) were not sanctioned by the referees of which 57% (n = 1087) were deemed dangerous. The attacking team were not sanctioned 92% (n = 1804) for illegal ruck clean outs. The first cleaner for both the attacking 68% (n = 1224) and defending 73% (n = 109) teams contributed to the majority of the illegal ruck clean outs that were not sanctioned by the referees. The majority of dangerous illegal ruck clean outs not sanctioned by the referees were "*shoulder charge*" (88%, n = 280), "*neck roll*" (86%, n = 100), and "*contact above the shoulder*" (81%, n = 201). Similar to the study by Brown et al. (2018), the current study was not designed to identify factors associated with non-sanctioning behaviors of on-field referees during match-play. The fact that on-field referees error rates did not change as the match progressed, suggests that the primary cause could not be associated with fatigue. What should be highlighted is that there was an increase in dangerous illegal ruck clean outs not sanctioned in the second half, quarter 2 and 4 of the match. However, to aid injury prevention efforts, future studies should explore why referees are not sanctioning all illegal ruck clean outs as per the WR *Laws of the Game*. Additional interventions like referee decision-making and specific fitness interventions need to be targeted at referees to improve this shortcoming. The results from this study highlight many areas for potential research. Future studies should investigate the non-sanctioning of illegal ruck clean outs in other elite competitions, as well as at the amateur level and should also include factors like zonal locations, score line, log position, and nationality of teams. Furthermore, studies should also focus on the behavioral aspects regarding the player's discipline toward technique used for cleaning out at the ruck and education of coaches.

AUTHOR CONTRIBUTIONS

WK was the leader author, responsible for data collection, and conceptualized the research idea with JB, SK, SH, and UJ. JB, SK, SH, and UJ were responsible for exporting the raw data from the Nacsport Basic+ software into Excel and conducted the literature search for the study. KS provided expert advice on the injury prevention and safety section of the article. All the authors were responsible for drafting and approval of the final manuscript.

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REFERENCES

Brown, J., Boucher, S., Lambert, M., Viljoen, W., Readhead, C., and Kraak, W. (2018). Non-sanctioning of illegal tackles in South African youth community rugby. *J. Sci. Med. Sport* 21, 631–634. doi: 10.1016/j.jsams.2017.10.016

Brown, J., Viljoen, W., Readhead, C., Baerecke, G., Lambert, M., and Finch, C. (2017). "Vision Zero": is it achievable for rugby-related catastrophic injuries in South Africa? *Br. J. Sports Med.* 51, 1106–1107. doi: 10.1136/bjsports-2016-096861

Brukner, P., and Khan, K. (2012). *Clinical Sports Medicine*, 4th Edn. Sydney: McGraw Hill Australia.

Burger, N., Lambert, M., Hall, H., and Hendricks, S. (2018). Assessing tackle performance using a novel collision sport simulator in comparison to a "live" one-on-one tackling drill. *J. Sports Sci.* 37, 74–81. doi: 10.1080/02640414.2018.1482590

Eaves, S., Lamb, K., and Hughes, M. (2008). The impact of rule and playing season changes on time variables in professional rugby league in the United Kingdom. *Int. J. Perform. Anal. Sport* 8, 45–54. doi: 10.1080/24748668.2008.11868434

Emmonds, S., O'Hara, J., Till, K., Jones, B., Brightmore, A., and Cooke, C. (2015). Physiological and movement demands of rugby league referees: influence on penalty accuracy. *J. Strength Cond. Res.* 29, 3367–3374. doi: 10.1519/JSC.0000000000001002

Fuller, C., Ashton, T., Brooks, J., Cancea, R., Hall, J., and Kemp, S. (2010). Injury risks associated with tackling in rugby union. *Br. J. Sports Med.* 44, 159–167. doi: 10.1136/bjsm.2008.050864

Fuller, C., Brooks, J., Cancea, R., Hall, J., and Kemp, S. (2007). Contact events in rugby union and their propensity to cause injury. *Br. J. Sports Med.* 41, 862–867. doi: 10.1136/bjsm.2007.037499

Gratton, C., and Jones, I. (2004). *Research Methods for Sport Studies*. London: Routledge.

Hancock, D. J., and Ste-Marie, D. M. (2013). Gaze behaviour and decision making accuracy of higher and lower ice hockey referees. *Psychol. Sport Exercise* 14, 66–71. doi: 10.1016/j.psychsport.2012.08.002

Hendricks, S., Van Niekerk, S., Wade Sin, W., Lambert, M., Den Hollander, S., James Brown, J., et al. (2018). Technical determinants of tackle and ruck performance in International rugby union. *J. Sports Sci.* 36, 522–528. doi: 10.1080/02640414.2017.1322216

Hughes, M., and Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *J. Sports Sci.* 20, 739–754. doi: 10.1080/026404102320675602

Kraak, W., Malan, D., and Van den Berg, P. (2011). Analysis of movement patterns and work-to-rest ratios for different panels of South African Rugby Union referees during match refereeing. *Int. J. Perform. Anal. Sport* 11, 344–355. doi: 10.1080/24748668.2011.11868554

Kraak, W., Venter, R., and Coetzee, F. (2016). Scoring and general match profile of Super Rugby between 2008 and 2013. *Int. J. Perform. Anal. Sport* 16, 786–805. doi: 10.1080/24748668.2016.11868923

Kraak, W., Venter, R., and Coetzee, F. (2017). Analysis of the general match profile of International rugby union between 2007 and 2013. *Int. J. Perform. Anal. Sport* 17, 303–318. doi: 10.1080/24748668.2017.1336689

Kraak, W., and Welman, K. (2014). Ruck-play as performance indicator during the 2010 Six Nations Championship. *Int. J. Sports Sci. Coach.* 9, 525–538. doi: 10.1260/1747-9541.9.3.525

Mascarenhas, D. R., Collins, D., Mortimer, P., and Morris, R. L. (2005). A naturalistic approach to training accurate and coherent decision making in Rugby Union referees. *Sport Psychol.* 19, 131–147. doi: 10.1123/tsp.19.2.131

Murray, A., Murray, I., and Robson, J. (2014). Rugby Union: faster, higher, stronger: keeping an evolving sport safe. *Br. J. Sports Med.* 48, 73–74. doi: 10.1136/bjsports-2012-091844

O'Donoghue, P. (2010). *Research Methods for Sports Performance Analysis*. Oxford: Routledge.

Ortega, E., Villarejo, D., and Palao, J. M. (2009). Differences in game statistics between winning and losing rugby teams in the Six Nations Tournament. *J. Sports Sci. Med.* 8, 523–527.

Posthumus, M., and Viljoen, W. (2008). BokSmart: safe and effective techniques in rugby union. *S. Afr. J. Sports Med.* 20, 64–68. doi: 10.17159/2078-516X/2008/v20i3a633

Roberts, P., Trewartha, G., England, M., and Stokes, K. (2015). Collapsed scrums and collision tackles: what is the injury risk? *Br. J. Sports Med.* 49, 536–540. doi: 10.1136/bjsports-2013-092988

Rugby Football Union (2018). *England Professional Rugby Injury Surveillance Project*. Available at: https://www.englandrugby.com/mm/Document/General/General/01/32/91/95/InjurySurveillanceReport2016-17_English.pdf (accessed November 15, 2018).

Souchon, N., Cabagno, G., Traclet, A., Dosseville, F., Livingstone, A., Jones, M., et al. (2010). Referees' decision-making and player gender: the moderating role of the type of situation. *J. Appl. Sport Psychol.* 22, 1–16. doi: 10.1080/10413200903250476

Spitz, J., Put, K., Wagemans, J., Williams, M., and Helsen, W. (2016). Visual search behaviors of association football referees during assessment of foul play situations. *Cogn. Res. Princ. Implic.* 1:12. doi: 10.1186/s41235-016-0013-8

Van Mechelen, W., and Hlobil, H. (1992). Incidence, severity, aetiology and prevention of sports injuries. *J. Sports Med.* 14, 82–99. doi: 10.2165/00007256-199214020-00002

Viljoen, W., and Patricios, J. (2012). BokSmart - implementing a national rugby safety programme. *Br. J. Sports Med.* 42, 692–693. doi: 10.1136/bjsports-2012-091278

Wheeler, K. W., Askew, C. D., and Sayers, M. G. (2010). Effective attacking strategies in rugby union. *Eur. J. Sport Sci.* 10, 237–242. doi: 10.1080/17461391.2010.482595

Wheeler, K. W., Mills, D., Lyons, K., and Harrinton, W. (2013). Effective defensive strategies at the ruck contest in rugby union. *Int. J. Sport Sci. Coach.* 8, 237–242. doi: 10.1260/1747-9541.8.3.481

Williams, S., Trewartha, G., Kemp, S., and Stokes, K. (2013). A meta-analysis of injuries in senior men's professional Rugby Union. *Sports Med.* 43, 1043–1055. doi: 10.1007/s40279-013-0078-1

World Rugby (2018). *Laws of the Game*. Available at: http://laws.worldrugby.org/?law=10. (accessed July 15, 2018).

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Influence of Anthropometry, Age, Sex, and Activity Level on the Hand Reach Star Excursion Balance Test

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The influence of anthropometric measurements, age, sex, and activity level have been found to influence tests of dynamic postural control such as the star excursion balance test (SEBT). The hand reach star excursion balance test (HSEBT) measures different aspects of dynamic postural control. The purpose of the present study was to explore the influence of these factors on the HSEBT. A convenience sample of 223 subjects performed four horizontal (L45, R45, L135, and R135) and two rotational (LROT and RROT) reaches. The influence of anthropometric measurements (height, arm length, leg length, and wingspan) on reach measurements were assessed using stepwise multiple linear regression. Influence of age (young: <20 years; adult: >20 years), sex (male; female) and activity level (athletes; recreational) on reach measurements were analyzed using independent samples *t*-test ($p < 0.05$) and interpreted using effect size (Cohens *d*) and established values of minimal detectable change (MDC). Wingspan explained a significant portion of the variance of only R45 (34.6%) and L45 (11.7%) reach measurements and normalized (percentage of wingspan). A medium effect of age, sex, and activity level was observed for normalized L45 and R45 reaches ($d = 0.50$–72). Group differences greater than MDC values and a medium effect for age ($d = 0.55$) and activity level ($d = 0.75$) were observed for the R135 reach. L45 and R45 reaches should be normalized to wingspan, but not the other reaches. Between individual or group comparisons should consider age, activity level and sex as potential covariates.

Keywords: mobility, postural control, testing, instrument development, normalization

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INTRODUCTION

The hand reach star excursion balance test (HSEBT) has proven to be a valid and reliable measurement tool for dynamic postural control (Eriksrud et al., 2017). The hand reaches performed on each foot capture different aspects of dynamic postural control as compared to the well-established star excursion balance test (SEBT) (Eriksrud et al., 2018). Furthermore, it measures functional mobility, i.e., the combined utilization of the ranges of motion (ROMs) of multiple joints for the accomplishment of activities of daily living and athletic performance in an ecological manner. In comparison to the SEBT the HSEBT elicits greater lower extremity and trunk movements with additional hip (extension) and upper extremity joint movements. Specifically, when compared to conventional ROM data, 8 of 22 joint movements were within these normative ranges (Eriksrud et al., 2018).

Currently, other hand reach tests such as the functional reach test (FR) (Duncan et al., 1990), standing lateral reach (Brauer et al., 1999), multidirectional reach test (Newton, 2001), and upper quarter Y balance test (Gorman et al., 2012a) are used to assess mobility and dynamic postural control. However, these tests are reaches in the horizontal plane that elicit small trunk and lower extremity joint movements (Duncan et al., 1990; Brauer et al., 1999; Newton, 2001), or are performed in positions non-specific to standing (i.e., planked position) (Gorman et al., 2012a). Since many actions in sports and activities of daily living are based on hand interactions with the environment (e.g., pushing, pulling, reaching, throwing) the HSEBT represents an alternative assessment offering better specificity in relation to such tasks (Eriksrud et al., 2018).

Patients with low back pain (LBP) have an altered lumbopelvofemoral rhythm (Laird et al., 2014) commonly assessed in standing flexion movements. However, lower extremity position, width and angulation, influence this rhythm with implications on postural stability (Zhou et al., 2016). Changes in stance not only influence base of support (BOS) but also lower extremity joint movements associated with the flexion task. The HSEBT can assess the lumbopelvofemoral rhythm not only in different flexion movements, but also in extension, lateral flexion and rotational movement patterns in a standardized manner. It may provide a better measurement tool to document such a rhythm, for example, in patients with LBP.

The HSEBT also appears to be a good addition to the assessment tools used for the evaluation of risk of falling, considering that falling often occurs while reaching, leaning (Nachreiner et al., 2007) or bending (Duckham et al., 2013). The functional reach test (FR), a single item hand reach test, has been reported to predict risk of falling (Scott et al., 2007). However, falls occur in multiple directions and it might be important to assess different directions to gain information about more multifaceted boundary conditions. In fact, Newton established that horizontal reaches in the anterior-posterior and medial-lateral direction quantify different limits of stability (Newton, 2001). The HSEBT therefore represents a promising addition to the assessment tools in fall risk management considering the high similarity of some of its tests with the movements already established as risk factors (Nachreiner et al., 2007; Duckham et al., 2013).

Shoulder dysfunction and injuries are common in throwing sports (Clarsen et al., 2014). Energy contribution and transfer through the kinetic chain to the shoulder have been described (Roach and Lieberman, 2014). For example, an increased leg drive in the tennis serve has been found to be associated with smaller shoulder and elbow torques while achieving the same serve speeds (Elliott et al., 2003), thus, potentially decreasing shoulder and elbow injury risks. Furthermore, restricting mobility of the torso by bracing resulted in a significant reduction in joint power generation throughout the kinetic chain, elastic storage of energy at the shoulder, and throwing velocity (Roach and Lieberman, 2014). Considering the importance of the full kinetic chain to shoulder function, the HSEBT may be a good alternative measure for shoulder function and dysfunction.

In the comparable SEBT, outcomes are known to be influenced by anthropometry, age, activity level, and sex. Specifically, leg length was the anthropometric measurement found to explain the largest portion of the variance in the SEBT reaches (range R^2:0.02–0.23). Consequently, SEBT measurements has since mostly been normalized to leg length (Gribble and Hertel, 2003; Gribble et al., 2012), while others have normalized to height (Glave et al., 2016). Physical activities influence SEBT measures, specifically, differences between sports have been observed (Bressel et al., 2007) with equivocal findings between athletes and recreational active individuals (Thorpe and Ebersole, 2008; Sabin et al., 2010; Ambegaonkar et al., 2013). The SEBT measures are also affected by sex, however there is a controversy with respect to the direction of the relationship. Sex has been found to have an equivocal effect on SEBT reach measures with no effect (Gribble and Hertel, 2003), greater reach measures in males than females (Gorman et al., 2012b; Holden et al., 2016), and vice versa (Gribble et al., 2009; Holden et al., 2016). In adolescents and young adults, the SEBT reaches were found to increase with age (Holden et al., 2016; Gonzalo-Skok et al., 2017; McCann et al., 2017).

Therefore, the purpose of the current study was to determine the influence of anthropometric measurements, age, sex, and activity level on HSEBT reaches and to provide reference values for future comparisons.

METHODS

Participants

A convenience sample of 223 subjects participated in the study. Recreational active ($n = 57$) and handball players ($n = 12$) were recruited. We defined recreationally active as individuals that regularly participated in physical activity for at least 30 min four times a week. Furthermore, 154 athletes competing at the Youth Olympic Games (YOG) were recruited.

Testers and Environment

Participation was voluntary and subjects were tested in different environments. The recreational active and the throwing athletes gave written informed consent prior to being tested by two experienced testers in the biomechanics laboratory of the university. The YOG athletes were evaluated at the Learn & Share area at the YOG Winter Games 2016 by four additional experienced testers (trainers and physical therapists). As a part of this experience the athletes had the opportunity to compare their HSEBT reach measurements to anonymous data from World and Olympic champions in their respective sport. The following anonymous data were obtained and stored electronically: number as an identifier without any key, anthropometry (height, leg length, wing span, and arm length), sex, sport, and year of birth. Information about the study was shown on a computer screen in English. Based on the recommendation of the International Olympic Committee this information was also available in writing in the following languages: Norwegian, Chinese, English, French, Japanese, German, Korean and Russian. Then informed consent was obtained by checking a box on the computer screen. These procedures were discussed and formulated with lawyers from the Norwegian Sports Federation, and the study was approved and authorized by the Norwegian Data Protection agency and the Regional Committees for Medical and Health Research Ethics. The study was conducted according to the Declaration of Helsinki.

Anthropometric Measurements

Height was obtained using a Seca model 217 stadiometer (Seca GmbH. & Co. Hamburg. Germany). Leg length was measured from the greater trochanter to the floor of one leg, arm length was measured from acromion to middle digit with shoulder abducted to 90° of one arm, and wingspan from middle digit to middle digit with both shoulders abducted to 90°. These measures were done with a standard tape measure [centimeter (cm)].

Testing Procedures

Subjects were tested on a subset (six) of the ten hand reaches that make up the HSEBT (Eriksrud et al., 2017, 2018). For clarity, HSEBT testing procedures are summarized here. The HSEBT reaches are defined from the anatomical position where the anterior (A0) and posterior (P180) reaches divide the body into left (L) and right (R) halves. Each half is then divided into reaches at 45-degree increments (R45, R90, R135, L135, L90, and R45). Of these eight reaches the R45, R135, L135, and L45 were tested on each foot. All of these are unilateral hand reaches and the hand selected to perform the reach was based on crossing midline (line connecting the A0 and P180 reach direction) with the opposite hand placed on the hip. Reach measurements were obtained on a mat with imprinted reaching directions with marks at two cm intervals and nine concentric circles at 10 cm intervals with the outer circle (90 cm radius) marked at 10-degree intervals (Athletic Knowledge Nordic AB, Stockholm, Sweden). The foot tested (stance foot) was placed in the center of the mat while the other foot (support foot) was placed (toe touch) at a 135-degree angle relative to the reaching direction between the 20 and 30 cm concentric circle. Maximum reach measurements from the center of the testing mat to the most distal point of the middle digit was then obtained. Specifically, position of the middle digit on the testing mat (light touch and no support) (R45 and L45), and from a plumb line projecting the position of the middle digit to the testing mat (R135 and L135) were obtained. Based on sagittal plane hip joint movements at maximum reach position, the R45 and L45 are considered flexion while the R135 and the L135 are considered extension movements. In addition, both left and right rotational reaches (LROT and RROT) were measured. For the rotational reaches the stance foot is placed in the middle of the testing mat with the support foot positioned parallel between the 20 and 30 cm concentric circle and allowed to rotate in the direction of the reach. Rotational reaches are bilateral hand reaches with the middle digits on top of each other. Maximum reach position was projected onto the concentric circles and quantified as the difference from A0 (0 degrees). Pictures of maximum reach positions standing on the right foot is presented in **Figure 1**. For all reaches, subjects were instructed to reach or rotate as far as possible at their own rate and then return to the starting position while maintaining balance. A minimum of three practice trials were given for each test to ensure that the test was understood, after which the maximum reach of three valid test trials were recorded for analysis.

Statistical Analysis

Descriptive statistics [mean and standard deviation (SD)] of participant characteristics (anthropometric measurements and age) and reach measurements (R45, R135, L135, R135, LROT, and RROT) shown in **Figure 1** were calculated using Excel for Mac OS 10.10.5 (Apple Inc., Cupertino, CA, USA), version 14.4.8 (Microsoft Corp., Redmond, WA, USA). Mirrored reach test measurements on the left and right foot were compared using paired samples *t*-test. Side differences were interpreted based on effect size (Cohen's *d*) as follows: trivial<0.2; small 0.2–0.5; medium 0.5–0.8; large >0.8 (Cohen, 1988), and minimal detectable change (MDC) from test-retest reliability (Eriksrud et al., 2017).

The influence of anthropometric measures (height, wingspan, arm length, leg length, and trunk), age, sex, and activity level (athletes; recreational) on HSEBT measurements was determined using multiple regression analysis (IBM SPSS, v 21.0, IBM, Armonk, NY, USA). Measurements for the same tests on the left and right foot (e.g., left foot R45 reach and right foot L45 reach) were averaged. Linearity was assessed by visual inspection of scatter plots of studentized residuals and predicted values. Multicollinearity was assessed using variable inflation factor (VIF) with a cutoff of >10. Independences of residuals were analyzed using Durbin-Watson statistics with cutoff values <1 and >3. Homoscedasticity was assessed by visual inspection of the scatter plots of the standardized predicted values of the model and the standardized residuals. Normality of residuals was determined by visual inspection the histograms of standardized residuals and probability-probability plots. Casewise diagnostics were set to three standard deviations to determine if 1% or less of the subjects had standardized residuals outside this distribution. Specifically, a random sample, 75% of participants, were used to generate the initial model using forward stepwise regression based on a statistical significance (*t*-test). The model was then validated on the remaining 25% of the participants using forced entry. The validation model was then compared to the initial model based on change of R^2 values, and independent variables that significantly contributed ($p < 0.05$) to the model were retained. Pearson correlation coefficients of the retained variables to their respective HSEBT reaches were then calculated. The criterion for normalization of HSEBT reaches to anthropometric measures was based on significant correlation coefficients and R^2 values or changes greater than the coefficient of variation (CV) of the respective reach (Eriksrud et al., 2017).

Independent samples *t*-tests were then used to explore significant differences between age groups (young:<20 years; adult: >20 years), sex (M; F) and activity level (recreational; athletes). Homogeneity of variance was assessed using Levene's test and normal distribution was assessed using Shapiro Wilks's test. In the presence a significant Shapiro Wilk's the test z-scores of both skewness and kurtosis were calculated to explore the necessity for data transformation. Effect size was calculated using Cohen's *d* and interpreted as described above (Cohen, 1988).

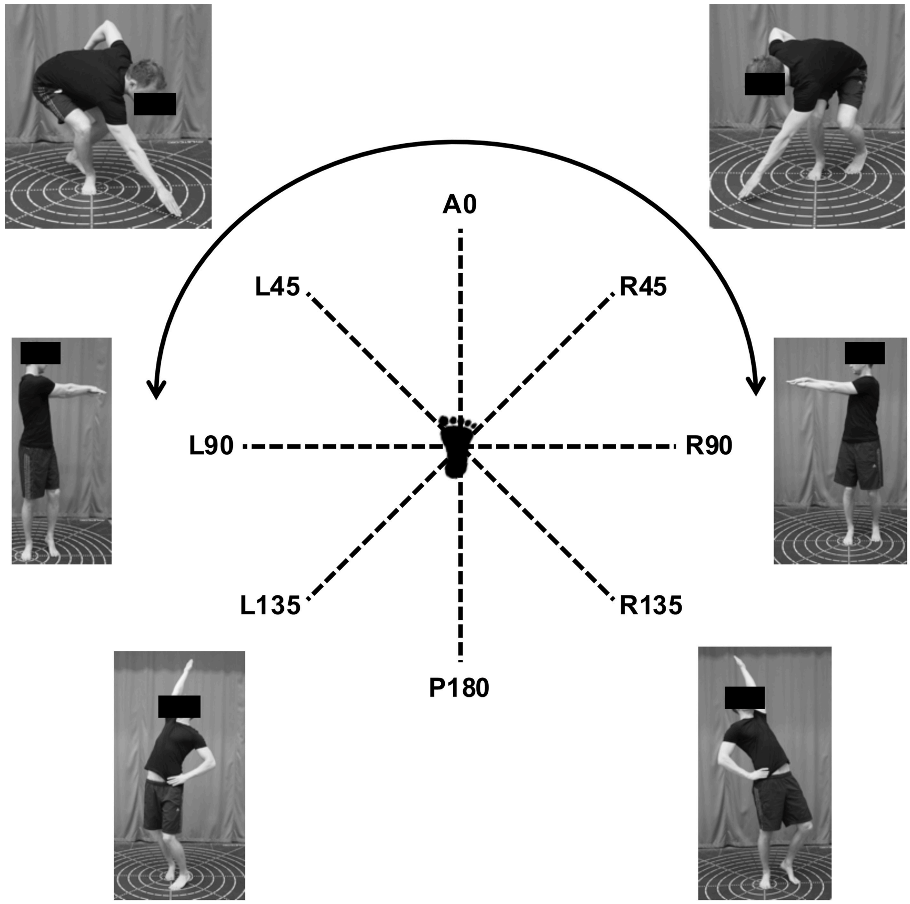

FIGURE 1 | Maximum reach position of HSEBT reaches standing on the right foot.

Outliers were removed based the criteria described by Hoaglin and Iglewics (Hoaglin and Iglewicz, 1987).

RESULTS

Mean values of all variables measured, of both athletic (sorted by sport) and recreational populations, are provided in **Table 1**. **Table 2** presents mean values for age, anthropometric measures and HSEBT reach measurements organized by groups (sex, age, and activity level). In addition, significance of group differences, effect sizes and established MDC values are presented (**Table 2**). The male group was older than the female group ($d = 0.83$) with greater anthropometric measures (range $d = 0.94–1.51$). The adult group also had greater anthropometric measures than the young group (range $d = 0.56–1.17$). Recreational active were older than athletes ($d = 2.00$) with greater anthropometric measures (range $d = 0.64–1.26$). Females, young participants and athletes demonstrated significantly greater normalized L45 and R45 reach measurements ($p \leq 0.001$) with medium effect sizes. Trivial effects were observed for the non-normalized comparisons for these reaches with one exception: males had greater R45 reach measurements than females (small effect) with a group difference greater than MDC values. Small to medium effects for sex, activity level and age were observed for the R135 reach. Specifically, the athletic group had reach measurements greater than MDC values, while the observed difference between the young and the adult group (7.6 cm) is within the range of MDC values. The athlete group had significantly greater L135 reach measurements than the recreational group (small effect). The observed group difference (4.1 cm) is within the range of MDC values. Trivial to small effects were observed for age, sex and activity level on rotational reach measurements (**Table 2**).

Regression Analysis

Multicollinearity (VIF ranged from 1.000-4.152) was not observed. Homogeneity of variance was observed, with residuals being independent (Durbin-Watson ranged from 1.699-2.397). Wingspan explained 34.6 and 11.7% of the variance in the R45 and L45 reach measurements, respectively. Leg length explained 2.7% of the L135 reach (**Table 3**). No anthropometric variable could explain a significant portion of the variance in the R135, LROT, and RROT reaches. Based on the aforementioned criteria, only the L45 and R45 measurements were normalized to

TABLE 1 | Age, anthropometry, and HSEBT results (absolute and normalized values) of the athletic and recreational populations.

	Athletes													Recreational
Measure	**Alpine skiing**	**Bobsleigh**	**CC and biathlon**	**Curling**	**Figure skating**	**Freestyle skiing**	**Icehockey**	**Luge**	**Skeleton**	**Snowboarding**	**Ski jumping**	**Ice skating**	**Throwing**	
Participants	28	9	4	6	14	13	36	17	8	16	1	2	12	57
Age (yrs)	17.5 ± 0.5	17.3 ± 0.5	17 ± 0	17 ± 0	16.6 ± 0.5	17.3 ± 0.6	16.6 ± 0.5	17.0 ± 0.5	17.1 ± 0.4	17.3 ± 0.6	17.0 ± 0	18.0 ± 0	21.7 ± 1.7	24.6 ± 4.9
Height (cm)	170.9 ± 4.8	170.1 ± 8.7	177.5 ± 5.4	169.8 ± 12.8	164.3 ± 7.6	170.6 ± 8.8	170.9 ± 7.9	174.6 ± 7.7	168.8 ± 5.5	167.9 ± 8.1	162.0	180.5 ± 10.6	174.8 ± 6.5	180.3 ± 7.8
Leg length (cm)	87.7 ± 3.3	87.8 ± 2.9	90.0 ± 2.7	88.3 ± 6.0	83.4 ± 5.5	88.8 ± 5.5	88.7 ± 5.8	89.5 ± 4.4	87.4 ± 3.4	85.1 ± 3.2	85.0	89.0 ± 4.2	89.7 ± 5.4	91.3 ± 5.0
Wingspan (cm)	174.8 ± 5.7	174.6 ± 12.1	178.8 ± 5.6	170.8 ± 16.2	166.6 ± 10.8	172.7 ± 9.4	172.1 ± 10.6	176.8 ± 7.7	170.5 ± 7.0	171.7 ± 9.6	167.0	186.5 ± 13.4	173.9 ± 8.6	180.2 ± 8.1
Arm length (cm)	73.5 ± 3.2	72.9 ± 5.0	73.8 ± 2.2	71.0 ± 6.8	68.9 ± 4.2	71.8 ± 3.8	72.4 ± 4.8	75.1 ± 4.7	71.3 ± 3.2	71.7 ± 40	71.0	77.5 ± 6.4	72.4 ± 4.3	75.0 ± 3.4
L SLS R45 (cm)	80.3 ± 5.6	78.0 ± 6.0	87.0 ± 2.4	76.0 ± 9.2	79.6 ± 6.2	77.4 ± 5.3	77.9 ± 6.4	80.1 ± 7.8	75.9 ± 5.3	78.8 ± 6.2	81.0	90.0 ± 2.8	79.3 ± 5.3	79.1 ± 6.8
L SLS R45 (%)	45.9 ± 2.9	44.7 ± 2.4	48.7 ± 2.6	44.4 ± 2.7	47.8 ± 2.3	44.8 ± 2.5	45.3 ± 3.0	45.3 ± 3.6	44.5 ± 3.1	45.9 ± 3.8	48.5	48.3 ± 2.0	45.7 ± 2.9	43.9 ± 3.1
L SLS L45 (cm)	71.0 ± 6.0	65.7 ± 6.5	75.0 ± 1.6	65.5 ± 9.3	67.1 ± 5.3	64.1 ± 6.2	69.1 ± 6.7	69.2 ± 7.6	68.5 ± 7.2	67.4 ± 8.5	78.0	77.0 ± 4.2	68.0 ± 5.7	67.0 ± 9.6
L SLS L45 (%)	40.6 ± 3.2	37.7 ± 3.4	42.0 ± 1.5	38.4 ± 5.4	40.4 ± 3.6	37.2 ± 3.6	40.2 ± 3.1	39.2 ± 3.9	40.1 ± 3.0	39.4 ± 5.4	46.7	41.5 ± 5.3	39.2 ± 3.6	37.1 ± 4.7
L SLS L135 (cm)	87.4 ± 9.7	87.4 ± 7.0	91.3 ± 9.4	75.2 ± 12.1	92.2 ± 6.5	79.5 ± 13.5	88.1 ± 8.9	91.1 ± 10.0	90.1 ± 4.4	86.2 ± 7.0	90.0	102 ± 2.8	87.8 ± 5.7	83.5 ± 11.3
L SLS R135 (cm)	65.9 ± 13.2	61.8 ± 13.9	63.3 ± 10.9	51.0 ± 12.2	68.8 ± 8.2	59.2 ± 12.0	65.5 ± 11.9	67.7 ± 9.8	63.3 ± 10.1	60.8 ± 12.7	66.0	72.0 ± 14.1	63.3 ± 11.0	55.0 ± 15.0
L SLS LROT (°)	133.3 ± 14.9	126.2 ± 16.2	135.0 ± 12.3	107.8 ± 25.7	127.6 ± 10.7	127.3 ± 16.5	131.9 ± 18.9	138.4 ± 12.6	131.4 ± 13.3	132.8 ± 17.6	150.0	122.0 ± 18.4	118.3 ± 11.6	128.2 ± 17.3
L SLS RROT (°)	136.5 ± 10.4	138.9 ± 13.4	138.8 ± 13.4	123.3 ± 11.0	131.0 ± 11.7	131.1 ± 12.9	135.2 ± 13.9	135.2 ± 14.7	131.8 ± 15.7	139.8 ± 10.1	128.0	143.0 ± 18.4	123.9 ± 9.1	132.1 ± 14.6
R SLS L45 (cm)	81.8 ± 4.9	79.8 ± 4.9	85.8 ± 1.5	77.5 ± 6.8	78.5 ± 6.0	78.6 ± 5.9	78.6 ± 6.3	81.3 ± 6.8	75.5 ± 5.7	79.1 ± 6.1	83.0	87.0 ± 4.2	81.3 ± 4.8	79.6 ± 7.4
R SLS L45 (%)	46.8 ± 2.6	45.8 ± 2.5	48.0 ± 2.1	45.5 ± 4.2	47.1 ± 2.6	45.5 ± 2.4	45.7 ± 2.8	46.0 ± 2.8	44.3 ± 2.4	46.2 ± 3.5	49.7	46.7 ± 1.1	46.8 ± 3.2	44.2 ± 3.3
R SLS R45 (cm)	71.1 ± 6.1	66.2 ± 5.9	72.5 ± 1.3	63.510.0	67.5 ± 5.9	63.4 ± 7.0	68.2 ± 6.6	70.3 ± 7.1	67.0 ± 5.8	67.0 ± 8.4	73.0	79.5 ± 2.1	68.6 ± 6.4	65.6 ± 9.3
R SLS R45 (%)	40.7 ± 3.4	38.0 ± 2.7	40.6 ± 0.72	37.2 ± 5.4	38.0 ± 11.3	36.8 ± 4.4	39.6 ± 3.2	39.8 ± 3.7	39.3 ± 2.3	39.1 ± 5.1	43.7	42.8 ± 4.2	39.5 ± 4.3	36.4 ± 4.7
R SLS R135 (cm)	86.5 ± 9.4	85.2 ± 12.9	91.0 ± 8.5	75.3 ± 9.2	92.8 ± 6.5	81.2 ± 12.4	84.7 ± 8.4	90.2 ± 8.3	89.1 ± 6.0	83.5 ± 7.1	83.0	104.0 ± 0.0	87.3 ± 5.9	80.8 ± 12.5
R SLS L135 (cm)	69.3 ± 12.8	66.2 ± 17.1	65.3 ± 10.4	49.7 ± 11.2	68.9 ± 8.8	60.9 ± 12.0	66.8 ± 10.3	68.6 ± 10.3	69.6 ± 10.3	60.4 ± 12.9	59.0	67.5 ± 17.7	62.5 ± 11.7	65.6 ± 9.3
R SLS RROT (°)	132.5 ± 17.8	127.4 ± 16.0	129.0 ± 22.8	107.0 ± 20.1	126.1 ± 10.1	123.9 ± 16.3	132.6 ± 15.3	136.8 ± 13.7	126.4 ± 18.9	130.4 ± 11.4	135.0	125.0 ± 14.1	115.92 ± 11.5	126.5 ± 17.4
R SLS LROT (°)	136.6 ± 12.2	135.9 ± 20.4	146.8 ± 18.1	124.0 ± 14.3	131.7 ± 8.5	132.0 ± 15.1	134.9 ± 14.4	136.5 ± 9.8	137.6 ± 14.6	138.1 ± 16.7	130.0	128.5 ± 5.0	124.2 ± 7.8	132.1 ± 14.6

Values are means ± standard deviations; CC, Cross country skiing; R, Right; L, Left; 45, 45 degree relative to anterior surface of body; 135, 135 degrees relative to anterior surface of body: ROT, Rotation; %, normalized HSEBT values (reach measurement/wingspan·100).

TABLE 2 | Age, anthropometry, and HSEBT results (absolute and normalized values) grouped by gender, age, and activity level with group comparisons.

	Male	Female	*d*	*p*	Young	Adult	*d*	*p*	Athletes	Recreational	*d*	*p*	MDC
n	133	90			159	64			166	57			
Age (yrs)	20.2 ± 4.3	17.6 ± 1.8	0.83	<0.001	17.1 ± 0.6	24.3 ± 3.4	12.5	<0.001	17.4 ± 1.4	24.1 ± 3.9	2.00	<0.001	
Height (cm)	177.5 ± 7.1	167.1 ± 6.7	1.51	<0.001	170.6 ± 8.0	179.6 ± 7.0	1.17	<0.001	170.7 ± 7.9	180.4 ± 6.8	1.26	<0.001	
Leg length (cm)	90.3 ± 4.6	86.1 ± 4.5	0.94	<0.001	87.5 ± 4.6	91.2 ± 5.0	0.78	<0.001	87.7 ± 4.7	91.3 ± 4.4	0.79	<0.001	
Wingspan (cm)	179.4 ± 8.2	168.5 ± 7.9	1.35	<0.001	173.0 ± 9.6	179.4 ± 8.5	0.68	<0.001	173.0 ± 9.6	180.2 ± 8.1	0.77	<0.001	
Arm length (cm)	75.0 ± 3.3	70.3 ± 3.6	1.38	<0.001	72.4 ± 4.3	74.7 ± 3.7	0.56	<0.001	72.4 ± 4.3	75.0 ± 3.4	0.64	<0.001	
R45 (cm)	80.1 ± 6.4	78.4 ± 5.8	0.28	0.043	79.3 ± 6.0	79.4 ± 6.3	0.01	0.942	79.4 ± 5.9	79.4 ± 6.9	0.01	0.928	1.5–2.1
R45 NORM (%)	44.7 ± 2.9	46.5 ± 2.8	0.64	<0.001	45.9 ± 2.8	44.4 ± 3.2	0.50	0.001	45.9 ± 2.8	44.0 ± 3.1	0.66	<0.001	NE
L45 (cm)	68.1 ± 7.6	68.4 ± 6.0	0.04	0.760	68.3 ± 6.8	67.7 ± 7.8	0.08	0.583	68.4 ± 6.7	67.5 ± 7.8	0.13	0.396	2.4–2.8
L45 NORM (%)	38.0 ± 3.9	40.6 ± 3.1	0.72	<0.001	39.6 ± 3.5	37.7 ± 4.0	0.50	0.001	39.7 ± 3.5	37.2 ± 3.9	0.67	<0.001	NE
L135 (cm)	85.6 ± 9.6	87.3 ± 7.8	0.19	0.181	87.0 ± 8.7	84.9 ± 8.7	0.24	0.110	87.5 ± 8.2	83.4 ± 9.6	0.48	0.003	3.9–4.2
R135 (cm)	60.7 ± 13.3	65.3 ± 9.7	0.41	0.004	64.5 ± 11.6	56.9 ± 14.6	0.55	<0.001	65.0 ± 11.1	54.5 ± 14.9	0.75	<0.001	7.2–7.9
LROT (°)	128.3 ± 16.1	129.8 ± 13.1	0.10	0.462	130.0 ± 13.7	125.5 ± 16.5	0.31	0.038	129.2 ± 14.0	127.3 ± 16.6	0.12	0.426	6.3–7.2
RROT (°)	134.4 ± 13.1	133.1 ± 10.5	0.11	0.431	134.8 ± 11.1	132.6 ± 14.0	0.17	0.211	134.9 ± 11.3	134.7 ± 14.1	0.06	0.679	4.7–5.2

Values are means ± standard deviations; R, Right; L, Left; 45, 45 degree relative to anterior surface of body; 135, 135 degrees relative to anterior surface of body; ROT, Rotation; %, normalized HSEBT values (reach measurement/wingspan·100); MDC, Minimal detectable change; NE, Not established.

wingspan and expressed as a percentage of wingspan. In R45 and L45 reaches, sex and leg length had a non-significant contribution in the validation model (**Table A1**). In addition, activity level and age explained 3.3 and 6.5%% of the L135 and R135 reaches, respectively (**Table 3**).

DISCUSSION

Influence of Anthropometry

Anthropometric measures influence HSEBT reach measurements differently, therefore reach specific normalization should be used. Flexion movement patterns yielded expected results: wingspan explained 11.7 and 34.6% of the variation in reach measurements. In addition, normalizing flexion movement patterns to wingspan resulted in significant differences for all groups (age, sex, and activity level). However, extension movement patterns unexpectedly were not influenced by any of the anthropometric measures. Leg length did explain 2.7% of the variation in the R135 reach measurement. However, this is less than the previously established CV (Eriksrud et al., 2017). In addition, leg length did not significantly correlate with the R135 reach measurement, suggesting normalization to leg length is not needed. As expected, the rotational reaches do not require normalization. The reach specific considerations for HSEBT normalization differ from the normalization procedures proposed by Gribble and co-workers for the SEBT (Gribble and Hertel, 2003). In their study leg length was found to have greater coefficients of determination than height to SEBT reaches (0.02–0.23), with significant correlations in six of eight SEBT reach measurements (Gribble and Hertel, 2003). Although lateral and posterolateral reaches were not significantly correlated with leg length, all SEBT reaches are normalized to this measure and since then widely applied (Gribble et al., 2012). In fact, leg length explained 4% of the variance of the posterolateral reach measurement (Gribble and Hertel, 2003), which is less than the CV for test-retest reliability (4.4%) (Plisky et al., 2006). The normalization of HSEBT measurements to anthropometric variables which explain variation beyond error, as done in the current study, appears to be a more appropriate procedure.

Influence of Age

There appears to be an effect of age on HSEBT reach measurements. Specifically, the young group has greater measurements in three of six reaches. Medium effects of age were observed for the normalized L45 and R45 reaches, as well as for the R135 reach. However, the group difference observed for the R135 reach (7.6 cm) is within the range of MDC values (**Table 2**). In their study Eriksrud and co-workers recommend 7 cm as an MDC for extension movement patterns based on calculations and clinical experience (Eriksrud et al., 2017). It is important to note that the MDC values in this study were calculated based on a 95% confidence interval, which is more conservative and generate greater values than the 90% confidence interval commonly used (Haley and Fragala-Pinkham, 2006). Consequently, we interpreted from our findings that the young participants had greater R135 reach measurements. The combination of significant group differences, effect sizes and comparison to established MDC values (R135) allows for a more robust interpretation of our findings. However, age did not explain a significant portion of the variation of any of the reach measurements in the regression analysis. Thus, it appears that age should be considered cautiously when performing between individual or group comparisons for the normalized L45 and R45 as well as for the R135 reach.

These findings contradict the influence of age on other measures of dynamic postural control such as the SEBT, where reach measurements increase with age (Holden et al., 2016; Gonzalo-Skok et al., 2017; McCann et al., 2017). However, these

TABLE 3 | Stepwise multiple linear regression of HSEBT reaches.

Test	*B*	SE *B*	Β	R^2
R45 STEP 1				
Constant	11.96	7.22		
Wingspan	0.39	0.041	0.59***	0.346
R45 STEP 2				
Constant	−3.93	8.45		
Wingspan	0.47	0.047	0.62***	
Sex	3.07	0.92	0.24***	0.388 (Δ R^2 = 0.042)
R45 STEP 3				
Constant	0.62	8.58		
Wingspan	0.58	0.069	0.89***	
Sex	3.1	0.90	0.24***	
Leg length	−0.279	0.12	−0.22*	0.407 (Δ R^2 = 0.019)
L45 STEP 1				
Constant	22.71	9.69		
Wingspan	0.26	0.055	0.34***	0.117
L45 STEP 2				
Constant	−3.86	11.13		
Wingspan	0.40	0.062	0.53***	
Sex	5.15	1.21	0.35***	0.206 (Δ R^2 = 0.089)
L135 STEP 1				
Constant	87.38	0.83		
Activity level	−3.86	1.67	−0.18*	0.033
L135 STEP 2				
Constant	59.67	12.86		
Activity level	−4.64	1.69	−22**	
Leg length	0.32	0.15	0.17*	0.060 (Δ R^2 = 0.027)
R135				
Constant	64.68	1.08		
Activity level	−7.21	2.17	−0.25**	0.065
RROT				
NE				
LROT				
NE				

*$^{*}p < 0.05$
$^{**}p < 0.01$
$^{***}p < 0.001$
B, Unstandardized coefficient; β, Standardized beta coefficient; SE, Standard error; R^2, Coefficient of determination; NE, No variables entered into the equation; R=Right; L=Left; 45, 45 degree relative to anterior surface of body; 135, 135 degrees relative to anterior surface of body: ROT, Rotation.*

findings are based on young populations. Older basketball players (16 years) had increased SEBT measurements in some directions when compared to younger players (14 years) (Gonzalo-Skok et al., 2017). In a similar age group Holden and co-workers reported that 13-year-olds increased all SEBT reaches tested over a 24-months period (Holden et al., 2016), while McCann and co-authors reported that older (20 years) had greater SEBT reach measures than younger (15 years) football players (McCann et al., 2017). However, only one study reported effect sizes (Gonzalo-Skok et al., 2017), and these studies did not compare group differences to recommended MDC values (5–7cm; 6–8% of leg length) (Munro and Herrington, 2010). Comparisons to these MDC values would change the interpretation of findings in the aforementioned studies. Older basketball players would still have greater SEBT reaches (Gonzalo-Skok et al., 2017) whereas older football players would not (McCann et al., 2017) in comparison to their younger counterparts. In addition, the observed increase in SEBT reaches over a 24-months period would only apply to the posterolateral reach (Holden et al., 2016). In the current study we calculated not only if group differences were significant, but also effect sizes before determining if group differences were greater than MDC values. This is a more robust analysis in comparison to what has been done for the SEBT, and allows us to be more certain about the effect of age on HSEBT reaches.

Influence Activity Level

Athletes have greater HSEBT reach measurements than recreationally active for three of six reaches. These reaches are the same as for the age group comparisons: normalized L45 and R45 reaches as well as the R135 reach. These group comparisons had medium effects, and the group difference for the R135 reach was greater than MDC values. Furthermore, activity level explained 3.3 and 6.5% of the variance of the L135 and R135 reaches. However, these values are less than most of the observed CV's for these reaches (5.2–14.6%) (Eriksrud et al., 2017). In addition, the observed influence of activity level on these HSEBT reaches are influenced by age, since the athlete group was significantly younger than the recreational group (large effect) (**Table 2**). Based on these findings, activity level should be considered when performing between individual or group comparisons for the normalized L45 and R45 as well as the R135 reach.

The influence of activity level on SEBT reaches has been found to be equivocal. Specifically, female modern dancers have better reach performance in some, but not all reach directions, in comparison to active non-dancers (Ambegaonkar et al., 2013). In a study comparing basketball players Sabin and co-authors found that active controls had greater SEBT reach measurements than basketball players (Sabin et al., 2010). Thorpe and co-authors found that female soccer players (NCAA division 1) had greater SEBT reach measurements than their recreationally active counterparts (Thorpe and Ebersole, 2008). In addition, there are SEBT reach differences between athletes participating in different sports. Specifically, soccer players have greater SEBT reaches than basketball players, while there is no difference between gymnasts and soccer players (Bressel et al., 2007). However, these studies neither report effect sizes nor compare to MDC values as advocated by Munro and co-authors (Munro and Herrington, 2010). Comparing group differences to MDC values in the aforementioned studies influence interpretation of findings. Specifically, dancers would not have demonstrated greater SEBT reaches than non-dancers (Ambegaonkar et al., 2013), and basketball players would only have lower SEBT measurements in the anterior direction, and not in the medial and posterior (Sabin et al., 2010). Furthermore, soccer players would still have greater anterior and posterior reaches than their active controls (Thorpe and

Ebersole, 2008). Overall, these findings indicate that there might not only be activity but also sports specific adaptations of dynamic postural as measured by the SEBT. In the current study it was not possible to determine sport specific adaptations due to the small sample sizes of the different sports included (**Table 1**), but the influence of activity level (athletic vs. recreational participation) could be analyzed. Since we calculated effect sizes and compared the group difference to established MDC values (R135), the inference that activity level leads to greater L45, R45, and R135 measurements is justified. However, some caution should be applied to the interpretation of these findings considering the that the athletic population was significantly younger (large effect), and that a smaller percentage of the reach measurement variance (3.3–6.5%) of only the L135 and R135 reaches could be explained by activity level.

Influence of Sex

Females had significantly greater HSEBT reach measurements for normalized L45 and R45 reaches with a medium effect. These findings could be influenced by the female group being younger than the male group ($d = 0.83$) since younger participants have greater normalized L45 and R45 reach measurements as discussed previously. It is interesting to note that males have significantly greater absolute R45 reach measurements with a small effect and a group difference less than MDC values. Normalization to wingspan changes this relationship completely with females having greater measurements ($d = 0.64$). These findings might be due to males having a greater wingspan (10.9 cm; $d = 1.51$), and that the R45 reach is where wingspan accounts for the greatest variation of the measurement (34.6%). Thus, females are better able to combine different joint movements to maximize R45 reach measurements despite having unfavorable anthropometrics.

Similar to our findings physically active females have been found to have greater SEBT reach measures than their male counterparts (Gribble et al., 2009). However, in their study Gribble and co-authors found no influence of sex on normalized SEBT reach measurements, and males having greater absolute SEBT reach measurements (Gribble and Hertel, 2003). Contrary to our findings, others have found males (Sabin et al., 2010) and athletic males (Gorman et al., 2012b) to have greater SEBT measures than their female counterparts. In the aforementioned studies neither effect sizes were reported nor were group differences compared to MDC values (Munro and Herrington, 2010). The group differences presented by Gribble and co-authors (Gribble and Hertel, 2003) are less than the established MDC values except for the posterior reach, while the group differences presented by Gribble and co-workers in their later study (Gribble et al., 2009) were all lower than established MDC values (visual interpretation from graphs). The values presented by Gorman and co-authors cannot be compared to MDC values since it is impossible to extract them from the graphs presented (Gorman et al., 2012b). Thus, it appears that sex has a small influence on SEBT reach measurements. Since sex had a medium effect and explained 4.2 and 8.9% of the variance of the R45 and L45 reach measurements respectively, greater than most CV's for R45 and L45 reaches (3.0–5.2%) (Eriksrud et al., 2017), it appears that sex influence these HSEBT reaches. However, sex was not found to have a significant contribution to the validation model for the R45 and L45 reaches. Thus, the interpretation of sex influencing these reaches should be done cautiously.

Outlook, Clinical Implications and Limitations

The current study established that HSEBT flexion movement patterns should be normalized to wingspan. However, wingspan explains only 34.6 and 11.7% of the variation in R45 and L45 reach measurements, respectively. This leaves a large percentage of the variance to be determined by other factors. To date the HSEBT has been proven to be reliable and valid (Eriksrud et al., 2017) and measuring different aspects of dynamic postural control than the SEBT (Eriksrud et al., 2018). SEBT reaches have been found to reflect different neuromuscular functions such as proprioception (Belley et al., 2016), lower extremity strength (Hubbard et al., 2007; Crossley et al., 2011; Norris and Trudelle-Jackson, 2011), muscular power (Booysen et al., 2015), and balance (Hubbard et al., 2007). A better understanding of the influence of neuromuscular functions on HSEBT reach measurements should be explored.

The current study has shown that age, sex and activity level influence HSEBT measurements and consequently should be considered when performing between individual and group comparisons. The age groups compared in the current study were teenagers (age 17.1 ± 0.6) and young adults (age 24.3 ± 3.4). To better understand the influence of age on the HSEBT, larger age ranges (>10 years) should be tested with measurements organized in age groups, as done for ROM data (Bell and Hoshizaki, 1981). This will allow for the development of reference values and the exploration of how HSEBT reach develops the across the life span. The development of such reference values can be important. Specifically, in an older population they can be useful in fall risk management, since the HSEBT is situation specific to risky movements such as reaching, leaning (Nachreiner et al., 2007) and bending (Duckham et al., 2013).

The HSEBT can be used to measure sports and activity dependent adaptations and characteristics and their influence on performance. In the current study, due to small sport specific sample sizes, we could only explore the influence of activity level and not sport specific adaptations and characteristics. Even if between sport comparisons were not done, we have presented reference data for different winter sports for future comparisons. The authors expect that athletes participating in different sports will have different HSEBT reach capacities. Specifically, sports where the use of the upper extremities is fundamental to the activity (golf, tennis, volleyball, overhead throwing sports etc.) are expected to show greater reach measures as compared to sports where the upper extremities are less important (i.e., soccer). In addition, specific cut-off values for athletic performances can be determined. For instance, it might be that extension movement pattern measurements up to a certain value increase tennis serve speed, while a further increase does not. Such reference and performance specific cut-off values can be useful in the development and rehabilitation of athletes.

CONCLUSION

Flexion movement patterns (L45 and R45 reaches) should be normalized to wingspan, since a significant variation of these measurements is explained by this measure. In fact, only when normalized L45 and R45 reach measurements were compared, group differences for age, sex and activity level became significant. On the contrary, extension movement patterns do not need to be normalized to anthropometric measures since only leg length had a small influence on the L135 reach measurement. Neither anthropometric measures nor age, sex and activity level influence the rotational reaches. Thus, reference and predictive values for research and clinical purposes should be based on flexion movement patterns normalized to wingspan. In a young and adult population it appears that age, sex and activity level influence HSEBT reach measurements.

ETHICS STATEMENT

Informed consent was obtained by electronic means and data was stored anonymously. The study was authorized and approved by Regional Committees for Medical and Health Research Ethics and the National Data Protection Authority and conducted according to the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

OE contributed to conception of the idea and design of the study. All authors OE, PF, and JC contributed to data analysis and writing of the manuscript.

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REFERENCES

Ambegaonkar, J. P., Caswell, S. V., Winchester, J. B., Shimokochi, Y., Cortes, N., and Caswell, A. M. (2013). Balance comparisons between female dancers and active nondancers. *Res. Q. Exerc. Sport* 84, 24–29. doi: 10.1080/02701367.2013.762287

Bell, R. D., and Hoshizaki, T. B. (1981). Relationships of age and sex with range of motion of seventeen joint actions in humans. *Can. J. Appl. Sport Sci.* 6, 202–206.

Belley, A. F., Bouffard, J., Brochu, K., Mercier, C., Roy, J. S., and Bouyer, L. (2016). Development and reliability of a measure evaluating dynamic proprioception during walking with a robotized ankle-foot orthosis, and its relation to dynamic postural control. *Gait Posture* 49, 213–218. doi: 10.1016/j.gaitpost.2016.07.013

Booysen, M. J., Gradidge, P. J., and Watson, E. (2015). The relationships of eccentric strength and power with dynamic balance in male footballers. *J. Sports Sci.* 33, 2157–2165. doi: 10.1080/02640414.2015.1064152

Brauer, S., Burns, Y., and Galley, P. (1999). Lateral reach: a clinical measure of medio-lateral postural stability. *Phys. Res. Int.* 4, 81–88. doi: 10.1002/pri.155

Bressel, E., Yonker, J. C., Kras, J., and Heath, E. M. (2007). Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *J. Athl. Train.* 42, 42–46.

Clarsen, B., Bahr, R., Andersson, S. H., Munk, R., and Myklebust, G. (2014). Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br. J. Sports Med.* 48, 1327–1333. doi: 10.1136/bjsports-2014-093702

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates.

Crossley, K. M., Zhang, W. J., Schache, A. G., Bryant, A., and Cowan, S. M. (2011). Performance on the single-leg squat task indicates hip abductor muscle function. *Am. J. Sports Med.* 39, 866–873. doi: 10.1177/0363546510395456

Duckham, R. L., Procter-Gray, E., Hannan, M. T., Leveille, S. G., Lipsitz, L. A., and Li, W. (2013). Sex differences in circumstances and consequences of outdoor and indoor falls in older adults in the MOBILIZE Boston cohort study. *BMC Geriatr.* 13:133. doi: 10.1186/1471-2318-13-133

Duncan, P. W., Weiner, D. K., Chandler, J., and Studenski, S. (1990). Functional reach: a new clinical measure of balance. *J. Gerontol.* 45, M192–197. doi: 10.1093/geronj/45.6.M192

Elliott, B., Fleisig, G., Nicholls, R., and Escamilia, R. (2003). Technique effects on upper limb loading in the tennis serve. *J. Sci. Med. Sport* 6, 76–87. doi: 10.1016/S1440-2440(03)80011-7

Eriksrud, O., Federolf, P., Anderson, P., and Cabri, J. (2018). Hand reach star excursion balance test: an alternative test for dynamic postural control and functional mobility. *PLoS ONE* 13:e0196813. doi: 10.1371/journal.pone.0196813

Eriksrud, O., Federolf, P., Sæland, F., Litsos, S., and Cabri, J. (2017). Reliability and validity of the hand reach star excursion balance test. *J. Funct. Morph. Kinesiol.* 2:13. doi: 10.3390/jfmk2030028

Glave, A. P., Didier, J. J., Weatherwax, J., Browning, S. J., and Fiaud, V. (2016). Testing postural stability: are the star excursion balance test and biodex balance system limits of stability tests consistent? *Gait Posture* 43, 225–227. doi: 10.1016/j.gaitpost.2015.09.028

Gonzalo-Skok, O., Serna, J., Rhea, M. R., and Marin, P. J. (2017). Age differences in measures of functional movement and performance in highly youth basketball players. *Int. J. Sports Phys. Ther.* 12, 812–821. doi: 10.26603/ijspt20170812

Gorman, P. P., Butler, R. J., Plisky, P. J., and Kiesel, K. B. (2012a). Upper quarter Y balance test: reliability and performance comparison between genders in active adults. *J. Strength Cond. Res.* 26, 3043–3048. doi: 10.1519/JSC.0b013e3182472fdb

Gorman, P. P., Butler, R. J., Rauh, M. J., Kiesel, K., and Plisky, P. J. (2012b). Differences in dynamic balance scores in one sport versus multiple sport high school athletes. *Int. J. Sports Phys. Ther.* 7, 148–153.

Gribble, P. A., and Hertel, J. (2003). Considerations for normalizing measures of the star excursion balance test. *Meas. Phys. Educ. Exerc. Sci.* 7, 89–100. doi: 10.1207/S15327841MPEE0702_3

Gribble, P. A., Hertel, J., and Plisky, P. (2012). Using the Star Excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J. Athl. Train.* 47, 339–357. doi: 10.4085/1062-6050-47.3.08

Gribble, P. A., Robinson, R. H., Hertel, J., and Denegar, C. R. (2009). The effects of gender and fatigue on dynamic postural control. *J. Sport Rehabil.* 18, 240–257. doi: 10.1123/jsr.18.2.240

Haley, S. M., and Fragala-Pinkham, M. A. (2006). Interpreting change scores of tests and measures used in physical therapy. *Phys. Ther.* 86, 735–743. doi: 10.1093/ptj/86.5.735

Hoaglin, D. C., and Iglewicz, B. (1987). Fine-tuning some resistant rules for outlier labeling. *J. Am. Stat. Assoc.* 82, 1147–1149. doi: 10.1080/01621459.1987.10478551

Holden, S., Boreham, C., Doherty, C., Wang, D., and Delahunt, E. (2016). A longitudinal investigation into the progression of dynamic postural stability performance in adolescents. *Gait Posture* 48, 171–176. doi: 10.1016/j.gaitpost.2016.04.019

Hubbard, T. J., Kramer, L. C., Denegar, C. R., and Hertel, J. (2007). Contributing factors to chronic ankle instability. *Foot Ankle Int.* 28, 343–354. doi: 10.3113/FAI.2007.0343

Laird, R. A., Gilbert, J., Kent, P., and Keating, J. L. (2014). Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis. *BMC Musculoskelet. Disord.* 15:229. doi: 10.1186/1471-2474-15-229

McCann, R. S., Kosik, K. B., Terada, M., Beard, M. Q., Buskirk, G. E., and Gribble, P. A. (2017). Associations between functional and isolated performance measures in college women's soccer players. *J. Sport Rehabil.* 26, 376–385. doi: 10.1123/jsr.2016-0016

Munro, A. G., and Herrington, L. C. (2010). Between-session reliability of the star excursion balance test. *Phys. Ther. Sport* 11, 128–132. doi: 10.1016/j.ptsp.2010.07.002

Nachreiner, N. M., Findorff, M. J., Wyman, J. F., and McCarthy, T. C. (2007). Circumstances and consequences of falls in community-dwelling older women. *J. Womens. Health (Larchmt).* 16, 1437–1446. doi: 10.1089/jwh.2006.0245

Newton, R. A. (2001). Validity of the multi-directional reach test: a practical measure for limits of stability in older adults. *J. Gerontol. A Biol. Sci. Med. Sci.* 56, M248–252. doi: 10.1093/gerona/56.4.M248

Norris, B., and Trudelle-Jackson, E. (2011). Hip- and thigh-muscle activation during the star excursion balance test. *J. Sport Rehabil.* 20, 428–441. doi: 10.1123/jsr.20.4.428

Plisky, P. J., Rauh, M. J., Kaminski, T. W., and Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J. Orthop. Sports Phys. Ther.* 36, 911–919. doi: 10.2519/jospt.2006.2244

Roach, N. T., and Lieberman, D. E. (2014). Upper body contributions to power generation during rapid, overhand throwing in humans. *J. Exp. Biol.* 217(Pt. 12), 2139–2149. doi: 10.1242/jeb.103275

Sabin, M. J., Ebersole, K. T., Martindale, A. R., Price, J. W., and Broglio, S. P. (2010). Balance performance in male and female collegiate basketball athletes: influence of testing surface. *J. Strength Cond. Res.* 24, 2073–2078. doi: 10.1519/JSC.0b013e3181ddae13

Scott, V., Votova, K., Scanlan, A., and Close, J. (2007). Multifactorial and functional mobility assessment tools for fall risk among older adults in community, home-support, long-term and acute care settings. *Age Ageing* 36, 130–139. doi: 10.1093/ageing/afl165

Thorpe, J. L., and Ebersole, K. T. (2008). Unilateral balance performance in female collegiate soccer athletes. *J. Strength Cond. Res.* 22, 1429–1433. doi: 10.1519/JSC.0b013e31818202db

Zhou, J., Ning, X., Hu, B., and Dai, B. (2016). The influences of foot placement on lumbopelvic rhythm during trunk flexion motion. *J. Biomech.* 49, 1692–1697. doi: 10.1016/j.jbiomech.2016.03.048

Conflict of Interest Statement: OE is a co-founder of Athletic Knowledge AB (Stockholm, Sweden) which commercially distributes a testing mat for HSEBT and SEBT.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX

TABLE A1 | Validation of the multiple linear regression of HSEBT reaches.

	Initial model (75%)				Validation model (25%)			
Test	***B***	**SE *B***	**B**	***R*²**	***B***	**SE *B***	**B**	***R*²**
R45 STEP 1								
Constant	11.96	7.22						
Wingspan	0.39	0.041	0.59***	0.346				
R45 STEP 2								
Constant	–3.93	8.45						
Wingspan	0.47	0.047	0.62***					
Sex	3.07	0.92	0.24***	0.388 ($\Delta R^2 = 0.042$)				
R45 STEP 3					**FORCED ENTRY**			
Constant	0.62	8.58			13.85	14.944		
Wingspan	0.58	0.069	0.89***		0.30	0.14	0.52*	
Sex	3.1	0.90	0.24***		2.27	1.73	0.22	
Leg length	–0.279	0.12	–0.22*	0.407 ($\Delta R^2 = 0.019$)	0.135	0.242	0.12	0.288
L45 STEP 1								
Constant	22.71	9.69						
Wingspan	0.26	0.055	0.34***	0.117				
L45 STEP 2					**FORCED ENTRY**			
Constant	–3.86	11.13			13.00	17.11		
Wingspan	0.40	0.062	0.53***		0.32	0.095	0.50**	
Sex	5.15	1.21	0.35***	0.206 ($\Delta R^2 = 0.089$)	0.93	2.02	0.068	0.215
L135 STEP 1								
Constant	87,38	0.83						
Activity level	–3.86	1.67	–0.18*	0.033				
L135 STEP 2					**FORCED ENTRY**			
Constant	59.67	12.86			44.16	19.64		
Activity level	–4.64	1.69	–22**		–7.35	2.71	–0.42**	
Leg length	0.32	0.15	0.17*	0.060 ($\Delta R^2 = 0.027$)	0.49	0.22	0.34*	0.134
R135					**FORCED ENTRY**			
Constant	64.68	1.08			66.07	1.69		
Activity level	–7.21	2.17	–0.25**	0.065	–14.20	3.17	–0.53***	0.28
RROT					**FORCED ENTRY**			
NE					NE			
LROT					**FORCED ENTRY**			
NE					NE			

*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

B, Unstandardized coefficient; β, Standardized beta coefficient; SE, Standard error; R^2, Coefficient of determination; NE, No variables entered into the equation; R, Right; L, Left; 45, 45 degree relative to anterior surface of body; 135, 135 degrees relative to anterior surface of body: ROT, Rotation.

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Scaling Demands of Soccer According to Anthropometric and Physiological Sex Differences: A Fairer Comparison of Men's and Women's Soccer

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Spectators frequently harass female soccer players, and women's soccer is frequently compared negatively to men's soccer by writers who make the comparison without the backing of any data and without taking into account anthropometric and physiological differences between the sexes. This affects female soccer players' self-confidence negatively and contributes to an undeservedly negative image of women's soccer. In the present paper, we argue that most differences between men's and women's soccer can be explained by women having to adapt to rules and regulations that are suited for men and their physical attributes. Thus, games are much more demanding for women. Furthermore, we argue that if men had to play with a degree of adaptation similar to that which women do today, they would have to alter their style of play radically. As support for our argument, we scale game demands for male and female soccer players according to anthropometric and physiological differences in order to highlight the differences, and use these to predict what would be the most appropriate adaptations. Finally, we show that our predictions are largely supported by the scarce pool of comparable data across the sexes.

Keywords: football, gender, stereotypes, biological differences, discrimination

INTRODUCTION

With all respect for what the ladies have done, and they've done it fantastically well, you can't compare men's and women's football. Give it up, it's not even funny. – Zlatan Ibrahimović to the Swedish newspaper Expressen (see The Guardian, 2013).

The above quote, while being correct enough, came at the end of yet another bout of criticism of female soccer. Even though he stated, "you can't compare. . ." the remainder of the quote does exactly that. As Hjelm (2011) correctly pointed out, a statement that men's and women's football cannot be compared is self-contradictory, as it presupposes that a comparison has already been made. A more interesting discussion, which can be found in Theberge (1998, 2015) or Sailors (2016), would be whether it is at all relevant to make such comparisons between the sexes.

Even the top female soccer teams will lose to average male teams, and even to boys' teams (e.g., The Local , 2013). Women's soccer teams are well aware that they are physically inferior to men's teams and more similar to boys' teams, and for that reason, many teams use boys' teams as sparring partners. This fact is sometimes taken as evidence that the performance level of female soccer is poor. Even worse, soccer fans use such results to harass female soccer players and women's soccer in general (Hjelseth and Hovden, 2014). Of course, such harassment usually comes from individuals of little expertise and skill (although the source of the above quote is one of the most skilful players in the game).

Even the (later questioned) time of Florence Griffith Joyner in the 100 m sprint at the 1988 Olympic Games (10.49 s) lowering the world record by 0.27 s and setting one that still stands 30 years later (IAAF, 2019), would be smashed by any talented under-20 male sprinter. The best times for these individuals lies at just over 10 s. Furthermore, the best under-18 s can run below 10.2 s (IAAF, 2019). Anyone using such a fact to argue for anything but biological differences between the sexes would be considered quite ignorant. Still, in soccer, many are not able to distinguish between physique and skill, thus giving female soccer an undeservedly bad reputation.

Why is it that so many commentators find it relevant to compare performances directly across the sexes in soccer, while so few would find it worthwhile to compare world records in, say, the high jump (standing currently at 2.45 m for males vs. 2.09 m for females)? Could it be that while the high jump looks similar for males and females – except for the actual height – women and men actually play soccer slightly differently? Alternatively, is it as Hjelm (2011) argued, that while many among the public have personal experience with soccer and thus feel that they could have performed equally as well as the female soccer players, they know very well that they simply *cannot*, themselves, jump 2 m up in the air to negotiate the bar in a high jump?

Although the situation has changed a lot in recent years and women's soccer has increased its status significantly (Peeters and Elling, 2015; Cardoso de Araújo and Mießen, 2017), the impression still shines through that "real" soccer is played by men and that women's soccer is inferior. Such impressions will negatively affect girls' opinions of themselves and their self-confidence as soccer players (Hermann and Vollmeyer, 2016) and may transfer to other domains (Schmader et al., 2008; Chalabaev et al., 2009).

The total number of female soccer players was 30 million in 2014 (FIFA, 2014), and the number is steadily rising. Based on numbers from Europe describing an almost exponential growth (UEFA , 2017), it is not an unreasonable estimate that around 40 million girls and women play soccer worldwide. These players have to live with prejudice and, sometimes, downright misogyny (Hjelseth and Hovden, 2014; Taylor, 2018). The dropout rate from soccer is much higher for girls compared with that for boys (Møllerløkken et al., 2015; Deelen et al., 2018), and one could speculate that one of the reasons why more girls quit soccer is the general negative perception of women's soccer as inferior.

In fact, it has recently been disclosed that the producers of soccer shoes (boots) do not manufacture their top models in sizes that fit the normal-sized female foot, thus the top players have to use shoes made for children (NRK , 2019). According to a survey conducted by Norwegian Public Broadcasting (NRK , 2019), this fact is perceived by 90% of the players in the premier national women's league as a sign of prejudice, and 22% of players affirm that they have experienced pain and discomfort due to their shoes not being properly adapted to their feet.

Few attempts have been made to compare men's and women's soccer by means of actual data to establish whether there are actually such large differences between the sexes or whether women's soccer is indeed so poor as often suggested (one notable example being Hjelm, 2011). Others have at least reported data for both sexes on the same match-related variables (Kirkendall, 2007; Gómez et al., 2009; Bradley et al., 2014; Cardoso de Araújo et al., 2018), which is not particularly common. The results have been mixed, partly due to the quality of data, but also due to the studies having been performed under the assumption that the data are actually directly comparable and thus have not been scaled.

The present paper will argue that many – or even most – of the differences between the sexes in the style of play in soccer are due to external physical factors, which lead to logical, strategic adaptations by the female players. Furthermore, it will be argued that male players, given equally challenging demands, would have to adapt somewhat similarly to the way that the females have done.

Firstly, a comparison of relevant anthropometric and physiological variables is presented between the two sexes. Thereafter, these variables are examined in relation to the rules and regulations of the game and scaled according to the anthropometric and physiological sex differences. Finally, the consequences of the differences for the style of play are discussed, followed by speculation about the men's playing conditions if they were determined by an imagined "anthropometric and physiologically superior sex."

It is not the scope of the present paper to identify or discuss all the relevant variables but rather to illustrate and exemplify the arguments by presenting a few of the differences. Furthermore, it is not so straightforward to determine which anthropometric or physiological variables would be most relevant to use for a comparison in every case. We have attempted, however, to find fitting variables for each example and to find authoritative sources for establishing the magnitude of sex differences on the included variables.

We would encourage researchers to come up with better variables or to argue for more correct or precise scaling, but we would hold that our argument would stand regardless of the exact magnitude of anthropometric/physiological sex differences. Sometimes, our choices of variables or scaling data may even be too conservative, while it is certainly possible to argue that differences at other times may be exaggerated.

Some Relevant Anthropometric and Physiological Differences Between the Sexes

In the comparisons seen in **Table 1**, average values for "ordinary" individuals are used, not sports specific ones involving soccer players. This seems fairer as it reflects pure sex differences and not the current fitness status within the sport, which of course is highly influenced by training. When comparing, for example, endurance values, the relative difference between the sexes is smaller for soccer players, at roughly 12% (Tønnessen et al., 2013; Haugen et al., 2014), compared with a 23% difference for ordinary individuals (Aspenes et al., 2011; Loe et al., 2013). This indicates that female soccer players' fitness status (more precisely, how much they have improved their fitness relative to the average individual) is better than that of male soccer players. Men's VO_{2max} values, if similarly enhanced by training, relative to the average ordinary individual would exceed 70 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, which is close to the male average plus one standard deviation (see **Table 1**).

For kicking velocity, differences between the sexes are some 18% (Sakamoto et al., 2014). Thus the differences are smaller than for leg strength, which is 33% (Miller et al., 1993), indicating that female soccer players have compensated for some of the strength differences, and furthermore that shooting technique may be more important than mere leg strength. Nevertheless, values for leg strength are used for comparison/scaling because this is consistent with the idea of using values for ordinary individuals – as stated above – and also more comparable to, for example, using VO_{2max} or VO_{2peak} values (the differences between these measures are not important for the present discussion of sex differences, so they will be used interchangeably) for comparing running capacity/endurance.

Height/Stature

Males stand, on average, some 10–15 cm taller than females (Garcia and Quintana-Domeque, 2007), with standard deviations of 7 and 6 cm, respectively (Subramanian et al., 2011). The exact difference will vary across countries, but the relative difference is somewhere around 8%. For Norway, an apt example as the home of the authors of the present paper, the difference is 14 cm (see **Table 1**). Norwegian males are, on average, 1.82 m in stature, while females are 1.68 m, according to the Norwegian Directorate for Health and Social Affairs (Helsedirektoratet, 2009). The standard deviation for males is 7 cm, which makes it probable that quite a few males are closer to 2 m. In fact, assuming a normal distribution of height among soccer players, one would expect 2.5% of them (+2 SD) to be above 1.96 m. The height of the tallest 2.5% of female players would be somewhere around the male average. Bear in mind that Norwegians are among the tallest people in the world (see NCD, 2016). Thus, the problem, although the relative sex difference is similar across countries, will be much greater for countries in which the average height is lower. For example, in the United States, the average height in 2011–2014 was 176.4 cm for males aged 20–29 and 162.9 cm for females of the corresponding ages, albeit with differences of similar relative size across different ethnic groups for both sexes (Fryar et al., 2016). Also, in most countries, even young girls play on the same pitches and use the same goals. In Norway, which is most certainly representative, girls of ages down to 14 years play on same-sized pitches and goalkeepers defend same-sized goals as grown men (NFF , 2019). Thus, they are learning quite different skills and playing a quite different form of soccer from what they will be playing later when their bodies are fully developed, instead of developing skills that are relatively the same as they will be using later on a pitch that is relatively the same (i.e., scaled). We will not be discussing this particular topic in the present article but will instead come back to it in a subsequent paper.

Other anthropometric variables are similarly different between the sexes, although not to the point that the proportions are the same. Simply scaling down a man by 8% would result in a smaller man, but not a woman. The relative difference in

TABLE 1 | Anthropometric and physiological differences across sexes.

	(−2 SD) "inferiors" (+2 SD)	Women (+2 SD)	Men (+2 SD)	"Supermen" (+2 SD)
Height[a] (also arm span[b])	(142) 155 (165) cm	168 (180) cm	182 (196) cm	197 (213) cm
Body (forearm-forearm) breadth[c]/5-player wall	40.2 cm/201 cm	46.9 cm/234 cm	54.6 cm/273 cm	63.7 cm/318 cm
Foot length[c]/shoe size	22.15 cm/size 36	24.44 cm/size 39	26.97 cm/size 43	29.76 cm/size 46
Weight at BMI = 23[d]	55 (63) kg	65 (75) kg	76 (95) kg	89 (109) kg
Weight at BMI = 22[e]	54 (64) kg	62 (73) kg	71 (83) kg	81 (96) kg
Speed 100 m (WR)	(12.6) 12.0 (11.4) s	10.9 (10.5) s	9.9 (9.6) s	9.0 (8.7) s
Speed 30 m (soccer)[f]	5.51 (0.8) s	4.84 (0.4) s	4.25 (0.2) s	3.73 (0.1) s
Endurance (VO_{2peak})[g]	34 (48) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	43 (58) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	54 (72) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	68 (90) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$
Soccer endurance[h]	50 (52) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	56.5 (59) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	64 (67) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	72 (76) $ml{\cdot}kg^{-1}{\cdot}min^{-1}$
% Muscle (average)[i]	28 (41) %	34 (46) %	42 (51) %	52 (57) %
Lower leg strength	(232) 254 (276) N	385 (416) N	584 (627) N	886 (945) N
Jumping height[k]	(13) 23 (33) cm	36 (48) cm	57 (71) cm	90 (104) cm
Kicking velocity (ball speed, instep)[l]	19 (21) m/s	22 (25) m/s	26 (30) m/s	31 (35) m/s

Actual differences between women and men (+2 SD indicates values for above average players, and −2 SD, similarly, indicates below average players on the team of "inferiors"), and estimated (accordingly scaled) values for individuals equally physically inferior to women as women to men ("inferiors") and equally superior to men as men to women ("supermen"). [a]Based on data for 20–25-year-olds from the Norwegian Directorate for Health (Helsedirektoratet, 2009). [b]A person's arm span is roughly the same as the same person's height (Reeves et al., 1996). [c]Based on data from Gordon et al. (1989). [d]Average BMI for elite European male soccer players, Bloomfield et al. (2005). [e]Argued to be the optimal BMI for female soccer players (Nikolaidis, 2014); also the average BMI for elite female soccer players, (Cardoso de Araújo et al., 2018). [f]Based on data from Baumgart et al. (2018). [g]Aspenes et al. (2011), data for 20–29-year-olds, very similar to Loe et al. (2013) data for 20–29-year-olds. [h]Based on data for national players from Tønnessen et al. (2013) (males) and Haugen et al. (2014) (females). Values extracted from figures. [i]Based on data for 18–29-year-olds in Janssen et al. (2000). [j]Based on data from Kanehisa et al. (1994) data for knee extension, very similar to Miller et al. (1993) data. [k]Scaled accordingly to Patterson and Peterson, 2004; data for 21–25-year-olds. [l]Based on data from Sakamoto et al. (2014).

size, however, is of somewhat similar magnitude, so scaling by 8% would be close enough for the present argument. For physiological sex differences, on the other hand, which are more variable and generally larger, each variable should definitely be scaled according to actual reported values from scientific papers.

Some relevant sex differences are included in **Table 1**, including the anthropometric variables: *body width* (forearm-to-forearm), *weight* (adjusted for BMI), and *foot size*. Also treated are the physiological variables: *endurance*, *muscle average*, and *body fat*. Finally, there are the performance differences: *speed*, *jumping height*, and *kicking speed.* The latter differences are, in addition to technique, highly dependent on physiological variables such as lower-leg strength (Patterson and Peterson, 2004; Andersen et al., 2016).

Rules and Regulations Relative to Anthropometric and Physiological Sex Differences

Soccer, unlike many other sports, possesses rules that are the same for women and men. In fact, handball, ice hockey, volleyball, and basketball all have rules and regulations that are different for the two sexes, such as using balls of smaller sizes/lower weights or various other adaptations of the rules (Theberge, 1998; Andersen et al., 2012). Thus, in soccer, female players have to cope with relatively much tougher demands than males. In the following section, we will present some examples by scaling those variables (rules and regulations) according to the already mentioned sex differences, in order to give the reader an idea of how much they might affect the play.

Goal Size

The distance between the posts of a goal is 7.32 m and the distance from the ground to the lower edge of the crossbar is 2.44 m (IFAB, 2018. A reasonable comparison of goal size across the sexes would have to be made relative to the goalkeepers' height. The average-sized man stands somewhere around 75% of goal height, while an above average-sized man (which is quite normal for goalkeepers) of, say, +1 SD is 78% of goal height (Bloomfield et al., 2005; Ziv and Lidor, 2011). The average heights of goalkeepers in the most recent World Cups for men and women, were 188.9 (5.0) cm, and 173.5 (5.2) cm, respectively. This gives a difference of 8%, which is exactly the same as the general difference between the sexes, but also indicates that female goalkeepers, like their male counterparts, stand one to two standard deviations higher than the average for their sex. Typically, the height of the male goalkeepers was easily accessible via fifa.com (FIFA, 2018a), whereas for the females we had to consult Wikipedia (2018), who have provided the information compiled directly from each association's official website.

The average-sized woman, on the other hand, is a mere 69% of goal height, while even the taller goalkeepers (+1 SD) would size up to only 72% of goal size. An average female goalkeeper's reach would be relatively equally shorter as the arm span of each person is proportionate to his or her height (Reeves et al., 1996). Should the goal be scaled down for women according to their relative height, it would be 6.76 m wide and 2.25 m high, while a goal that was scaled up for men to the relative size of the current goal for women would be 7.93 m wide and 2.64 m high.

Ball Size and Weight

The standard-sized soccer ball has a circumference of 68–70 cm, with a corresponding weight of 410–450 g (IFAB, 2018). The most relevant variable for comparison of men and women would seem to be foot size or body size, which should be relatively similar in terms of relative difference. Women's feet are on average some 10.5% shorter than men's (Gordon et al., 1989), which is similar to the 8% difference in height. This would mean that a fair-sized ball for women would be somewhere between 62 and 64 cm. In fact, this is exactly the same as a size 4 soccer ball which was used for younger age groups and futsal, and previously also in women's soccer until the early 1990s. Here is a statement made by the United States team after the initial women's FIFA World Cup in 1991 (FIFA, 2018b), when a size five ball was first used. These thoughts reflect the players' ambiguity on the matter during a period of a transition of the rules:

Ball size [no. 5] is acceptable, but the pressure should be lower than for the men's game. Because heading skills are not yet fully developed, but also because of differences in physique, women seem to suffer more from headaches. Another possibility would be to use a lighter ball, but one without unpredictable flight properties (*this condition might be difficult to meet*).

For a fair ball weight, the most relevant comparison would probably be leg strength. Here, the ratio of women to men is somewhere around 66% (Miller et al., 1993). A fair soccer ball weight for women would, consequently, be 66% of the median weight of a size five ball (430 g), corresponding to 287 g. The regulation weight of the size four ball is 350–390 g (IFAB, 2018), thus the women's ball would have to be proportionately even lighter. In fact, 287 g corresponds to a somewhat heavy volleyball (normally 260–280 g, FIVB , 2016). As mentioned, other sports like handball (IHF, 2018) and basketball (FIBA , 2018) use balls of smaller size and mass for women in order to compensate for physiological differences (Andersen et al., 2012). However, we should keep in mind that the weight of the ball could not actually be as low as 287 g, since the flight properties would be much different (as correctly stated in the United States team statement above).

Let us also imagine a reasonable size for the ball to be similarly as unfair for males as the regulation-sized ball is for females. Using the same comparisons (foot size and lower-leg strength), the unfair circumference of the ball would be 76 cm, which is comparable to a basketball (74.93–75.88 cm), of size 7 (FIBA , 2018). The unfair weight would equal some 650 g, which is a little heavier than the same basketball that has a regulation weight of 566.99–623.69 g (FIBA , 2018).

Pitch Size and Dimensions

Pitch sizes vary, with the regulations stating that the length of a pitch should be between 90 and 120 m. The width, correspondingly, should range between 45 and 90 m. For international matches, the pitch size should range between 100 × 64 m and 110 × 75 m (IFAB, 2018), with recommended dimensions of 105 × 68 m. Regardless of pitch size, it is a fact that pitches are relatively larger for women. How much larger depends on which measure is used for comparison. One could, for instance, choose to compare the pitch size relative to leg length (i.e., how many strides to cross the pitch), or relative to average height (which corresponds with leg length but is easier to measure). One could compare with reference to endurance (i.e., how much energy is needed to negotiate the pitch), speed (how fast one can run across the pitch), or leg strength (how many kicks are needed to transport the ball across the pitch). All of the above could be argued to be relevant, and one could further argue that a weighted combination would give the fairest comparison. However, two measures could be argued to stand out as more important, namely endurance and leg strength. As can be found in **Table 1**, females have VO_{2peak}/VO_{2max} values that are some 77% of males' values (Aspenes et al., 2011), or slightly less since Loe et al. (2013) found a 26% sex difference for 20–29 year olds. This means, that a fair relative size of the pitch for female soccer players would be 77% of that for male players. Alternatively, female soccer players would need relative VO_{2max} values that were much higher than males', and which would place them together with athletes from endurance sports such as long distance running or cross-country skiing (Tønnessen et al., 2015). Alternatively, if leg strength was used for comparison, the women's pitch area would be 66% of that of the men's pitch (Miller et al., 1993; Janssen et al., 2000), which corresponds well to actual differences in other areas such as jumping height (Patterson and Peterson, 2004; see **Table 1**).

It is not only the total pitch area that is unfair to female players. The pitch length and width will also act as constraints due to the mentioned differences in leg strength (Miller et al., 1993). As shown in **Table 1**, kicking speed is quite different between the sexes (Sakamoto et al., 2014). This difference will affect corner kicks as well as crosses into the box. In order to execute a corner kick or a cross in front of goal with similar speed to that of men, a fair distance for women would be some 66% of that for men. Translated to pitch width, this would mean that the female pitch should be 45 m wide, with the corner spot 22.5 m away from the center of goal (instead of 34 m). A similarly unfair crossing distance for male players would be some 45 m, corresponding to a pitch width of 90 m. Alternatively, female players would have to cross the ball from spaces on the pitch that are relatively closer to the goal, thus functionally narrowing the play relatively, in order to compensate, and to use different strategies for corner kicks than to play the ball directly in front of the goal, as this would involve a lofted kick with a curve that is easier for the goalkeeper and defenders to calculate and hence to defend.

Distance to the Wall at Free Kicks (9.15 m)

At free kicks close to the goal, the defending team will usually organize a "wall" of players in order to make it more difficult to score from a direct shot. The goalkeeper defends one side of the goal, while the wall is supposed to defend the other side. In women's soccer, this wall is lower since players are on average shorter and is thus less effective as a defending strategy. The fact that players are required to stand the same distance away from the ball (9.15 m) as the men, makes it easier to hit the goal by shooting over the wall (due to differences in the required curve of the ball for passing over the wall). Simple maths tells us that the relative effect of the wall is reduced by some 8% (due to the smaller angle of 10.4 degrees compared with 11.25 degrees for men), and that women should be allowed to stand 8.45 m away from the kick for the angle to be equal to that of the men. For a wall of male players to be equally (in-) effective as the female one (same angle), it would have to be placed 10 m away from the kick. The wall is, assuming the same number of players, also narrower as each player is narrower (by some 8.5%, Gordon et al., 1989); hence, a wall of five players will be 20 cm narrower. Consider also that the goal is wider for the female goalkeeper, and the goalkeeper's reach and jump/dive are shorter. Thus, in order to cover a similarly wide area effectively, one more player would be needed in the wall, leaving one more attacking player free, while the height of the wall cannot be amended at all. In total, the lower and narrower wall makes it much more difficult for female goalkeepers to defend the goal on free kicks.

Match Duration

Both men's and women's soccer games have a duration of 90 min. Again, a relevant measure for comparison would be the relative endurance between the sexes. As is shown in **Table 1**, correcting for physiological differences would mean that the women's game time should be 77% of that for men, thus equalling 70 min. In fact, this was the rule in the earlier days of female soccer when women's games were actually shorter. In the first World Championship for Women, in 1991, matches were 80 min, a difference of 11%. After the tournament, teams were asked their opinions about the special rules for women. Both finalists, Norway and the United States, when asked about the game time, argued that games should be 90 min, like the men's, but the United States suggested that there should be unlimited substitution (FIFA, 2018b). At the next WC, in Sweden in 1995, the game time was 90 min. However, teams were allowed up to two timeouts each. For comparison, if the game duration for men was extended so it would be equally as challenging as the women's game duration is today, it would be 113 min.

When games sometimes go into extra time, another 2×15 min are added, and these are played without a break between them. The relative extra time should thus be 24 min (2×12 min) to be "fair" for women, and a similarly "unfair" extra time for men would be 37 min ($\sim 2 \times 19$ min). The total "unfair" game time for men, including extra time, would be 2×56.5 min, followed by 2×19 min, or in all 151 min.

SOME CONSEQUENCES OF ANTHROPOMETRIC AND PHYSIOLOGICAL SEX DIFFERENCES FOR THE STYLE OF PLAY

Goalkeeping

The female goalkeeper is one player that clearly will suffer from anthropometric/physiological (sex-) differences. It should thus not come as a surprise that this is the position in which female players struggle the most and make the highest number of "mistakes". Nor would it be surprising that the female goalkeeper is at the receiving end of the majority of harassment. Because female goalkeepers are shorter than their male counterparts are, they will more often let in shots over their heads and not reach shots to either side. Penalties are taken from a distance of 11 m (12 yards), making them hard enough to save for male goalkeepers, especially those shots that are placed close to the goalposts. As female goalkeepers are smaller relative to the goal and have less lower-leg strength (thus, not able to dive equally far or quickly), it is even more difficult for them to save penalties, even though the shots will be relatively weaker (due to the inferior leg strength). Such examples are frequently cited as evidence that the standard of female goalkeepers is inferior (Kirkendall, 2007; see also Hjelseth and Hovden, 2014). However, many such goals are not the result of poor goalkeeping but simply due to female goalkeepers having to defend a relatively much larger goal. The average male goalkeeper, for example, would be able to stop a ball shot with some force to a position just under the crossbar without having to leave the ground, while his average female counterpart would have to jump in order to get enough of her hand behind the ball to deflect it. Furthermore, a female goalkeeper would have to stay much closer to her goal line in order to be able to reach high (lofted) shots with her fingertips so she could push the ball over the crossbar. In all, a female goalkeeper's relative size leaves much larger spaces undefended in the goal, and taken together with differences in muscle strength she will not be able to reach those spaces fast enough by diving, or jumping, in a manner similar to that of a male goalkeeper.

Interestingly enough, women's average height today equals that of men's just before the turn of the 20th century when modern soccer rules were decided, including the goal size. The average height of United Kingdom males born in 1861–1865, who would be adults in 1886 when the basic rules were decided (IFAB, 2018), was 166.25 cm (Hatton and Bray, 2010). Thus, it is not so surprising to find in an old Norwegian book with the title *Football* (Andersen, 1924) a discussion of the height of the goalkeeper when at the time the average height of males in Norway (and in the United Kingdom), was around 170 cm (Hatton and Bray, 2010). Andersen recommended a goalkeeper height of 178–184 cm, which equals the average height at the time plus one-to-two standard deviations. Furthermore, Andersen warned against the goalkeeper leaving his goal because he would then be susceptible to the risk of letting in goals from long-range shots.

In male soccer, the goalkeeper more and more often adopts a sweeper role, in which he can also intercept passes making their way through or over the defense, either with his feet or with his head. The rewards of such a tactic come at the expense of risking making "silly looking" errors. In order to be effective as a sweeper, the goalkeeper must stay as far out from his goal line as possible without leaving the goal open to long-range shots. Thus, there is a clear trade-off between not staying close enough to the goal to stop shots from distance and staying far enough away to intercept through balls. For female goalkeepers, such a trade-off is particularly difficult to cope with as the risk of letting in long-range shots increases proportionally to the goalkeeper's distance away from the goal. Their relative increased risk arises due to their relative lack of height and because they are relatively slower and need more time to get back to the goal. The cost of errors is similar to that of male goalkeepers who overestimate their ability and try to play sweeper too far out from the goal, but since it will happen more often as the decision is more difficult it has contributed to the female goalkeepers' reputation for letting in easy goals. Nevertheless, YouTube flourishes with videos of male goalkeepers, including top international ones, making mistakes similar to those of the female goalkeepers.

In men's soccer, the number of goals per match has decreased in recent years, and it has been increasingly easier for teams to "park the bus" (play extremely defensively) and secure a good result. The steady trend is that fewer goals are scored per game (Njororai, 2013). In the 2018 World Cup in Russia, only 169 goals were scored in the 64 games (2.64 goals per game, FIFA, 2018c). In contrast, in the 1954 World Cup, in Switzerland, an average of 5.38 goals were scored in each game (FIFA, 2018d). Perhaps one should take a closer look at Hertha Berlin manager Dárdai (2018) idea, mentioned in an interview with the newspaper *Märkische Allgemeine*, of increasing the goal size in the men's game to see more goals scored. Dárdai said that he would rather see games with scores like 4–4 or 5–3 and argued, very similarly to the present argument, that while the average goalkeeper has grown in height over time, the goals have remained the same size, thus they are relatively smaller. Dárdai wanted to increase the goal size by one half meter in height, and a whole meter in width ("Einen halben Meter nach oben und einen halben Meter nach links und rechts"). Doing so would result in goals in the men's game that are relatively larger than the current ones for women, which relatively equal men's goals of 7.93 × 2.64 m (see **Table 2**), but when accounting also for lower-leg strength may perhaps not be so different after all from what female goalkeepers struggle with on a daily basis.

Passes and Shots

As women have less muscle mass compared to men (Janssen et al., 2000) and are thus not equally as strong (Miller et al., 1993; see **Table 1**), they use a larger percentage of their total energy to move the ball around, whether on or off the ground. Furthermore, they use relatively more energy moving themselves around. This will consequently lower the tempo of the game, as the alternative would induce fatigue relatively earlier in the game (given that they play the same game length as men) and the quality of play would deteriorate proportionally toward the end of the game (Krustrup et al., 2010).

Another consequence of women's lesser muscle strength is that the ball will be moved a relatively shorter distance per pass; thus, a team will need more passes, or longer passes, to transport the ball along the length of the pitch. A strategy using more (necessarily shorter) passes would require more time for transportation of the ball across the pitch, which would introduce more possibilities of ball loss, and more shifts in possession. One possible solution would be to move the ball off the ground more often, using so-called lofted passes. This way the ball would travel longer with each pass but would also stay longer in the air due to air resistance (drag), and would be easier to defend, as defenders would have more time available to predict the course of the ball.

Each pass requires a higher percentage of a female player's maximal force. This will come at the expense of accuracy (as there is a trade-off between force and accuracy; see Fitts, 1954); thus, the probability of errors increases. Alternatively, passes can be made with the same relative force as males with the increased risk of interceptions because the ball velocity will be slower. One could argue that players should then opt for accuracy and sacrifice velocity by applying less force, as (female) opponents are equally slower and not able to intercept the passes anyway. Such a strategy would, however, be hampered by the fact that turf friction remains constant. Unless the turf is wet, the rate at which the ball loses speed would increase almost exponentially. Lofted passes are also more difficult to control for the player receiving the pass and are much more difficult to play on to a teammate or to return using only one touch, which contributes to the slower play.

The same strategy could be argued for shooting using lofted shots more often that are less powerful but more precise (Fitts, 1954). This would seem to be an effective strategy as goalkeepers are smaller and the goal is relatively larger. Being unable to produce force equal to that of males, female players must either come closer to the goal before taking a shot or must choose a different technique such as a lofted shot. Taking into account that goalkeepers are smaller relative to the goal, an effective strategy would be to choose accurate shots over forceful. Placing the ball in the goal, outside the goalkeeper's reach, is much easier in women's soccer, both because of the relative goal size (mentioned earlier) and the goalkeepers' jumping height (Patterson and Peterson, 2004; Ziv and Lidor, 2011); thus, accuracy should be chosen over force.

With less force available, corners and crosses would have to be kicked higher (lofted) instead of being shot rather straight, as is usual in the men's game. This way the ball stays longer in the air and is easier to defend, due to the goalkeeper's reach being higher relative to other players' jumping height. Furthermore, as was argued for long passes, defenders have more time to predict the flight of the ball. However, many of these adaptations would be redundant if the relative ball size was equal to that of men's soccer. While a smaller ball would definitely be more suited for the female foot, it could be discussed how much lighter the ball should be. There would certainly be a trade-off somewhere as a very light ball, even if hit with great force, would travel slower due to air resistance (drag). Remember also the statement from the United States 1991 WC team, mentioned earlier, where they were clearly aware of the trade-off between ball weight and flight properties. Interestingly enough, they also wanted to use lower pressure, due to the fact that women more often suffer from headaches due to headings. This argument would seem to be supported by the recent findings of Rubin et al. (2018) that women suffer more severe brain injuries from an equal number of headings (see also Pedersen and Stalsberg, 2019). It is not unreasonable to speculate that young female soccer players would avoid headings, and thus develop a different movement pattern because heading the heavier ball is more uncomfortable, which would also affect their heading technique later in their careers.

As it happens, experiments using a smaller, lighter ball in women's soccer have been performed (Andersen et al., 2012, 2016). According to the developers, speed of play increased, and the ball allowed shots from longer distance as well as other actions described as "impossible with the size five ball" (Eir Soccer, 2019). The basic idea behind designing the ball was that equal foot velocities for men and women would result in equal ball velocities. Thus, it should fly equally far when kicked by a female player as an ordinary soccer ball kicked by a male player with the same relative force (Andersen et al., 2012). True, it was found that female players of different ages are able to kick the lighter ball a longer distance by some 5–6 m compared with the regular ball (Andersen et al., 2016) and by 3–4 m longer for young players (Andersen et al., 2012). Somewhat against expectations, however,

TABLE 2 | Rules and regulations with relevance for sex differences in style of play.

	"Fair" for women	Actual situation	"Unfair" for men
Pitch length[a]	84 m (72–96 m)	105 m (90–120 m)	132 m (113–151 m)
Pitch width[a]	54 m (36–72 m)	68 m (45–90 m)	85 m (57–113 m)
Pitch area[a]	5686 m^2 (~93 × 61 m)	7140 m^2 (105 × 68 m)	8967 m^2 (~118 × 76m)
Goal width[b]	6.76 m	7.32 m	7.93 m
Goal height[b]	2.25 m	2.44 m	2.64 m
Ball size (diameter)[c]/-weight[d]	62–63 cm/273–300 g	68–70 cm/410–450 g	75–77 cm/621–682 g
Distance for corner kicks[e]	23 m (15–30 m)	34 m (22.5–45 m)	45 m (30–60 m)
Distance to wall at free-kicks[b]	8.45 m	9.15 m	10.7 m
Match duration[a]	72 min	90 min	113 min
Extra time duration[a]	24 min	30 min	38 min
Penalty spot (executer's point of view)	10 m	11 m	12 m
Penalty spot (goalkeeper's point of view)[f]	12 m	11 m	10 m

Actual situation and relative situation when adjusted for anthropometric/physiological differences across sexes. [a]Scaled according to average endurance $VO_{2peak/max}$ (±26%), Aspenes et al. (2011); data for 20–29-year-olds, very similar to Loe et al. (2013) data for 20–29-year-olds. [b]Scaled according to average height (±8%), based on data for 20–25-year-olds from the Norwegian Directorate for Health (Helsedirektoratet, 2009). [c]Scaled according to foot-length data from Gordon et al. (1989). [d]Scaled according to differences in lower-leg strength, taken from Miller et al. (1993). [e]Distance from the corner-spot to the center of goal on a pitch of standard international width (68 m); Scaled according to difference in lower leg strength (±33%, Miller et al., 1993). [f]Scaled according to average height (±8%); assuming that lower muscle power plays an equally large role for the executer's shot and the goalkeeper's take-off for the dive; however, the disadvantages for the goalkeeper are probably underestimated and should be compensated even more.

no significant differences in style of play were evident. However, players reported a lower degree of perceived exertion in the lower legs. This latter finding, it was argued, may be due to the fact that the ball could be moved around the field with relatively less force which, it was argued, might again reduce injuries.

WHAT ARE THE ACTUAL DIFFERENCES IN THE STYLE OF PLAY BETWEEN MEN'S AND WOMEN'S SOCCER?

While there are relatively few studies comparing men's and women's soccer performance directly, we will mention a few results from the relatively scarce data available that are consistent with our hypothesis that differences between the sexes are due to differences in physique.

Female soccer players run less (i.e., shorter total distance) than their male counterparts do, and they play slower. Not only are they unable to sprint as fast as male players (Baumgart et al., 2018), but females also spend longer periods of the game at lower velocities (Bradley et al., 2014). Despite this, female players get more fatigued earlier in the game (Mohr et al., 2005; Krustrup et al., 2010), and their performance decreases more, relative to males, in the second half (Bradley et al., 2014), as well as within the latter quarters of each half.

Female players experience more ball losses than male players do, and they have a lower percentage of successful passes (Bradley et al., 2014). More goals are scored from long-range shots (from outside the penalty area) in female soccer compared with male soccer (Kirkendall, 2007). Furthermore, female players take more shots after team-plays, while male players' shots are more often preceded by individual play (Gómez et al., 2009). The total number of shots is similar across the sexes, but female players have more shots on goal. The latter, argued Gómez et al. (2009), may be due to the fact that male defenders are able to clear more shots compared with their female counterparts. The conversion rate (goals per shot) of female players is higher, due to many more shots being saved by the male goalkeepers (Gómez et al., 2009). The fact that female players take more shots from long range compared with male players may be argued to be inconsistent with predictions based on differences in lower-leg strength, but it is consistent with predictions based on the goalkeeper's size relative to the goal.

To give a fair comparison of female and male soccer, one would have to scale values according to the relative physiological capacities and establish, for example, gender specific thresholds for running intensity, as was suggested in Bradley et al. (2014). Thus, it would seem fair to compare the female players' running distances at above 12 km h^{-1} with the male players' corresponding distances above 15 km h^{-1}. Furthermore, as was noted by Kirkendall (2007), there is an overlap in running distance between the sexes in that while women average 10 km per game, men's distances range from 10 to 14 km, thus some female players run as much as many male players.

Modern styles of play often involve a high-pressing system. Pressing high requires extreme endurance because of the relatively larger pitch. Such tactics, if applied by women's teams, would necessitate a high (-er than for males) amount of physical conditioning (which turns out to be the case judging from the relatively higher VO_{2max} values). Such training might come at the expense of technical skills practice (see Kirkendall, 2007).

A THOUGHT EXPERIMENT

Let us now imagine a "third sex," or the discovery of a different species, with the same relative anthropometric/physiological advantages over men that men have over women. What might this comparison look like? As can be seen in **Table 2**, the average player of such a team would be just below 2 m in height, with the occasional player (+2 SD) of over 2.10 m, among them an extremely quick goalkeeper of 2.15 m, with an arm span the same as his height. The "supermen," as we may call them, would weigh about 10 kg more than men, of which most would be muscle. "Supermen" would average VO_{2max} values of 77 ml·kg^{-1}·min^{-1} with some values as high as in the mid-80 s. Such values, as mentioned, are comparable with the top athletes in endurance sports.

While male players, with their average 30 m sprint times of 4.25 s and best times of just over 4 s (Baumgart et al., 2018) can easily outsprint their female counterparts who are, on average, 0.6 s slower, the "supermen" would average their 30 m sprints in some 3.75 s. Their fastest players would run the distance in closer to 3.7 s. Of course, as for the difference between males and females, even the slowest players from the team of "supermen" would beat the average player from the men's team, and most all would beat the fastest man.

A game between men and "supermen" would of course be played according to rules and regulations suited for the supermen, with a game time of 113 min on a pitch that was some 118 × 76 m (8967 m^2) or even larger. We should bear in mind that this size is still within the actual regulations (IFAB, 2018), which state that the maximum pitch length is 120 m and the maximum pitch width is 90 m.

We will not have to be equally imaginative to find individuals similarly inferior to average women as average women to average men. As it happens, the "inferiors" in **Table 2**, with a height of 155 cm, and weight of 54 kg (at BMI = 22), are comparable in body size to 12–13-year-olds, whether boys or girls, as they are more or less equal in size at this age (see Hamill et al., 1979). In other variables more directly relevant to soccer, for example, speed and power, the adult females may be more similar to 14-year-old boys (Baumgart et al., 2018). This latter observation effectively closes our argument, as it explains why women's teams play against 15–16-year-old boys (who are physically superior but not by much) and why, as mentioned in the beginning of this article, the Swedish women's national team could lose against a decent team of 17-year-old boys.

CONCLUDING REMARKS

The present authors will not advocate changing the rules and regulations of soccer. That is the job of FIFA (or more specifically, IFAB) to decide and for female players and their coaches and leaders to argue for, should they wish to do so. The intention is rather to point at the obvious (but still not sufficiently recognized) anthropometric/physiological differences, and argue that differences in style of play between men's and women's soccer are logical and strategic adaptations to those differences. Thus, one should not expect women's soccer to be exactly like men's. Should one, however, wish to see women's soccer look more like men's it would require quite a number of regulation changes. The pitch would have to be some 93 × 61 m, with goals of 6.78 × 2.26 m. The ball would have to be a size 4, slightly heavier than a volleyball (note however previous arguments about flight properties), and the duration of the game would have to be 70 min.

What we want people to understand, is that the present situation for women is comparable to men playing on a 118 × 76 m pitch (and bear in mind that this is a conservative estimate), with goals of 7.93 × 2.64 m, and playing with a ball very similar in size and weight to a basketball. The game would last 113 min (ca. 2 × 56 min), which is comparable to that of a game going into extra time, especially when taking into account that there would be no extra break at 90 min. (Remember that should such a prolonged game extend into extra time, another 38 min would await the players.) Even without the imagined "supermen" as opponents, this would be a very interesting game, and one that the authors of the present paper would certainly encourage broadcasters to organize and televise.

An even better solution than making rule changes, however, would be to enjoy the game as it is today, with its small differences between the sexes, and perhaps work to increase the competence level of the spectators.

DATA AVAILABILITY

All datasets analyzed for this study are included in the manuscript and the Supplementary Files.

AUTHOR CONTRIBUTIONS

All authors made substantial contributions to the paper, participated in drafting and revising the article, and approved the final version for publication. AVP conceived the idea of the paper.

REFERENCES

Andersen, P. C. (1924). *Fotball.* Kristiania: H. Aschehoug & Co.

Andersen, T. B., Bendiksen, M., Pedersen, J. M., Ørntoft, C., Brito, J., Jackman, S. R., et al. (2012). Kicking velocity and physical, technical, tactical match performance for U18 female football players–effect of a new ball. *Hum. Mov. Sci.* 31, 1624–1638. doi: 10.1016/j.humov.2012.07.003

Andersen, T. B., Krustrup, P., Bendiksen, M., Orntoft, C. O., Randers, M. B., and Pettersen, S. A. (2016). Kicking velocity and effect on match performance when using a smaller, lighter ball in women's football. *Int. J. Sports Med.* 37, 966–972. doi: 10.1055/s-0042-109542

Aspenes, S. T., Nilsen, T. I. L., Skaug, E. A., Bertheussen, G. F., Ellingsen, Ø, Vatten, L. J., et al. (2011). Peak oxygen uptake and cardiovascular risk factors in 4631 healthy women and men. *Med. Sci. Sports Exerc.* 43, 1465–1473. doi: 10.1249/MSS.0b013e31820ca81c

Baumgart, C., Freiwald, J., and Hoppe, M. W. (2018). Sprint mechanical properties of female and different aged male top-level german soccer players. *Sports* 6:E161. doi: 10.3390/sports6040161

Bloomfield, J., Polman, R., Butterly, R., and O'Donoghue, P. (2005). Analysis of age, stature, body mass, BMI and quality of elite soccer players from 4 European Leagues. *J. Sports Med. Phys. Fit.* 45, 58–67.

Bradley, P. S., Dellal, A., Mohr, M., Castellano, J., and Wilkie, A. (2014). Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. *Hum. Mov. Sci.* 33, 159–171. doi: 10.1016/j.humov.2013.07.024

Cardoso de Araújo, M., Baumgart, C., Jansen, C. T., Freiwald, J., and Hoppe, M. W. (2018). Sex differences in physical capacities of German Bundesliga soccer players. *J. Strength Cond. Res.*

Cardoso de Araújo, M., and Mießen, K. A. (2017). Twenty years of the FIFA women's world cup: an outstanding evolution of competitiveness. *Women Sport Phys. Act. J.* 25, 60–64. doi: 10.1123/wspaj.2015-0047

Chalabaev, A., Sarrazin, P., and Fontayne, P. (2009). Stereotype endorsement and perceived ability as mediators of the girls' gender orientation–soccer performance relationship. *Psychol. Sport Exerc.* 10, 297–299. doi: 10.1016/j.psychsport.2008.08.002

Dárdai, P. (2018). *Hertha-Trainer Dardai Wünscht Sich Größere Tore*. Available at: http://www.maz-online.de/Sportbuzzer/Fussball/Hertha-Trainer-Dardai-fordert-groessere-Tore (accessed September 9, 2018).

Deelen, I., Ettema, D., and Kamphuis, C. B. (2018). Time-use and environmental determinants of dropout from organized youth football and tennis. *BMC Public Health* 18:1022. doi: 10.1186/s12889-018-5919-2

Eir Soccer (2019). *Smaller and Lighter Ball Speeds up the Game*. Available at: http://eirsoccer.com/wp-content/uploads/Smaller-and-lighter-ball-speeds-up-the-game-UK-version.pdf (accessed March 3, 2019).

FIBA (2018). *Fédération Internationale de Basketball. Official Basketball Rules, 2018 – Basketball Equipment*. Available at: http://www.fiba.basketball/OBR-2018-Basketball-Equipment-Yellow-Version-2.pdf (accessed November 28, 2018).

FIFA (2014). *Fédération Internationale de Football Association Women's Football Survey*. Available at: https://resources.fifa.com/image/upload/fifa-women-s-football-survey-2522649.pdf?cloudid=emtgxvp0ibnebltlvi3b (accessed March 3, 2019).

FIFA (2018a). *Fédération Internationale de Football Association. 2018 FIFA World Cup Russia/Teams*. Available at: https://www.fifa.com/worldcup/teams/ (accessed March 3, 2019).

FIFA (2018b). *Fédération Internationale de Football Association. Technical Reports from Women's Championships*. Available at: https://resources.fifa.com/mm/document/afdeveloping/technicaldevp/50/08/19/wwc_91_tr_part2_260.pdf (accessed November 28, 2018).

FIFA (2018c). *Fédération Internationale de Football Association. 2018 FIFA World Cup Russia/Matches*.

FIFA (2018d). *Fédération Internationale de Football Association. 2018 FIFA Worldcup/Archive/Switzerland1954/Index*.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *J. Exp. Psychol.* 47, 381–391. doi: 10.1037/h0055392

FIVB (2016). *Fédération Internationale de Volleyball. Official Volleyball Rules 2017-2020*. Available at: http://www.fivb.org/EN/Refereeing-Rules/documents/FIVB-Volleyball_Rules_2017-2020-EN-v04.pdf (accessed on November 28, 2018).

Fryar, C. D., Gu, Q., Ogden, C. L., and Flegal, K. M. (2016). Anthropometric reference data for children and adults; United States, 2011-2014. *Vital Health Stat.* 39, 1–46.

Garcia, J., and Quintana-Domeque, C. (2007). The evolution of adult height in Europe: a brief note. *Econ. Hum. Biol.* 5, 340–349. doi: 10.1016/j.ehb.2007.02.002

Gómez, M., Álvaro, J., and Barriopedro, M. I. (2009). Behaviour patterns of finishing plays in female and male soccer. *Kronos* 15, 15–24.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., et al. (1989). *Anthropometric Survey of US Army Personnel: Summary Statistics, Interim Report for 1988*. Yellow Springs, OH: Anthropology Research Project Inc.

Hamill, P. V. V., Drizd, T. A., Johnson, C. L., Reed, R. B., Roche, A. F., and Moore, W. M. (1979). Physical growth: national center for health statistics percentiles. *Am. J. Clin. Nutr.* 32, 607–629. doi: 10.1093/ajcn/32.3.607

Hatton, T. J., and Bray, B. E. (2010). Long run trends in the heights of European men, 19th–20th centuries. *Econ. Hum. Biol.* 8, 405–413. doi: 10.1016/j.ehb.2010.03.001

Haugen, T. A., Tønnessen, E., Hem, E., Leirstein, S., and Seiler, S. (2014). VO2max characteristics of elite female soccer players, 1989–2007. *Int. J. Sports Physiol. Perform.* 9, 515–521. doi: 10.1123/ijspp.2012-0150

Helsedirektoratet. (2009). *Fysisk Aktivitet Blant Voksne og Eldre i Norge*. Available at: https://helsedirektoratet.no/Lists/Publikasjoner/Attachments/715/Fysisk-aktivitet-blant-voksne-og-eldre-resultater-fra-en-kartlegging-i-2008-og-2009-IS-1754.pdf (accessed November 28, 2018).

Hermann, J. M., and Vollmeyer, R. (2016). "Girls should cook, rather than kick!"– female soccer players under stereotype threat. *Psychol. Sport Exerc.* 26, 94–101. doi: 10.1016/j.psychsport.2016.06.010

Hjelm, J. (2011). The bad female football player: women's football in Sweden. *Soccer Soc.* 12, 143–158. doi: 10.1080/14660970.2011.548352

Hjelseth, A., and Hovden, J. (2014). Negotiating the status of women's football in Norway. an analysis of online supporter discourses. *Eur. J. Sport Soc.* 11, 253–277. doi: 10.1080/16138171.2014.11687944

IAAF (2019). *The International Association of Athletics Federations. All time top lists*. Available at: https://www.iaaf.org/records/all-time-toplists/sprints/ (accessed March 3, 2019).

IFAB (2018). *The International Football Association Board. Laws of the Game 2018/2019*. Available at: https://www.knvb.nl/downloads/bestand/11263/laws-of-the-game (accessed on November 28, 2018).

IHF (2018). *The International Handball Federation. Rules of the Game*. Available at: http://ihf.info/files/Uploads/NewsAttachments/0_RuleGame_GB.pdf (accessed November 28, 2018).

Janssen, I., Heymsfield, S. B., Wang, Z., and Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *J. Appl. Physiol.* 89, 81–88. doi: 10.1152/jappl.2000.89.1.81

Kanehisa, H., Ikegawa, S., and Fukunaga, T. (1994). Comparison of muscle cross-sectional area and strength between untrained women and men. *Eur. J. Appl. Physiol. Occup. Physiol.* 68, 148–154. doi: 10.1007/BF00244028

Kirkendall, D. T. (2007). Issues in training the female player. *Br. J. Sports Med.* 41(Suppl. 1), i64–i67. doi: 10.1136/bjsm.2007.036970

Krustrup, P., Zebis, M., Jensen, J. M., and Mohr, M. (2010). Game-induced fatigue patterns in elite female soccer. *J. Strength Cond. Res.* 24, 437–441. doi: 10.1519/JSC.0b013e3181c09b79

Loe, H., Rognmo, Ø, Saltin, B., and Wisløff, U. (2013). Aerobic capacity reference data in 3816 healthy men and women 20–90 years. *PloS One* 8:e64319. doi: 10.1371/journal.pone.0064319

Miller, A. E., MacDougall, J. D., Tarnopolsky, M. A., and Sale, D. G. (1993). Gender differences in strength and muscle fiber characteristics. *Eur. J. Appl. Physiol. Occup. Physiol.* 66, 254–262. doi: 10.1007/bf00235103

Mohr, M., Krustrup, P., and Bangsbo, J. (2005). Fatigue in soccer: a brief review. *J. Sports Sci.* 23, 593–599. doi: 10.1080/02640410400021286

Møllerløkken, N. E., Lorås, H., and Pedersen, A. V. (2015). A systematic review and meta-analysis of dropout rates in youth soccer. *Percept. Mot. Skills* 121, 1–11. doi: 10.2466/10.PMS.121c23x0

NCD (2016). Risk Factor Collaboration (NCD-RisC). A century of trends in adult human height. *eLife* 5:e13410. doi: 10.7554/eLife.13410

NFF (2019). *(Norges Fotballforbund, The Norwegian Football Association). Spilleregler og Retningslinjer – Ungdomsfotball 13-16 år (Rules and Regulations for Youth Soccer 13-16 Years)*. Available at: https://www.fotball.no/lov-og-reglement/spilleregler/spilleregler-og-retningslinjer---ungdomsfotball-13-16-ar/#71023 (accessed March 3, 2019).

Nikolaidis, P. T. (2014). Weight status and physical fitness in female soccer players: is there an optimal BMI? *Sport Sci. Health* 10, 41–48. doi: 10.1007/s11332-014-0172-2

Njororai, W. W. S. (2013). Downward trend of goal scoring in world cup soccer tournaments (1930 to 2010). *J. Coach. Educ.* 6, 111–120. doi: 10.1123/jce.6.1.111

NRK (2019). *The Norwegian Broadcasting Corporation. Norske Toppspillere må Bruke Barnesko, Ekstra Strømper og Såler (Norwegian Top [Soccer] Players have to Use Shoes Made for Kid)*. Available at: https://www.nrk.no/sport/norske-toppspillere-ma-bruke-barnesko_-ekstra-stromper-og-saler-1.14386279 (accessed March 3, 2019).

Patterson, D. D., and Peterson, D. F. (2004). Vertical jump and leg power norms for young adults. *Meas. Phys. Educ. Exerc. Sci.* 8, 33–41. doi: 10.1207/s15327841mpee0801_3

Pedersen, A. V., and Stalsberg, R. (2019). Differences in soccer heading injuries between male and female soccer players may be due to equal ball weight causing differences in relative impacts. *Radiology* 290, 579–580. doi: 10.1148/radiol.2018182384

Peeters, R., and Elling, A. (2015). The coming of age of women's football in the Dutch sports media, 1995–2013. *Soccer Soc.* 16, 620–638. doi: 10.1080/14660970.2014.963313

Reeves, S. L., Varakamin, C., and Henry, C. J. (1996). The relationship between arm-span measurement and height with special reference to gender and ethnicity. *Eur. J. Clin. Nutr.* 50, 398–400.

Rubin, T. G., Catenaccio, E., Fleysher, R., Hunter, L. E., Lubin, N., Stewart, W. F., et al. (2018). MRI-defined white matter microstructural alteration associated with soccer heading is more extensive in women than men. *Radiology* 289, 478–486. doi: 10.1148/radiol.2018180217

Sailors, P. R. (2016). Off the beaten path: should women compete against men? *Sport in Society* 19, 1125–1137. doi: 10.1080/17430437.2015.1096255

Sakamoto, K., Sasaki, R., Hong, S., Matsukura, K., and Asai, T. (2014). Comparison of kicking speed between female and male soccer players. *Procedia Eng.* 72, 50–55. doi: 10.1016/j.proeng.2014.06.011

Schmader, T., Johns, M., and Forbes, C. (2008). An integrated process model of stereotype threat effects on performance. *Psychol. Rev.* 115, 336–356. doi: 10.1037/0033-295X.115.2.336

Subramanian, S. V., Özaltin, E., and Finlay, J. E. (2011). Height of nations: a socioeconomic analysis of cohort differences and patterns among women in 54 low- to middle-income countries. *PLoS One* 6:e18962. doi: 10.1371/journal.pone.0018962

Taylor, S. (2018). *How Misogyny Affects Soccer in Italy. Girls Soccer Network*. Available at: https://girlssoccernetwork.com/news/world/soccer-lifestyle-misogyny-in-italy/ (accessed March 3, 2019).

The Guardian (2013). *Zlatan Ibrahimovic Branded 'Boring' and 'SAd' for Women's Football Remarks, The Guardian, 26 Dec 2013*. Available at: https://www.theguardian.com/football/2013/dec/26/zlatan-ibrahimovic-branded-boring-sad-womens-football-remarks(accessed March 3, 2019).

The Local (2013). *Swedish Football Ladies Beaten by Teen Boys*. Available at: https://www.thelocal.se/20130116/45646 (accessed November 28, 2018).

Theberge, N. (1998). "Same sport, different gender" a consideration of binary gender logic and the sport continuum in the case of ice hockey. *J. Sport Soc. Issues* 22, 183–198. doi: 10.1177/019372398022002005

Theberge, N. (2015). Should women move like men? the construction of gender and difference in research on anterior cruciate ligament injuries. *Quest* 67, 424–438. doi: 10.1080/00336297.2015.1085884

Tønnessen, E., Haugen, T. A., Hem, E., Leirstein, S., and Seiler, S. (2015). Maximal aerobic capacity in the winter-Olympics endurance disciplines: Olympic-medal benchmarks for the time period 1990–2013. *Int. J. Sports Physiol. Perform.* 10, 835–839. doi: 10.1123/ijspp.2014-0431

Tønnessen, E., Hem, E., Leirstein, S., Haugen, T., and Seiler, S. (2013). Maximal aerobic power characteristics of male professional soccer players, 1989–2012. *Int. J. Sports Physiol. Perform.* 8, 323–329. doi: 10.1123/ijspp.8.3.323

UEFA (2017). *Women's Football Across the National Associations 2017*. Available at: https://preview.thenewsmarket.com/Previews/UEFA/DocumentAssets/490985.pdf (accessed March 3, 2019).

Wikipedia (2018). *2015 FIFA Women's World Cup Squads*. Available at: https://en.wikipedia.org/wiki/2015_FIFA_Women%27s_World_Cup_squads (accessed March 3, 2019).

Ziv, G., and Lidor, R. (2011). Physical characteristics, physiological attributes, and on-field performances of soccer goalkeepers. *Int. J. Sports Physiol. Perform.* 6, 509–524. doi: 10.1123/ijspp.6.4.509

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Wheelchair Basketball Competition Heart Rate Profile According to Players' Functional Classification, Tournament Level, Game Type, Game Quarter and Playing Time

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Heart rate is a popular parameter observed in team sports to plan training sessions with regard to load and sport specificity. Wheelchair basketball is an intermittent team game for physically impaired players. The study aim was to define heart rate profile of wheelchair basketball players in terms of their functional classification (category A: 1.0–2.5 points, category B: 3.0–4.5 points), tournament level (championships and friendly games), game type (close, balanced, and unbalanced), game quarter (1st, 2nd, 3rd, and 4th) and playing time (40–59%, 60–79%, and 80–100% in a quarter). Heart rate of 18 wheelchair basketball players was monitored in 22 games in four different tournaments, i.e., European Championships 2017, World Championships 2018, two friendly international tournaments of national teams (2017 and 2018). Heart rate (HR_{mean}, HR_{peak}, $\%HR_{peak}$, HRR, and %HRR) was monitored by Polar Team Pro (Kempele, Finland) during playing time on the court. Timeouts, quarter breaks, a half break, time on a bench were not taken into account in HR monitoring. The Kolmogorov–Smirnov test, the Mann–Whitney U test and the Kruskal–Wallis test were used. Fourteen players divided according to the classification into category A and B were included in the final calculations (n = 457 cases). Significantly higher HR_{mean}, $\%HR_{peak}$, HR_{peak}, and %HRR were noted among category B players, and higher $\%HR_{peak}$ and %HRR among category A players at the highest tournament level compared to friendly games. There were significant differences in %HRR and the percentage of time spent in HR zone I between the players with different playing time (40–59% versus 60–79%) in category B. No significant differences in HR were noted between four quarters. Among category A players, differences in HR in zone II were observed. Among category B players, statistically significant differences in $\% HR_{peak}$, the percentage of time spent in HR zones I, II, III, and %HRR between close, balanced and unbalanced games were found. In conclusion, the intermittent nature of wheelchair basketball was confirmed. Monitoring heart rate in a game could be helpful in creating exercises with proper loads for better physical preparation of wheelchair basketball players. High intensity training sessions would be more beneficial in preparing players for game demands.

Keywords: Paralympic sport, wheelchair basketball players, classification in sport, heart rate, match load, match analysis, physiological demands, adaptive sports

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INTRODUCTION

Heart rate (HR) is a popular parameter showing the frequency of electrical heart activity in team sports training sessions and games. HR and oxygen consumption are used for predicting maximal oxygen consumption during tests. HR is a useful parameter to monitor exercise intensity, to assess fatigue status, and to quantify internal training loads in intermittent team sports, e.g., running basketball (Berkelmans et al., 2018).

Wheelchair basketball is an intermittent team game for people with physical impairments characterized by chronic or serious conditions limiting their possibility to use lower limbs to play running basketball, e.g., spinal cord injury, cerebral palsy, musculoskeletal conditions, spina bifida, amputation, poliomyelitis (Coutts, 1992; International Wheelchair Basketball Federation, 2014). The International Wheelchair Basketball Federation (IWBF) controls the classification and game rules of wheelchair basketball. Wheelchair basketball game rules are different compared to running basketball game rules due to the manner of moving (the player performs more than two pushes while in possession of the ball without dribbling, passing or shooting), type of faults (wheelchair contacts), and functional classification of players on the court (the sum of points of five players on the court cannot exceed 14.0 points, e.g., 4.5, 4.0, 3.0, 1.0, and 1.5) (International Wheelchair Basketball Federation, 2014; International Wheelchair Basketball Federation, 2018). All time rules (3 s in the opponents' restricted area, 5 s to release the ball toward the court, 8 s to advance the ball over the center line, reset the shot clock to 14 s, 24 s to put up the legal shot, quarter time, break time), size of the court, the ball, height of baskets and point scoring system (throws for 1, 2, or 3 points) are the same for wheelchair basketball and running basketball (International Wheelchair Basketball Federation, 2018). Functional classification of the players is based on the observations carried out by experts (classifiers in wheelchair basketball) during a match. There are five main classes in wheelchair basketball: 1.0, 2.0, 3.0, 4.0, and 4.5, and three mixed classes 1.5, 2.5, and 3.5 (mixed functional characteristics of neighboring classes). Players are often divided into two categories: A (1.0–2.5) and B (3.0–4.5) (International Wheelchair Basketball Federation, 2014).

In wheelchair basketball, similar to running basketball, HR monitoring was applied to assess match load, i.e., the intensity of activity (Pérez et al., 2007; Croft et al., 2010; Yanci et al., 2014; Iturricastillo et al., 2016a,b; dos Santos et al., 2017). However, in wheelchair basketball it is important to underline certain disadvantages of HR measurement in people with spinal cord injury above Th5/6 characterized either by the loss of sympathetic outflow to the heart, where maximal HR (HR_{peak}) is around 100 to 140 beats/min, or by autonomic dysreflexia (Theisen, 2012). Nevertheless, research related to running basketball is similar to research regarding wheelchair basketball. For instance, Delextrat and Kraiem (2013) showed that a small-sided game training exerted a positive influence on aerobic capacity and technical skills in running basketball players (Delextrat and Kraiem, 2013). Yanci et al. (2014) monitored HR during small-sided wheelchair basketball games (four sets in each session, 2-min intervals between the sets). They concluded that small-sided games are similarly demanding compared to official wheelchair basketball matches in terms of HR_{mean} values and can be a good predictive factor for a coach regarding the players' anaerobic and aerobic preparation, and their reactions to the intensity of exercises (Yanci et al., 2014). Mason et al. (2018) compared 3 vs. 3 (small-sided games on a half court) and 5 vs. 5 wheelchair basketball games, and found that HR_{peak} and HR_{mean} were higher for 5 vs. 5 games. It turned out that 3 vs. 3 games are good to practice the specificity of wheelchair basketball because of more severe rotations, turnovers, rebounds and other high-intensity technical skills (Mason et al., 2018).

Taking into account all the above-mentioned studies (Pérez et al., 2007; Croft et al., 2010; Yanci et al., 2014; Iturricastillo et al., 2016a,b; dos Santos et al., 2017; Mason et al., 2018) the authors of only three of them compared the participants' HR in a wheelchair basketball game according to the players' functional classification (they were observing differences in HR between the players from category A and players from category B) (Pérez et al., 2007; Iturricastillo et al., 2016b; Marszalek et al., 2019). In three studies, HR, oxygen consumption and blood lactate were analyzed in an aerobic test and HR was monitored during an international wheelchair basketball competition (Croft et al., 2010; dos Santos et al., 2017; Marszalek et al., 2019). In other studies, HR during small-sided wheelchair basketball games was monitored (Yanci et al., 2014; Mason et al., 2018), and two methods of match load assessment, i.e., HR and rate of perceived exertion (RPE), were compared (Iturricastillo et al., 2016a). The research group in the above-mentioned studies included 3–10 wheelchair basketball players. Moreover, we found that there were no global analyses of players' HR response and playing time, differences in HR between game quarters, tournament level, overall game outcome (final result of a game) regarding wheelchair basketball, but there was research on running basketball players (Vaquera Jiménez, 2008; Puente et al., 2017; Ramos-Campo et al., 2017; Montgomery and Maloney, 2018), and it also seems to be important for wheelchair basketball (Berkelmans et al., 2018). The importance of HR quantifying and monitoring with regard to the players' classification as well as to playing time, game quarters, tournament level or game outcome would be useful for coaches and players to conduct training practice adapted to intermittent game effort (wheelchair basketball game load) and to plan pre-season and in-season exercise intensity for the players to reach the highest level according to their classification (type of impairments). Measuring HR according to playing time and game quarter will help coaches to create effective endurance training (to improve the players' anaerobic and aerobic capacity). Taking into account these HR observations, coaches can adapt exercise time, number of repetitions and number of exercise series individually to each player. It will help coaches to conduct training sessions at the intensity similar to the one observed during a game (similar HR parameters of training efforts) with regard to the tournament level (championships or friendly games), the final game outcome (close, balanced, and unbalanced games), HR in a selected quarter (1st, 2nd 3rd, and 4th quarter) or playing time (40–59, 60–79, and 80–100% of playing time in a quarter). In particular, monitoring typical responses of players in a game allows basketball practitioners to better tailor training activities that meet or exceed the internal intensities of a game (Ben Abdelkrim et al., 2007). Thus, we see that these types of analyses would be helpful for wheelchair basketball coaches. The aim of the current study was to define the profile of heart rate of wheelchair basketball players in terms of their functional classification, tournament level, game type, game quarter and playing time.

MATERIALS AND METHODS

Participants

Eighteen wheelchair basketball players (national team players) were monitored in four different tournaments, i.e., European Championships in Tenerife, Spain 2017, World Championships in Hamburg, Germany 2018 (eight and six games, respectively) and two friendly international tournaments of national teams (Walbrzych, Poland 2017 and 2018; four and four games, respectively). In total, 18 players in 22 games were observed and their HR was monitored. All the players were members of the national team. They practiced regularly (at least 6–8 h per week) with their league teams, and they participated in national camps: 7 days (1 week) per month in the 4th–6th month before the tournaments and 20 days per month in the 1st to 3rd month before the tournaments. Game schedule for European Championships in Tenerife, Spain (2017), and World Championships in Hamburg, Germany (2018) was similar (one game per day, in the afternoon or in the morning). During friendly international tournaments of national teams there were two games per day, one in the morning and one in the evening (with at least a 7-h break).

Participants were informed about the purpose of the study and were asked to sign the consent form. All the procedures were approved by the Local Bioethics Committees (the Commission of Ethics and Bioethics at Cardinal Stefan Wyszyński University in Warsaw: KEIB - 10/2016, and the Senate Ethics Commission at Jozef Piłsudski University of Physical Education in Warsaw: SKE 01-16/2017) and were completed in accordance with the ethical standards as described in the Declaration of Helsinki.

Playing time in a quarter (a player had to spend at least 40% of the time in a quarter without timeouts or substitutions; at least 6 min in a quarter) was an inclusion criterion applied in the study. For instance, one player was on the court for the first 6 min in the first quarter. A coach took timeout and the same player participated in this quarter for the next 5 min. The first quarter took 15 min in total (with breaks, timeouts, etc.) and the athlete's playing time in a quarter was 40 and 33%, respectively. In our analysis, we included the 6 min of his playing time in a quarter because it took more than 40% of the total time of the first quarter. Moreover, the player had to play at least five times on the court in one match. In conclusion, any problem with a chest strap, less than 40% of playing time in a quarter without time outs or substitutions, less than 5 times on the court in one match excluded the player from our calculations. The inclusion and exclusion criteria concerned each participant in each game type (close, balanced, unbalanced, championships, and friendly games).

Heart Rate Recording

Heart rate (HR; HR_{mean}, HR_{peak}, and $\%HR_{peak}$) of all the players was monitored during each match with the use of downloadable, wireless Polar Team Pro (Polar Team Pro, Kempele, Finland) and Polar heart rate sensor attached to a chest strap. HR frequency was coded at 1-s registration intervals. Inactive time (e.g., quarter breaks, half-time break, time outs in each match) was also registered by Polar Team Pro. Each situation in a game such as the start of a match, quarter breaks, a half-time break, time outs in each match, substitutions of each player, time after the end of a match was marked in the Polar Team Pro software. Moreover, markers applied in the Polar Team Pro software and observations of all the matches on video footage made it possible to delete the time of the above-mentioned situations from the players' HR history.

Five HR zones (I – 50–59%, II – 60–69%, III – 70–79%, IV – 80–89%, and V – 90–100%) are originally set in the Polar Team Pro software and % of time in each zone was taken as outcome measure. Heart rate reserve (HRR) and the percentage of heart rate reserve (%HRR) were calculated. HRR is the difference between maximum heart rate (HR_{peak}) from a valid and reliable aerobic test and resting heart rate (HR_{rest}) (Janssen et al., 1994; Pérez et al., 2003):

[1] $HRR = HR_{peak}$ from a test $- HR_{rest}$

The percentage of heart rate reserve (%HRR) was calculated using the formula:

[2] $\%HRR = (HR_{mean} - HR_{rest})*100/HRR$

To do the above calculations, HR_{peak} for each player was determined before match analyses (1–4 weeks before tournaments, May 2017 and May 2018) in a valid and reliable aerobic performance laboratory test (Molik et al., 2017; Marszalek et al., 2019) on an arm crank ergometer (Lode ACE; Groningen; Netherlands). Resting heart rate (HR_{rest}) was measured in each player on the examination day in the morning immediately after waking up.

Analyzed Variables

Heart rate profile of wheelchair basketball players was observed in terms of their functional classification, tournament level, game type, game quarter, and playing time.

Functional classification of all the players was done by IWBF panel of classifiers, and the players were divided into two functional categories: A and B (category A players with the classification of 1.0–2.5 points and category B players with the classification of 3.0–4.5 points). Tournament level means that the analyzed games were divided into championships (European Championships 2017 and World Championships 2018) and friendly international games (two friendly international tournaments). Playing time means that a player spent 40–59, 60–79, or 80–100% of the time playing actively in a game. HR was also analyzed with regard to a quarter

(1st, 2nd, 3rd, and 4th quarter), and final point differential (close games – differences in the scores ranged from 1 to 6 points, balanced games – differences in the scores ranged from 7 to 17 points, and unbalanced games - differences in the scores were larger than 18 points).

Statistical Analysis

All the analyses were performed using the SPSS IBM Statistics 24 for Windows. Means and standard deviation (SD) of HR data were calculated. The distribution of the results was checked with the use of the Kolmogorov–Smirnov test. All the results had non-parametric distribution so the Mann–Whitney *U* test and the Kruskal–Wallis test for independent samples were used to compare the results of players depending on their functional category (category A and B), tournament level (European Championships 2017 and World Championships 2018 versus two friendly international tournaments), playing time (40–59, 60–79, and 80–100%), quarter (1st, 2nd, 3rd, and 4th quarter), and final point differential (the cluster analysis showed the following: close games – differences in the scores ranged from 1 to 6 points, balanced games – differences in the scores ranged from 7 to 17 points and unbalanced games – differences in the scores were larger than 18 points). The significance level deemed acceptable was $p < 0.05$. Additionally, effect size (ES) was calculated. The following levels of effect sizes were estimated: small 0.2, medium 0.5, and large 0.8 (Cohen, 1988).

RESULTS

After considering all inclusion and exclusion criteria, 14 out of 18 players were taken into account in the final calculations and we received 457 cases (HR data) to analyze. The characteristics of HR data of wheelchair basketball players are presented in **Table 1**. These 14 players were divided into two groups, i.e., category A (functional classification 1.0–2.5 points; $n = 6$) and category B (functional classification 3.0–4.5 points; $n = 8$). Category A players had such impairments as spinal cord injury ($n = 6$) and category B players had such impairments as amputation ($n = 4$), spina bifida ($n = 2$), cerebral palsy ($n = 1$), and others ($n = 1$).

TABLE 1 | The characteristics of heart rate data of wheelchair basketball players (*N* = 457 cases).

Parameters	Median	Mean	*SD*
HR_{mean} [beats/min]	159.00	156.78	15.69
HR_{peak} [beats/min]	177.00	174.52	13.29
HR_{peak} [%]	96.00	96.48	6.48
HR zone I [%]	0.00	0.85	3.75
HR zone II [%]	1.06	5.25	11.04
HR zone III [%]	10.41	15.37	15.55
HR zone IV [%]	37.47	36.91	20.35
HR zone V [%]	38.21	38.70	27.83
HRR	124.00	121.90	9.10
%HRR	79.84	78.93	10.23

N, number of cases; HR, heart rate; SD, standard deviation; HRmean, mean heart rate; %HRpeak, the percentage of maximal heart rate in a match; HRpeak, maximal heart rate in a match; HRR, heart rate reserve; %HRR, the percentage of heart rate reserve.

Table 2 shows differences in the analyzed HR data of wheelchair basketball players between the two functional categories (A and B). Significantly higher values of HR_{mean}, HR_{peak}, $\%HR_{peak}$, HRR and %HRR were observed in players from category B, while the effect size was large. Players from category B spent significantly more time in HR zone V compared to category A players (43.24% vs. 31.12%). There were no differences in the percentage of time spent in HR zone IV between the players from category A and B (**Table 2**).

Table 3 shows differences in the analyzed HR data separately for wheelchair basketball players from category A and B according to the tournament level (European Championships 2017 and World Championships 2018 versus two friendly international tournaments). Significantly higher HR_{mean}, $\%HR_{peak}$, HR_{peak}, and %HRR were observed in the players from category B in the highest level of tournaments compared to friendly games. The effect size was large or medium for these differences. The values of $\%HR_{peak}$ and %HRR in players from category A were significantly higher in the highest-level tournaments compared to friendly games (**Table 3**).

Table 4 shows differences in HR data of wheelchair basketball players from category A and B according to playing time. There were no statistically significant differences in HR data between the percentage of playing time for category A players. Two differences in %HRR and the percentage of time spent in HR zone I were found with regard to playing time (40–59% versus 60–79%; **Table 4**) for players from category B ($n = 8$).

Table 5 shows differences in HR data of wheelchair basketball players from category A and B with regard to game quarter. We did not observe statistically significant differences in any HR data of players from category A and B between four quarters (**Table 5**).

Table 6 shows differences in HR data of wheelchair basketball players from category A and B according to final point differential (game types: close, balanced and unbalanced games). Among players from category A, no differences in HR data were noted except for the percentage of time spent in HR zone IV and HRR between balanced and unbalanced games, and HRR between close and unbalanced games (in each case, higher values of variables were observed in unbalanced games). In the case of category B players, there were statistically significant differences between close and balanced games regarding HR_{peak} (higher values were observed in balanced games), between the percentage of time spent in HR zones IV (higher values were observed in close games) and V (higher values were observed in balanced games), between close and unbalanced games in HRR (higher values were observed in close games), and between balanced and unbalanced games in HR_{peak} and $\%HR_{peak}$ (higher values were observed in balanced games), as well as in the percentage of time spent in HR zones III and IV (higher values were observed in unbalanced games) and in zone V (higher values were observed in balanced games) and HRR (higher values were observed in balanced games) (**Table 6**).

TABLE 2 | Differences in heart rate data of wheelchair basketball players according to functional category (A and B).

Parameters	Wheelchair basketball players										
	Category A (class from 1.0 to 2.5) (*n* = 6)				Category B (class from 3.0 to 4.5) (*n* = 8)						
	Median	Mean	*SD*	*N*	Median	Mean	*SD*	*N*	*Z*	*p*	ES
HR_{mean} [beats/min]	151.00	148.99	17.48	171	162.00	161.44	12.39	286	−7.297	***	2.49
HR_{peak} [beats/min]	171.00	167.81	15.21	171	180.00	178.53	10.06	286	−7.436	***	2.59
HR_{peak} [%]	95.00	94.51	6.43	171	97.00	97.66	6.22	286	−4.000	***	0.75
HR zone I [%]	0.00	1.67	5.81	171	0.00	0.35	1.33	286	−3.416	***	0.55
HR zone II [%]	2.27	8.96	15.31	171	0.25	3.03	6.47	286	−5.044	***	1.19
HR zone III [%]	16.15	19.75	17.52	171	8.73	12.75	13.62	286	−4.203	***	0.83
HR zone IV [%]	39.55	37.53	18.66	171	35.45	36.54	21.32	286	−0.862	n.s.	–
HR zone V [%]	27.44	31.12	26.96	171	43.90	43.24	27.40	286	−4.570	***	0.98
HRR	119.00	117.99	8.39	171	124.00	124.23	8.71	286	−7.491	***	2.62
%HRR	76.85	75.37	11.64	171	80.69	81.06	8.64	286	−5.160	***	1.25

****p < 0.001; n.s., no statistically significant differences; N, number of cases; HR, heart rate; SD, standard deviation; Min, minimum; Max, Maximum; ES, effect size for the U-Mann–Whitney test; HRmean, mean heart rate; %HRpeak, the percentage of maximal heart rate in a match; HRpeak, maximal heart rate in a match; HRR, heart rate reserve; %HRR, the percentage of heart rate reserve.*

TABLE 3 | Differences in heart rate data of wheelchair basketball players from category A and B according to tournament level.

Parameters	Championships				Friendly international tournaments						
	Median	Mean	*SD*	*N*	Median	Mean	*SD*	*N*	*Z*	*p*	ES
Wheelchair basketball players category A											
HR_{mean} [beats/min]	152.00	151.26	16.03	100	151.00	145.79	19.00	71	−1.604	n.s.	–
HR_{peak} [beats/min]	170.00	169.43	14.03	100	172.00	165.52	16.56	71	−1.315	n.s.	–
HR_{peak} [%]	96.00	95.96	5.72	100	93.00	92.46	6.85	71	−3.711	***	1.05
HR zone I [%]	0.00	0.55	1.77	100	0.00	3.24	8.55	71	−2.331	*	0.42
HR zone II [%]	1.28	6.84	13.60	100	4.55	11.95	17.09	71	−2.885	**	0.64
HR zone III [%]	11.19	16.33	15.59	100	20.16	24.57	19.02	71	−2.938	**	0.66
HR zone IV [%]	39.33	38.42	17.85	100	39.61	36.28	19.80	71	−0.513	n.s.	–
HR zone V [%]	35.93	36.54	26.56	100	16.32	23.48	25.81	71	−3.379	***	0.87
HRR	111.00	116.36	7.77	100	123.00	120.28	8.75	71	−2.950	**	0.67
%HRR	80.47	78.72	10.82	100	71.20	70.64	11.17	71	−4.406	***	0.48
Wheelchair basketball players category B											
HR_{mean} [beats/min]	165.00	164.38	11.98	180	157.00	156.45	11.49	106	−5.143	***	1.56
HR_{peak} [beats/min]	181.00	180.63	9.66	180	176.00	174.95	9.75	106	−4.529	***	1.21
HR_{peak} [%]	97.00	98.24	5.69	180	95.00	96.68	6.96	106	−2.467	*	0.36
HR zone I [%]	0.00	0.28	1.16	180	0.00	0.48	1.58	106	−2.944	**	0.51
HR zone II [%]	0.00	1.95	4.26	180	1.72	4.87	8.79	106	−4.465	***	1.18
HR zone III [%]	7.89	10.57	11.76	180	12.80	16.46	15.68	106	−3.413	***	0.69
HR zone IV [%]	30.67	34.20	20.55	180	41.92	40.51	22.11	106	−2.329	*	0.32
HR zone V [%]	51.48	48.93	26.51	180	33.51	33.58	26.28	106	−4.572	***	1.24
HRR	124.00	124.81	8.80	180	124.00	123.25	8.50	106	−1.414	n.s.	–
%HRR	82.74	83.19	8.43	180	78.08	77.44	7.77	106	−3.394	***	1.72

**p < 0.05; **p < 0.01; ***p < 0.001; n.s., no statistically significant differences; N, number of cases; HR, heart rate; SD, standard deviation; Min, minimum; Max, Maximum; ES, effect size for the U-Mann–Whitney test; HRmean, mean heart rate; %HRpeak, the percentage of maximal heart rate in a match; HRpeak, maximal heart rate in a match; HRR, heart rate reserve; %HRR, the percentage of heart rate reserve.*

DISCUSSION

The aim of this study was to define the profile of heart rate of wheelchair basketball players in terms of their functional classification, tournament level, game type, game quarter and playing time.

Considering all exclusion and inclusion criteria, HR data of 14 people were analyzed. The players' HRR, HR_{mean}, HR_{peak},

TABLE 4 | Differences in heart rate data of wheelchair basketball players from category A and B according to playing time.

Parameters	Players with 40–59% of playing time				Players with 60–79% of playing time				Players with 80–100% of playing time					
	Median	**Mean**	***SD***	***N***	**Median**	**Mean**	***SD***	***N***	**Median**	**Mean**	***SD***	***N***	***p***	**ES**
Wheelchair basketball players category A														
HR_{mean} [beats/min]	153.00	149.47	17.08	99	147.00	146.58	19.36	33	151.00	149.79	17.12	39	n.s.	–
HR_{peak} [beats/min]	171.00	167.77	15.30	99	167.00	165.82	15.87	33	170.00	169.59	14.59	39	n.s.	–
HR_{peak} [%]	95.00	94.40	6.93	99	94.00	93.73	6.63	33	96.00	95.44	4.76	39	n.s.	–
HR zone I [%]	0.00	1.54	5.80	99	0.00	2.86	8.00	33	0.00	0.99	2.90	39	n.s.	–
HR zone II [%]	2.34	9.17	16.57	99	2.63	9.58	14.62	33	2.05	7.91	12.61	39	n.s.	–
HR zone III [%]	16.91	19.64	17.73	99	19.60	22.60	18.49	33	12.31	17.60	16.23	39	n.s.	–
HR zone IV [%]	39.00	36.29	18.32	99	41.51	37.54	22.34	33	41.19	40.68	16.04	39	n.s.	–
HR zone V [%]	30.35	32.43	28.33	99	21.20	25.55	25.57	33	29.83	32.52	24.42	39	n.s.	–
HRR	123.00	118.40	8.39	99	111.00	116.36	7.99	33	111.00	118.33	8.76	39	n.s.	–
%HRR	76.42	75.49	11.52	99	76.42	74.85	13.72	33	77.48	75.48	10.26	39	n.s.	–
Wheelchair basketball players category B														
HR_{mean} [beats/min]	164.00	162.30	12.44	150	158.00	158.64	12.69	75	162.00	162.79	11.53	61	n.s.	–
HR_{peak} [beats/min]	180.00	178.79	9.62	150	177.00	176.73	10.67	75	180.00	180.10	10.17	61	n.s.	–
HR_{peak} [%]	96.00	97.69	5.97	150	96.00	96.97	6.43	75	97.00	98.46	6.56	61	n.s.	–
HR zone I [%]	0.00	0.31	1.33	150^	0.00	0.48	1.64	75^	0.00	0.31	0.83	61	*	0.52
HR zone II [%]	0.00	3.17	7.72	150	0.69	3.67	5.72	75	0.79	1.91	2.97	61	n.s.	–
HR zone III [%]	8.47	11.75	12.34	150	10.42	15.43	15.02	75	8.21	11.94	14.57	61	n.s.	–
HR zone IV [%]	30.52	35.07	21.78	150	39.87	38.70	19.08	75	41.12	37.50	22.82	61	n.s.	–
HR zone V [%]	46.61	45.11	26.83	150	39.62	39.66	28.76	75	43.80	43.02	27.11	61	n.s.	–
HRR	124.00	123.52	8.55	150	124.00	124.89	9.10	75	124.00	125.18	8.62	61	n.s.	–
%HRR	82.24	82.22	8.96	150^	78.23	78.47	8.32	75^	80.15	81.40	7.61	61	*	0.77

**$p < 0.05$; ^, differences between groups $p < 0.05$; n.s., no statistically significant differences; N, number of cases; HR, heart rate; SD, standard deviation; Min, minimum; Max, Maximum; ES, effect size for the U-Mann–Whitney test; HRmean, mean heart rate; %HRpeak, the percentage of maximal heart rate in a match; HRpeak, maximal heart rate in a match; HRR, heart rate reserve; %HRR,the percentage of heart rate reserve.*

TABLE 5 | Differences in heart rate data of wheelchair basketball players from category A and B according to game quarter.

	1st quarter				2nd quarter				3rd quarter				4th quarter				
Parameters	**Median**	**Mean**	***SD***	***N***	**Median**	**Mean**	***SD***	***N***	**Median**	**Mean**	***SD***	***N***	**Median**	**Mean**	***SD***	***N***	***p***
Wheelchair basketball players category A																	
HR_{mean} [beats/min]	150.50	149.81	17.92	48	154.00	149.24	18.43	46	150.00	146.72	15.92	43	155.00	150.35	17.94	34	n.s.
HR_{peak} [beats/min]	168.00	168.13	15.70	48	172.50	167.78	16.43	46	169.00	166.26	14.16	43	171.00	169.35	14.55	34	n.s.
HR_{peak} [%]	96.00	95.21	6.33	48	95.00	94.46	7.16	46	94.00	93.51	6.06	43	95.00	94.85	6.08	34	n.s.
HR zone I [%]	0.00	1.75	5.00	48	0.00	1.60	5.32	46	0.00	1.92	7.28	43	0.00	1.34	5.65	34	n.s.
HR zone II [%]	1.84	8.22	13.60	48	2.18	10.04	18.53	46	2.95	8.34	12.74	43	2.31	9.34	16.32	34	n.s.
HR zone III [%]	9.28	15.52	15.95	48	18.37	20.13	17.48	46	19.70	24.81	19.74	43	16.36	18.80	15.71	34	n.s.
HR zone IV [%]	37.96	38.71	19.72	48	32.59	33.86	18.63	46	44.37	40.64	17.86	43	37.63	36.89	18.05	34	n.s.
HR zone V [%]	32.80	35.16	26.84	48	24.67	32.54	29.77	46	15.89	23.77	24.52	43	30.49	32.79	25.38	34	n.s.
HRR	111.00	117.19	8.31	48	119.00	117.91	7.99	46	119.00	118.67	8.44	43	115.00	118.35	9.45	34	n.s.
%HRR	78.39	76.12	11.11	48	77.64	75.89	12.43	46	74.07	73.28	10.60	43	78.51	76.25	12.26	34	n.s.
Wheelchair basketball players category B																	
HR_{mean} [beats/min]	164.00	162.32	10.88	82	160.00	161.39	12.50	74	159.00	159.16	12.08	67	165.00	162.79	14.26	63	n.s.
HR_{peak} [beats/min]	178.00	178.24	9.74	82	180.00	179.30	9.46	74	176.00	176.94	9.48	67	181.00	179.68	11.63	63	n.s.
HR_{peak} [%]	97.00	97.83	6.28	82	98.00	98.07	6.20	74	96.00	97.01	6.37	67	96.00	97.67	6.11	63	n.s.
HR zone I [%]	0.00	0.30	0.80	82	0.00	0.47	1.62	74	0.00	0.44	1.84	67	0.00	0.19	0.75	63	n.s.
HR zone II [%]	0.76	2.09	3.60	82	0.00	3.79	8.78	74	0.65	3.26	6.30	67	0.00	3.13	6.37	63	n.s.
HR zone III [%]	6.44	10.24	12.80	82	9.87	12.70	12.12	74	9.68	14.84	14.43	67	9.00	13.87	15.17	63	n.s.
HR zone IV [%]	36.68	38.19	22.89	82	29.77	33.35	20.27	74	40.87	40.58	21.54	67	31.94	33.83	19.67	63	n.s.
HR zone V [%]	45.28	44.72	27.02	82	48.55	46.09	28.03	74	39.88	37.26	27.11	67	47.31	44.30	27.18	63	n.s.
HRR	124.00	124.63	9.38	82	124.00	123.46	9.01	74	124.00	124.21	8.70	67	124.00	124.66	8.93	63	n.s.
%HRR	80.88	81.56	7.06	82	80.19	81.56	9.11	74	80.15	79.21	8.22	67	81.45	81.79	10.18	63	n.s.

**$p < 0.05$; n.s., no statistically significant differences; N, number of cases; HR, heart rate; SD, standard deviation; Min, minimum; Max, Maximum; ES, effect size for the U-Mann–Whitney test; HRmean, mean heart rate; %HRpeak, the percentage of maximal heart rate in a match; HRpeak, maximal heart rate in a match; HRR, heart rate reserve; %HRR,the percentage of heart rate reserve.*

TABLE 6 | Differences in heart rate data of wheelchair basketball players from category A and B according to final point differential.

Parameters	Close games Score difference between 1–6 points (*n* = 8)				Balanced games Score difference between 7–17 points (*n* = 10)				Unbalanced games Score difference above 18 points (*n* = 5)					
	Median	**Mean**	***SD***	***N***	**Median**	**Mean**	***SD***	***N***	**Median**	**Mean**	***SD***	***N***	***p***	**ES**
Wheelchair basketball players category A														
HR_{mean} [beats/min]	150.00	147.42	19.31	72	147.00	147.96	17.33	53	155.50	152.63	14.15	46	n.s.	–
HR_{peak} [beats/min]	167.50	165.82	16.66	72	169.00	167.43	14.68	53	175.00	171.35	12.96	46	n.s.	–
HR_{peak} [%]	95.00	93.50	7.30	72	96.00	95.49	5.93	53	96.00	94.96	5.33	46	n.s.	–
HR zone I [%]	0.00	2.91	8.52	72	0.00	0.96	2.31	53	0.00	0.55	1.56	46	n.s.	–
HR zone II [%]	2.35	9.61	15.59	72	2.56	9.86	14.85	53	1.92	6.93	15.55	46	n.s.	–
HR zone III [%]	18.66	21.85	18.82	72	15.62	19.76	18.50	53	12.47	16.45	13.69	46	n.s.	–
HR zone IV [%]	39.81	36.84	21.09	72	30.95	32.60	15.02	53§	46.21	44.30	16.61	46§	**	1.18
HR zone V [%]	17.07	27.42	27.85	72	34.29	35.79	28.00	53	28.69	31.53	23.82	46	n.s.	–
HRR	119.00	118.00	8.64	72⨍	111.00	115.26	7.31	53§	125.00	121.11	8.24	46⨍§	⨍ * §**	⨍0.38 §1.07
%HRR	74.89	74.12	13.05	72	79.28	76.91	11.66	53	76.64	75.54	8.98	46	n.s.	–
Wheelchair basketball players category B														
HR_{mean} [beats/min]	162.50	160.90	11.56	108	164.00	162.98	12.31	104	159.00	160.08	13.57	74	n.s.	–
HR_{peak} [beats/min]	179.00	177.42	9.52	108^	181.00	180.64	9.66	104^§	176.50	177.18	10.98	74§	^* §*	^0.39 §0.44
HR_{peak} [%]	96.00	97.72	6.91	108	98.00	98.91	5.70	104§	96.00	95.82	5.45	74§	§***	§0.99
HR zone I [%]	0.00	0.20	0.67	108	0.00	0.26	1.05	104	0.00	0.71	2.13	74	n.s.	–
HR zone II [%]	0.00	2.85	5.15	108	0.06	2.95	7.98	104	1.51	3.43	5.88	74	n.s.	–
HR zone III [%]	8.01	12.49	14.55	108	8.04	10.90	11.77	104§	12.50	15.74	14.29	74§	*	0.32
HR zone IV [%]	39.36	38.51	23.78	108^	29.25	31.03	17.75	104^§	42.61	41.41	20.71	74§	^* §***	^0.33 §0.81
HR zone V [%]	37.97	40.12	28.17	108^	52.06	51.17	24.73	104^§	34.84	36.63	27.53	74§	^** §***	^0.56 §0.88
HRR	124.00	124.64	8.58	108⨍	124.00	125.63	8.63	104§	121.00	121.68	8.58	74⨍§	⨍* §**	⨍0.47 §0.72
%HRR	80.70	80.53	7.66	108	81.54	81.67	8.50	104	79.63	80.99	10.12	74	n.s.	–

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; ^ ⨍ §, differences between groups $p < 0.05$; n.s., no statistically significant differences; N, number of cases; HR, heart rate; SD, standard deviation; Min, minimum; Max, maximum; ES, effect size for the U-Mann–Whitney test; HRmean, mean heart rate; %HRpeak, the percentage of maximal heart rate in a match; HRpeak, maximal heart rate in a match; %HRR, the percentage of heart rate reserve.

$\%HR_{peak}$ were high and %HRR was 78.9%, which demonstrates the demanding nature of wheelchair basketball (Janssen et al., 1994; Pérez et al., 2007). This information can be a premise for physical performance coaches to determine HRR zones in which each wheelchair basketball player should train to be well prepared to basketball games, regardless of tournament rank or match score. HRR zones should be determined individually for each player considering their HR_{rest}, HR_{peak}, which was also underlined by Croft et al. (2010). It should be highlighted that our study results as well as the findings of Croft et al. (2010) indicated that high-intensity training sessions may be more beneficial for wheelchair basketball players and better prepare players for games (Croft et al., 2010).

While comparing our results to the results of other studies, we received similar values of %HRR to the ones obtained by Pérez et al. (2007), i.e., 78.9 and 78.5%, respectively (Pérez et al., 2007). However, we expected to observe differences in %HRR between players from the category A and B. Therefore, we divided our research group and finally confirmed these differences in %HRR (75.4% vs. 81.1%; $p < 0.001$). Pérez et al. (2007) evaluated five participants (highly trained wheelchair basketball players), divided according to their functional classification (two players from category A, and three players from category B) and found that category A players manifested lower HR_{mean} and %HRR compared to category B (143.9 and 73.1% vs. 162.7 and 81.7%, respectively) (Pérez et al., 2007). In this study we observed significantly higher HR_{mean} and similar %HRR compared to the results of Pérez et al. (2007) (HR_{mean}: category A players – 167.8 vs. 143.9 and category B players – 178.5 vs. 162.7; %HRR: category A players – 75.4% vs. 73.1% and category B players – 81.1% vs. 81.7%). These results indicate that the participants of our study achieved higher HR_{peak} or lower HR_{rest} (the formula of %HRR). However, in our study more participants were recruited than in the study by Pérez et al. (2007) and a different protocol of a laboratory test to access HR_{peak} was used (Pérez et al., 2007).

We found one study (a case study) comparing HR response of a player with spinal cord injury (level TH 1–2) with two players without spinal cord injury (Iturricastillo et al., 2016b). The authors of this study observed higher HR_{peak} and HR_{mean} in the players without spinal cord injury. They underlined that the autonomic innervation of the heart influences HR_{peak} but relative HR ($\%HR_{peak}$) can be similar in these two groups (Iturricastillo et al., 2016b). Moreover, we considered the explanation by dos Santos et al. (2017) that less trained players will experience more physiological stress in a match (dos Santos et al., 2017). therefore, in order to avoid this aspect in our study, we selected well prepared (in terms of aerobic and anaerobic performance) elite players from the national team who won sixth place in the European Championships in 2017 and sixth place in the World Championships in 2018. We concluded that the observed HR data in the current study support wheelchair basketball as a demanding team game that comprises of short efforts like dynamic pushing and breaking, passes, turnovers, shooting, etc., which is reflected in high HRR, HR_{mean}, HR_{peak}, $\%HR_{peak}$.

We aimed at confirming the hypothesis that players with spinal cord injury are characterized by higher HR data (Iturricastillo et al., 2016b). In the current study, we divided players into two functional groups, i.e., category A (players with a spinal cord injury) and category B (players without a spinal cord injury), to analyze their results separately. In our opinion, if it is possible, it should be a recommendation for all future studies on wheelchair basketball to divide participants at least into two functional categories because of the specificity of wheelchair basketball rules and classification. In the current study, we noted statistically significant differences in all HR data between category A and B. Differences in HR data between these two categories were also confirmed in the previous analysis of other authors (Pérez et al., 2007; Marszalek et al., 2019). However, in the current study we divided players into groups and observed their playing time (time without the half break, time outs, and time staying on the bench), which seems to be a more proper approach to the match load assessment. This approach was also underlined by Marszalek et al. (2019), as they examined the players' HR taking into account their playing time together with all breaks, stops, etc., and they suggested observing HR data in a game without a half break, timeouts, other breaks in the future studies because the results of HR_{mean} compared to HR_{peak} were low (for category A players the results were 120 beats/minute and 174 beats/minute, respectively; for category B players it was136 beats/minute and 183 beats/minute, respectively), and these breaks influenced HR_{mean} (Marszalek et al., 2019).

In the current study, it was observed that the percentage of time spent in HR zones (except in zone IV) differed between category A and category B players, and both groups spent the longest time in zones IV and V. Summarizing these differences regarding time contribution in HR zones between the players with and without spinal cord injury, it may be concluded that differences occurred due to the impairment, as players from category A could not achieve HR zone V for a long time (players from category B were significantly longer in HR zone V; large effect size: ES = 1.61) and their $\%HR_{peak}$ was also significantly lower compared to the players from category B (large effect size: ES = 1.23). This finding is opposite to the one presented by Iturricastillo et al. (2016a) that relative HR parameters ($\%HR_{peak}$) and the percentage of time spent in a high-intensity zone (85–95% of HR_{peak}) was similar among their players. Their finding indicated that it was not the impairment, but probably the characteristics of a basketball game (tactical and strategic aspects, position of a player) that influences the percentage of time spent in HR zones (Iturricastillo et al., 2016a).

Pérez et al. (2007) also highlighted the fact that some situations during a basketball game are more demanding than others. They introduced a categorical frame of observation and established seven different "game categories" (Pérez et al., 2007). An offensive game with the ball was the most demanding part of a match (high HR data), which is the confirmation of previous analyses of Coutts (1992) and Gomez et al. (2015) (Coutts, 1992; Gomez et al., 2015). It was shown that high-point players (category B) had a much bigger number of game actions with the ball (shooting, rebounding, and stills) compared to low-point players (category A) (Vanlandewijck et al., 2003; Molik et al., 2009; Gomez et al., 2015). In the current study, all the players from category A had spinal cord injury below TH6 and they used wheelchairs in everyday life. Players from category B were at least able to stand, which means that lower limbs had muscle power (no significant atrophy or vascular tissues) and were active in terms of isometric strength in wheelchair propulsion, and their cardiovascular system was active in the whole body (Theisen and Vanlandewijck, 2002). It is an additional argument that the impairment may be the cause of HR data differences. However, Baumgart et al. (2018) suggested that disability possibly influences VO_{2peak} in Paralympic sitting sports (a high variation in VO_{2peak}) with different disability classes compared to disciplines without different sports classes and recommended further research (Baumgart et al., 2018).

In the second part of this study, we noticed that all HR data (except HRR) were significantly different during Championships matches compared to friendly tournament matches for players from category B. Less significant differences were observed for players from category A (HR_{mean} and HR_{peak} were not different). Different HR data in different tournament rank competitions were noticed probably because of players' higher motivation and excitement as well as better physical preparation during Championships matches (aerobic capacity and anaerobic performance) to the high-level competition. We underline that it is only a hypothesis because no research has been conducted examining this. Iturricastillo et al. (2018) observed higher intensity during playoffs compared to friendly wheelchair basketball games (higher HR_{mean} and HR_{peak}) (Iturricastillo et al., 2018). However, Montgomery et al. (2010) compared HR between training games (5 on 5 scrimmage) and tournament games in running basketball and found that HR_{mean} and HR_{peak} were similar (Montgomery et al., 2010). These comparisons seem to be interesting and they show that even though wheelchair basketball has similar game rules to running basketball and both games are dynamic and intermittent, such situations as friendly games, scrimmages or small-sided games on a half court require a different response from wheelchair basketball players than from running basketball players.

In the third part of our study, we wanted to compare HR between the players from category A and B according to their playing time. We divided the players into three sub-groups in terms of their percentage contribution to playing time in a game: 40–59, 60–79, and 80–100%. There were no statically significant differences in HR data between the players from category A. These results indicate that players were engaged similarly and could maintain a similar level of intensity regardless of time which they spent on the court in a match. Significantly higher %HRR values were observed among category B players whose playing time was at the level of 40–59% than among the players whose contribution was at the level of 60–79%. We suppose that players who spend less time on the court in a quarter (lower percentage contribution in playing time) can achieve higher-intensity effort (higher %HRR because they are less tired). For coaches it can be an important lead to substitute players from category B every 6 min while the quarter takes around 15 min (40% of playing time in a quarter). On the other hand, Iturricastillo et al. (2018) also checked differences in HR data in terms of the participants' playing time, but did not remove the time of breaks and timeouts from the calculation. They observed HR data with all breaks in a game and they found significant differences in HR_{mean} and HR_{peak} which were higher in athletes who played between 30 and 40 min compared to those who played shorter (Iturricastillo et al., 2018). In other words, players with more bench time will have lower HR_{mean} and HR_{peak} if break times are included in HR game analyses. Breaks and active time on the court can be taken into account in global HR analysis to see the ratio between breaks and active time on the court. This approach could provide some direct indication of training based on the ratio of breaks and active time of exercises.

In the fourth part of this study, we found that there were no significant differences in HR data of players from category A and B between all four quarters in wheelchair basketball. However, it is quite easy to observe the trend that the first and the last quarters are the most important in wheelchair basketball because %HRR was the highest in these quarters (however, these differences were not statistically significant). The analysis of HR in different parts of a wheelchair basketball match was conducted by Yanci et al. (2014), who monitored HR during small-sided wheelchair basketball games (Yanci et al., 2014). They divided a small-sided game into four bouts, and found significant differences regarding HR_{peak} and HR_{mean} between bouts 2, 3, 4 and bout 1 (HR_{peak} and HR_{mean} were significantly lower in bout 1). Further analyses are necessary to explore this aspect in more detail because the study by Yanci et al. (2014) delivered different findings to our study. Yanci et al. (2014) found that HR_{peak} and HR_{mean} in the first bout were significantly the lowest (Yanci et al., 2014). In our study we observed that HR_{peak} and HR_{mean} in all quarters were similar and the highest values were noticed in the first and the last quarter.

In the last part of this study, we noted similar values of HR data among players from category A related to final point differential (close, balanced, and unbalanced games). However, significant differences in HR data were noted among the players from category B between close and balanced games as well as between close and unbalanced games. In close and balanced games HR_{peak} and the percentage of time spent in HR zone V were significantly higher probably because of the fact that players from category B had more contact with the ball. Coutts (1992) and Pérez et al. (2007) wrote that offensive game with the ball was the most demanding part of a match, Gomez et al. (2015) evidenced that players from category B have more contact with the ball and Gomez et al. (2014) observed that they shoot successfully more often in balanced games (Coutts, 1992; Pérez et al., 2007; Gomez et al., 2014, 2015). The above-mentioned studies as well as our observations point to a probable reason why players from category B had significantly higher HR parameters.

Practical Implications, Limitations and Recommendations for Future Studies

Heart rate observation during games could be helpful for coaches, as they can determine HRR zones in which players should exercise during training sessions to be better prepared for elite wheelchair basketball games. HR in wheelchair basketball exercises should be understood as a physical fitness indicator rather than a marker of fatigue or performance (Coutts et al., 2018; Schneider et al., 2018) because we did not collect information about fatigue (e.g., Rating of Perceived Exertion scale points) and performance in our study. High-intensity training sessions may benefit wheelchair basketball players because of high HRR observed in the current study and time spent in zones IV and V. The intermittent nature of wheelchair basketball was confirmed (all the players were observed in all HR zones, even though they spent most of the time in zones IV and V). In all analyses among wheelchair basketball players, researchers should divide players at least into two functional categories according to the classification in wheelchair basketball and consider differences in HR responses between players from category A and B. Hydration of players should be taken into account in the future analyses because hypohydration can increase HR during training in running basketball (Berkelmans et al., 2018), and hydration was not considered in the current study. It is recommended that more global analyses should be carried out in order to examine the players' classification in regard to their percentage contribution in playing time, tournament level (friendly matches, championships), game quarters, final game outcome and final point differential. The players' hydration and diet should be taken into account in future studies. Further analyses should be conducted on a larger sample group. We recommend analyzing HR in small-sided wheelchair basketball games to identify optimal training approaches to prepare wheelchair basketball players for competition.

CONCLUSION

The intermittent nature of wheelchair basketball was confirmed. Wheelchair basketball players from category A and B performed in all HR zones during a game, and they spent most of the time in zones IV and V (80–89% and 90–100% of HR_{peak}). It is recommended that more global analyses should be carried out in order to examine the players' classification in regard to their percentage contribution in playing time, tournament level (friendly matches, championships), game quarters, final game outcome and final point differential. The players' hydration and proper diet should be taken into account in future studies. Further analyses should be conducted on a larger sample group in order to plan a proper schedule and types of exercises in training sessions.

AUTHOR CONTRIBUTIONS

JM devised the structure of the paper, drafted the manuscript, collected and analyzed the data, and commented on the final version. KG and AK collected and analyzed the data, and commented on the final version. NM-A and AM collected and analyzed the data. BM devised the structure of the manuscript, drafted the manuscript, oversaw the whole research process, collected and analyzed the data, and commented on the final version.

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REFERENCES

Baumgart, J. K., Brurok, B., and Sandbakk, O. (2018). Peak oxygen uptake in paralympic sitting sports: a systematic literature review, meta- and pooled-data analysis. *PLoS One* 13:e0192903. doi: 10.1371/journal.pone.0192903

Ben Abdelkrim, N., El Fazaa, S., and El Ati, J. (2007). Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br. J. Sports Med.* 41, 69–75. doi: 10.1136/bjsm.2006.032318

Berkelmans, D. M., Dalbo, V. J., Kean, C. O., Milanovic, Z., Stojanovic, E., Stojiljkovic, N., et al. (2018). Heart rate monitoring in basketball: applications, player responses, and practical recommendations. *J. Strength Cond. Res.* 32, 2383–2399. doi: 10.1519/JSC.0000000000002194

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences*. New York, NY: Lawrance Erlbaum Associates.

Coutts, A. J., Crowcroft, S., and Kempton, T. (2018). "Developing athlete monitoring systems: theoretical basis and practical applications," in *Sport Recovery and Performance: Interdisciplinary Insights*, eds M. Kellmann and J. Beckmann (Abingdon: Routledge), 19–32.

Coutts, K. D. (1992). Dynamics of wheelchair basketball. *Med. Sci. Sports Exerc.* 24, 231–234. doi: 10.1249/00005768-199202000-00012

Croft, L., Dybrus, S., Lenton, J., and Goosey-Tolfrey, V. (2010). A comparison of the physiological demands of wheelchair basketball and wheelchair tennis. *Int. J. Sports Physiol. Perform.* 5, 301–315. doi: 10.1123/ijspp.5.3.301

Delextrat, A., and Kraiem, S. (2013). Heart-rate responses by playing position during ball drills in basketball. *Int. J. Sports Physiol. Perform.* 8, 410–418. doi: 10.1123/ijspp.8.4.410

dos Santos, P. P., de Souza, G. C., Alves, D. L., Rodacki, A. L. F., Lima-Silva, A. E., and De-Oliveira, F. R. (2017). Physiological demands of wheelchair basketball. *J. Exerc. Physiol. Online* 20, 52–59.

Gomez, M. A., Molik, B., Morgulec-Adamowicz, N., and Szyman, R. J. (2015). Performance analysis of elite women's wheelchair basketball players according to team-strength, playing-time and players' classification. *Int. J. Perform. Anal. Sport* 15, 268–283. doi: 10.1080/24748668.2015.11868792

Gomez, M. A., Pérez, J., Molik, B., Szyman, R. J., and Sampaio, J. (2014). Performance analysis of elite men's and women's wheelchair basketball teams. *J. Sports Sci.* 32, 1066–1075. doi: 10.1080/02640414.2013.879334

International Wheelchair Basketball Federation (2014). *Official Player Classification Manual*. Winnipeg, MB: IWBF.

International Wheelchair Basketball Federation (2018). *Official Wheelchair Basketball Rules & Wheelchair Basketball Equipment*. Winnipeg, MB: IWBF.

Iturricastillo, A., Granados, C., Camara, J., Reina, R., Castillo, D., Barrenetxea, I., et al. (2018). Differences in physiological responses during wheelchair basketball matches according to playing time and competition. *Res. Q. Exerc. Sport* 89, 474–481. doi: 10.1080/02701367.2018.1511044

Iturricastillo, A., Yanci, J., Granados, C., and Goosey-Tolfrey, V. (2016a). Quantifying wheelchair basketball match load: a comparison of heart rate and perceived exertion methods. *Int. J. Sports Physiol. Perform.* 11, 508–514. doi: 10.1123/ijspp.2015-0257

Iturricastillo, A., Yanci, J., Los Arcos, A., and Granados, C. (2016b). Physiological responses between players with and without spinal cord injury in wheelchair basketball small-sided games. *Spinal Cord* 54, 1152–1157. doi: 10.1038/sc.2016.43

Janssen, T. W., van Oers, C. A., van der Woude, L. H., and Hollander, A. P. (1994). Physical strain in daily life of wheelchair users with spinal cord injuries. *Med. Sci. Sports Exerc.* 26, 661–670. doi: 10.1249/00005768-199406000-00002

Marszalek, J., Gryko, K., Prokopowicz, P., Kosmol, A., Mróz, A., Morgulec-Adamowicz, N., et al. (2019). The physiological response of athletes with impairments in wheelchair basketball game. *Hum. Mov.* 20 (in press).

Mason, B. S., van der Slikke, R. M. A., Hutchinson, M. J., Berger, M. A. M., and Goosey-Tolfrey, V. L. (2018). The effect of small-sided game formats on physical and technical performance in wheelchair basketball. *Int. J. Sports Physiol. Perform.* 13, 891–896. doi: 10.1123/ijspp.2017-0500

Molik, B., Kosmol, A., Morgulec-Adamowicz, N., Laskin, J. J., Jezior, T., and Patrzałek, M. (2009). Game efficiency of elite female wheelchair basketball players during world championships. *Eur. J. Adapt. Phys. Activ.* 2, 26–38. doi: 10.5507/euj.2009.007

Molik, B., Kosmol, A., Morgulec-Adamowicz, N., Lencse-Mucha, J., Mroz, A., Gryko, K., et al. (2017). Comparison of aerobic performance testing protocols in elite male wheelchair basketball players. *J. Hum. Kinet.* 60, 243–254. doi: 10.1515/hukin-2017-0140

Montgomery, P. G., and Maloney, B. D. (2018). 3x3 basketball: performance characteristics and changes during elite tournament competition. *Int. J. Sports Physiol. Perform.* doi: 10.1123/ijspp.2018-0011 [Epub ahead of print].

Montgomery, P. G., Pyne, D. B., and Minahan, C. L. (2010). The physical and physiological demands of basketball training and competition. *Int. J. Sports Physiol. Perform.* 5, 75–86. doi: 10.1123/ijspp.5.1.75

Pérez, J., Rabadán, M., Pacheco, J. L., and Sampedro, J. (2007). "Heart rate assessment during wheelchair basketball competition: its relationship with functional classification and specific training design," in *Sport for Persons with a Disability Perspectives the Multidisciplinary Series of Physcial Education and Sport Science*, eds C. Higgs, and Y. C. Vanlandewijck (Berlin: ICSSPE).

Pérez, J., Rabadán, M., and Sampedro, J. (2003). "Wheelchair basketball competition exigency profile: heart rate evaluation concerning specific team sport variables" in *Proceedings of the Electronic VISTA 2003 Conference* (Bollnä: Swedish Development Center for Disability Sport).

Puente, C., Abian-Vicen, J., Areces, F., Lopez, R., and Del Coso, J. (2017). Physical and physiological demands of experienced male basketball players during a competitive game. *J. Strength Cond. Res.* 31, 956–962. doi: 10.1519/JSC.0000000000001577

Ramos-Campo, D. J., Rubio-Arias, J. A., Avila-Gandia, V., Marin-Pagan, C., Luque, A., and Alcaraz, P. E. (2017). Heart rate variability to assess ventilatory thresholds in professional basketball players. *J. Sport Health Sci.* 6, 468–473. doi: 10.1016/j.jshs.2016.01.002

Schneider, C., Hanakam, F., Wiewelhove, T., Doweling, A., Kellmann, M., Meyer, T., et al. (2018). Heart rate monitoring in team sports: a conceptual framework for contextualizing heart rate measures for training and recovery prescription. *Front. Physiol.* 9:639. doi: 10.3389/fphys.2018.00639

Theisen, D. (2012). Cardiovascular determinants of exercise capacity in the Paralympic athlete with spinal cord injury. *Exp. Physiol.* 97, 319–324. doi: 10.1113/expphysiol.2011.063016

Theisen, D., and Vanlandewijck, Y. C. (2002). Cardiovascular responses and thermoregulation in individuals with spinal cord injury. *Eur. Bull. Adapt. Phys. Activ.* 1, 1–17.

Vanlandewijck, Y. C., Evaggelinou, C., Daly, D. D., Van Houtte, S., Verellen, J., Aspeslagh, V., et al. (2003). Proportionality in wheelchair basketball classification. *Adapt. Phy. Activ. Q.* 20, 369–380. doi: 10.1123/apaq.20.4.369

Vaquera Jiménez, A. (2008). Heart rate responses to game-play in professional basketball players. *J. Hum. Sport Exerc.* 3, 1–9. doi: 10.4100/jhse.2008.31.01

Yanci, J., Iturricastillo, A., and Granados, C. (2014). Heart rate and body temperature response of wheelchair basketball players in small-sided games. *Int. J. Perform. Anal. Sport* 14, 535–544. doi: 10.1080/24748668.2014.11868741

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Misbehavior During Penalty Kicks and Goalkeepers Holding the Ball Too Long as Trivial Offenses in Football

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Rule violations occur in every sport and the respective book of rules prescribes how match officials need to sanction them. However, there are some rule violations that are nearly never penalized, even if they are perceived by the match officials. A phenomenon that has been neglected in the scientific community so far, for which we want to introduce the term trivial offenses. This research focuses on two potential trivial offenses in football: rule violations regarding the six-seconds rule, the time a goalkeeper is allowed to control the ball with his hands, and rule violations during the performance of penalty kicks. The aim is to provide empirical proof of the existence of those trivial offenses and describe the respective patterns. For this purpose, two observation systems were constructed; one to investigate 45 games from the German Bundesliga with respect to the six-seconds rule and one to study rule violations during 618 penalty kicks from four European football leagues and one cup event. The following variables were collected: *Goalkeeper*, *MatchLocation*, *Minute* (representing the minute of the game), *PreviousAction*, *CurrentScore*, *Time* (representing the time the goalkeeper controlled the ball with his hands), and *Penalization* for the six-seconds study; *Responsibility for infringement*, *Decision of the referee,* and *Outcome* for the penalty study. Reliability tests showed almost perfect agreement for the data of both samples. On average, goalkeepers control the ball 6.0 s (SD:4.54) with their hands and the six-second rule was violated in 38.4% of the situations, none of which was penalized. This duration was significantly influenced by *CurrentScore* ($p < 0.001$), which indicates a tactical abuse of this situation. None of the investigated penalty kicks was conducted without a rule violation either. In most incidents (96.3%) outfield players from both teams as well as the goalkeeper commit offenses. The umpire only judges 2.8% of these incidents correctly, most of them by approving the scored goal. In total, this research proves the existence of trivial offenses in football and shows how methods and tools of performance analysis can serve to investigate and even solve this issue.

Keywords: trivial offenses, rule violations, football, penalty kicks, six-second-rule

INTRODUCTION

The International Football Association Board (hereinafter referred to as IFAB) claims in their current version of the official book of rules, pretentiously called *Laws of the game*, "[that] the same Laws apply in every match in every confederation, country, town and village throughout the world is a considerable strength which must be preserved" and further that "[the] integrity of the Laws, and the referees who apply them, must always be protected and respected" (IFAB, 2018, p. 11). These statements might be rhetorically overflourished, but they are in line with views of sport theorists, which describe rules as a substantial part of the answer to the metaphysical question "what is (a) sport?" (Reid, 2012). Suits (1988) describes how rules are the underlying reason that specific skills are developed, for example to control the football with all parts of the body except the upper extremities, as the deliberate use of these is prohibited by the rules. Of course, rules can fulfill further purposes, for example to ensure player's safety, but all contribute to the matter of defining a (game) sport. Besides this, sport philosophers also believe in the concept of informal agreements about the way a sport should be performed (D'Agostino, 1995). Such so-called unwritten rules cover various aspects which also can include an agreement of the acceptance of minor rule violations.

It is a well-accepted public perception in many sports that there are frequent minor rule violations, which are not punished by the umpires or referees (both terms are used interchangeably throughout this manuscript, based on the specific terminology of the respective sports). A specific part of unwritten rules for which we wish to introduce the term *trivial offenses* in sport. However, whereas there is already a solid research base for some areas of refereeing behavior, like the existence of different sorts of bias (see the well-structured review of Dohmen and Sauermann, 2015) and how this bias is influenced by different external factors (crowd noise: Unkelbach and Memmert, 2010; crowd proximity: Scoppa, 2008), just two trivial offenses have been subjected to scientific publications so far. Based on an incident at the 2009 US Open Women's semi-finals, Serena Williams threatened a line judge after a punished foot fault, two legal theorists discussed foot-faults as an issue of temporal variance: Should foot-faults only be called in less important stages of a match or all the time? Whereas Standen (2013) argued that offenses need to be punished at all times, Berman (2011) saw circumstances in which a no-call could be more beneficial for the sake of a sport. The only empirical study with an emphasis on trivial offenses also included the violation of a restriction that should ensure a specific distance. In an evaluation of the vanishing spray in football, Kolbinger and Link (2016) found that, even after the introduction of this officiating aid, the minimum distance rule was violated frequently but not punished a single time in their sample. This work of Kolbinger and Link (2016) is so far the only published research that uses methods and tools of performance analysis to investigate the phenomenon of trivial offenses in sport. Therefore, the aim of this study is to investigate two further issues of trivial offenses in football: The rule applications during penalty kicks (hereinafter referred to as *penalty study*) and the enforcement of the rule that prohibits the goalkeepers from controlling the ball with their hands for more than six seconds (hereinafter referred to as *six-seconds study*). For both, there is the common belief that the respective situations are often not conducted in accordance with the prevailing rules.

Watching penalty kicks, one often has the impression that at least one player is breaking the rules and sometimes even more than one. Regarding penalty shootouts, there are non-scientific analyses based on small sample sizes that seem to underpin this common belief. For instance, a German football magazine stated that 16 out of 20 penalty kicks during two round four matches at the World Cup 2018 in Russia were not performed correctly (Kicker, 2018). However, we were not able to find scientific research that investigated rule violations with respect to penalty kicks in football. This is quite surprising, as up to 10% of all goals result from penalty kicks (Yiannakos and Armatas, 2006; Wright et al., 2011; Michailidis et al., 2013). To overcome this lack of research, the aim of the *penalty study* is to investigate the conducting of penalty kicks in soccer in four professional European leagues and one cup event. Of particular interest is if and in which way penalties are conducted irregularly and what the referee's decision was in the respective situation. However, only penalty kicks that were not a part of penalty shootouts were considered.

Concerning the *six-seconds study*, there is no scientific literature either. As it often seems that goalkeepers of teams that are in the lead holding on to the ball for more than six seconds and delaying the game is a widespread – and promising (Siegle and Prüßner, 2013) – practice in football, we want to investigate the influence of the score and the elapsed game time on the ball-in-hand time. Further, we look for additional variables that could influence this duration, like match location, game context and individual characteristics. Based on the findings of both studies, we furthermore would like to demonstrate how methods and tools of performance analysis can be used to identify trivial offenses and support associations to solve the respective issues.

MATERIALS AND METHODS

Data Collection

For the *penalty study*, an experienced operator extracted the data from video footage of football matches provided by Sportradar. Matches from four European leagues (Austrian Bundesliga, German Bundesliga, Serie A, and Premier League) and one cup event (DFB-Pokal, the German cup event) from two complete seasons (2015/16, 2016/17) and the beginning of the 2017/18 season were considered. Parameters for each penalty kick that occurred during one of these matches were collected using an observation system that will be introduced in the following paragraphs. In total, 618 were investigated (cf. **Table 1**).

The information on the *penalty study* was collected using a systematic observation system considering the Laws of the Game. The FIFA book of rules states the following guidelines that describe a penalty kick taken in accordance with the rules (IFAB, 2018):

- Regarding all players of both teams (excluding the player that performs the penalty kick and the respective goalkeeper): Before a penalty is taken, they have to be

outside the penalty area, but within the field of play and behind the penalty mark, at least 10 yards (9.15 m). Further, these players are not allowed to enter the penalty area before the kick is taken.
- It must be obvious for the goalkeeper who takes the penalty kick. Further, the goalkeeper has to stand on the goal line between the goal posts until the penalty kick taker touches the ball.
- The penalty kick taker can only conduct the penalty kick after the referee blows his/her whistle indicating that the penalty kick can be conducted. During the run-up the penalty kick taker can make feinting moves until he/she touches the ball. The ball must be kicked forward toward the goal.

In case of rule violations, the FIFA book of rules instructs the referee how to decide who is responsible for the infringement and the outcome of the penalty kick (cf. **Table 2**).

The parameters gathered for this part of the study were the following:

- *Country*: Austria, England, Germany, and Italy
- *Event*: League, Cup
- *Year*: 2015/16, 2016/17, 2017/18
- *Responsibility for infringement* (*Rfi*):
  - Goalkeeper, player(s) of attacking team, player(s) of defending team
  - Player(s) of both teams
  - Combinations of the goalkeeper and player(s) of one team or both teams
  - No infringement
- *Decision of the referee* (*Df*): Binary, recognizing an infringement or not
- *Outcome*: Goal, saved by goalkeeper, or shot misses goal

The data for the *six-seconds study* was recorded manually by an expert (sport science student in his final semester) using the broadcast footage of 45 games from the German Bundesliga (random sample). Each team had a minimum occurrence of four games and a maximum of six. Using a self-designed systematic observation system, the following attributes were collected for each of the 458 ball-in-hand incidents: *Goalkeeper*, *MatchLocation*, *Minute* (representing the minute of the game), *PreviousAction*, *CurrentScore*, *Time* (representing the time the goalkeeper controlled the ball with his hands) and *Penalization*. The levels of the attribute are listed in **Table 3**. *Time* was measured using an ordinary stopwatch.

Reliability

The reliability of the *penalty study* was tested using an intra-rater reliability test. For this, the operator collected data from 100 randomly chosen penalty kicks for a second time, one month after the first observation. The reliability of the data was assessed regarding the actual agreement and Cohen's kappa. For *Country*, *Year*, *Event*, *Df*, and *Outcome* there was perfect agreement (100%), which means Cohen's kappa equals 1. Regarding *Rfi* the actual agreement was 99% and $\kappa = 0.944$.

TABLE 1 | Distribution of the investigated penalty kicks with regard to the leagues and the cup event.

	Austrian Bundesliga	German Bundesliga	Serie A	Premier League	DFB-Pokal	Total
2015/16	31	60	56	40	19	38
2016/17	41	98	127	92	17	374
2017/18	6	6	11	3	12	206
Total	78	166	194	135	48	618

TABLE 2 | Overview on how the referee has to decide considering the outcome of the penalty kick.

Responsibility for rule infringement	Goal	No goal
Player(s) of attacking team	Rekick	Indirect free kick
Player(s) of defending team	Goal	Rekick
Both	Rekick	Rekick

TABLE 3 | Observational system used for the six-seconds study.

Attribute	Attribute levels and/or operationalizations
Goalkeeper	Name of the goalkeeper
MatchLocation	*Home*: Goalkeeper playing for the hosting team *Away*: Goalkeeper playing for the visiting team
Minute	Integer between 1 and 90. Extra time was assigned to the values 45 and 90, respectively
PreviousAction	*Shot*: Opponent performed a shot on goal as last action before the goalkeeper gained control of the ball *Cross*: Goalkeeper intercepts a cross *Pass*: Teammate passing the ball to the goalkeeper in a way which allows the goalkeeper to control the ball with his hands *Other*: Otherwise
CurrentScore	Integer that illustrates the goal difference from the goalkeeper's perspective (positive value means winning, negative value means losing and zero means drawing)
Time	Time between the moment the goalkeeper starts to control the ball with his hands according to rule 12 of the official "Laws of the Game" and when it finally leaves his hands. Measured in seconds (one decimal)
Penalization	*True*: Referee award an indirect free kick to the other team *False*: Otherwise

The inter-rater agreement for the *six-seconds study* was performed for 103 incidents over nine matches, using a research assistant with six years of experience in game observation as the second independent observer. There was a perfect agreement (Cohen's kappa equals one) for *Goalkeeper*, *MatchLocation*, and *Minute* (which was treated as nominal variable for this purpose), *PreviousAction* and *CurrentScore*. It was not possible to calculate Cohen's kappa for *Penalization,* as the same level occurred in all situations for both observers (which equals an agreement percentage of one). For *Time* we calculated the linear correlation coefficient, which was 0.99, and some descriptive statistics to further describe the agreement. Mean difference between the two observers was 0.01 s and the mean absolute difference 0.09 s with an absolute maximum difference of 0.5 s. In total, there is almost perfect agreement for both studies (Landis and Koch, 1977).

Statistical Analysis

The descriptive and inferential analysis for the *penalty study* were performed using SPSS (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY, United States: IBM Corp.). Statistical differences were determined using the chi-square test and, where necessary, using its non-parametrical equivalent the Fisher's exact test (based on Monte Carlo simulation). Effect sizes were determined using Cramer's V and interpreted based on the limits suggested by Cohen (1988).

For the *six-seconds study*, descriptive statistics were used to show the prevalence of rule violations and the frequency of respective sanctions by the referee. Further, we ran regression analysis to describe how the collected variables (*Goalkeeper*, *MatchLocation*, *Minute, PreviousAction,* and *CurrentScore*) influence the ball-in-hand time (*Time*). Two of those variables were polytomous: *Goalkeeper* and *PreviousAction*. Both were included without further processing in Model 1, which means that both were transformed into dummy variables. In more detail, for *Goalkeeper* this led to 23 dummy variables (as 24 goalkeepers appeared in our sample) that equal one if the respective goalkeeper was involved and zero if not. For *PreviousAction*, we had to include three dummy variables (as we pooled the previous actions into four categories) that equal one if the ball-in-hand incident was initiated by a certain action and zero if not.

$$Time_i = \beta_0 + \beta_1 Goalkeeper_i + \beta_2 MatchLocation_i + \beta_3 Minute_i + \beta_4 PreviousAction_i + \beta_5 CurrentScore_i + \varepsilon_i$$

To improve comprehensibility, we performed a second regression model (Model 2), for which we transformed the two polytomous variables. *Goalkeeper* was substituted by *GK_Mean*, which displays the average ball-in-hand time for each goalkeeper. This transformation does not interfere with the objectives of this study, as the aim is not to gain knowledge about an increase or decrease in the ball-in-hand time that is affected by a certain goalkeeper. Instead, we wanted to show how much of the respective variance is explained by interindividual differences. Further, based on the descriptive results, *PreviousAction* was transformed into a dichotomous variable for Model 2, equaling one if *PreviousAction* was classified as *Shot* or *Cross*.

$$Time_i = \beta_0 + \beta_1 GK\_Mean_i + \beta_2 MatchLocation_i + \beta_3 Minute_i + \beta_4 PreviousAction_i + \beta_5 CurrentScore_i + \varepsilon_i$$

To clarify the appropriateness of the data processing for the second model, which should be used for the interpretation of the results, the two models were compared in order to check for differences in goodness of fit.

None of the included metric variables was z-transformed. First, we think it is more beneficial to describe the increase or decrease of the dependent variable *Time* in seconds for each predictor, not standard deviations. Vice versa, the same applies for the predicting variables *Minute* and *CurrentScore*. The severity of multicollinearity was measured using the variance inflation factor (VIF). The data processing and the statistical analysis for the *six-seconds study* were conducted in R (R Development Core Team, 2015).

RESULTS

Penalty Study

Descriptive analyses (**Table 4**) of the investigated penalty kicks reveal that there was no penalty that was conducted according to the prevailing football rules. In most of these cases (96.3%), even players of both teams (including the goalkeeper) misbehaved. This varied slightly from league to league ($p < 0.001$; Cramer's $V = 0.13$). In the German Bundesliga (93.9%), and in particular in the Austrian Bundesliga (88.5%) there were fewer incidents in which players of both teams (including the goalkeeper) broke the rules. However, this proportion was much higher in the English Premier League (99.3%) and the Italian Serie A (98.5%). No statistical difference can be found between the cup competition and the leagues ($p = 0.809$).

In total, the referees correctly judged 2.8% ($n = 17$) of the infringements. In most of these incidents (82.4%; $n = 14$) the referee judged correctly by not actively interrupting the game because the penalty kick resulted in a goal and the players of the attacking team behaved according to the football rules. In three cases, the referee actively interrupted the game and made the players repeat the penalty kick due to the misbehavior of outfield players from both teams as well as the goalkeeper.

Six-Seconds Study

The goalkeepers in our sample controlled the ball with their hands for an average time of 6.0 s (SD:4.54 s), which equals the permitted six seconds mark. As illustrated in **Figure 1**, the respective rule was violated in 38.4% of the observed ball-in-hand situations. For 12.2% of incidents the time limit was exceeded for more than six seconds, the maximum value was 20.1 s. None of the rule violations were penalized.

Table 5 shows both models, as well as additional information for the included variables in column two. For the metric

TABLE 4 | Descriptive results are presented with respect to infringements, who is responsible for the infringements, and how many of the respective cases were correctly judged by the umpire.

Infringement	Infringement by	% (n)	Referee's decision correct in % (n)
No		0.0% ($n = 0$)	
Yes	Total	100.0% ($n = 618$)	2.8% ($n = 17$)
	Attackers	–	–
	Defenders	0.3% ($n = 2$)	100.0% ($n = 2$)
	Both	1.0% ($n = 6$)	0.0% ($n = 0$)
	Goalkeeper	–	–
	Goalkeeper + Attackers	–	–
	Goalkeeper + Defenders	2.4% ($n = 15$)	80.0% ($n = 12$)
	Goalkeeper + Defenders + Attackers	96.3% ($n = 595$)	0.5% ($n = 3$)

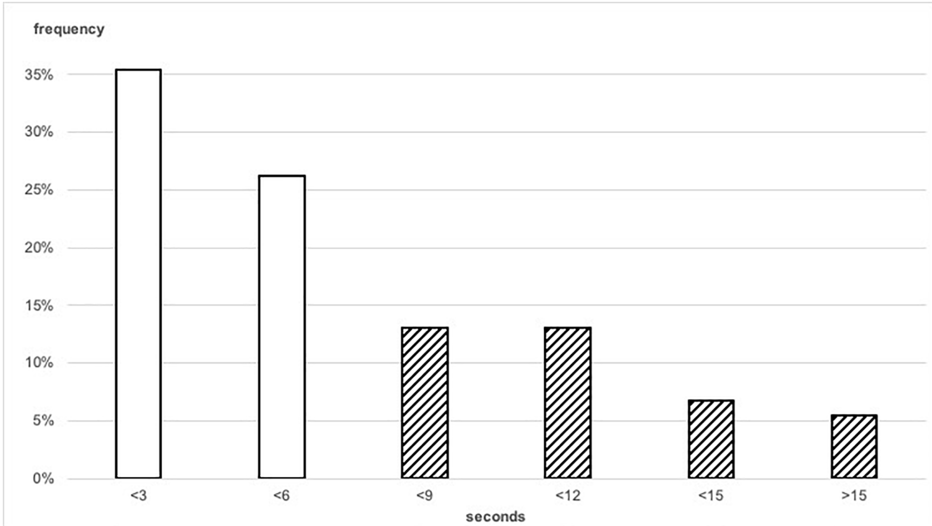

FIGURE 1 | Histogram for the ball-in-hand times, pooled into three-second bins. Crosshatched bars illustrate groups that exceed the six second maximum.

predictor variables, we calculated the correlations with the dependent variable *Time*, which were significant for *GK_Mean* ($r = 0.33$, $t = 7.38$, $p < 0.001$) and *CurrentScore* ($r = 0.23$, $t = 5.09$, $p < 0.001$). In more detail, *Time* is on average under six seconds for any score for trailing teams and above six seconds for teams in the lead. For the nominal variables, we calculated descriptive statistics and compared the respective attribute levels. As we show in column two of **Table 5**, if the *PreviousAction* was labeled as shot or cross, *Time* was significantly higher compared to the other levels.

As Model 2 only showed a minor decrease of the R^2_{adj} and no significant difference compared to Model 1, we use the results of Model 2 to describe and interpret the influence of the predictor variables. *Time* increases by 2.34 s if the previous action was a shot or cross and decreases by 0.85 s if the goalkeeper is playing for the home team. *Minute* does not show a significant independent influence on the ball-in-hand time. Concerning individual influence, an additional second at *GK_Mean* increases *Time* by 0.96 s. The coefficient for the current score difference shows a highly significant influence as well ($t = 5.10$, $p < 0.001$), with an average increase of 0.78 s for each positive increase in the goal difference.

DISCUSSION

There is a common belief among various stakeholders from causal fans to sport theorists that some sports have unwritten rules, which includes the intentional mishandling of some rules. In this paper we could provide empirical proof supporting this common believe for two such trivial offenses: various misbehaviours during the performance of penalty kicks and violations of the maximum time limit a goalkeeper can have control of the ball with his hands.

Regarding the *penalty study*, this research shows that all investigated penalty kicks were not conducted as the book of rules prescribes. Misbehavior occurs in all investigated European football leagues. During each penalty kick at least one player commits a rule violation. Interestingly, in most incidents none of the parties involved behaves correctly. However, it is not too surprising that players try to stretch the rules as far as possible in order to profit from it. In most incidents, the fact that the players misbehave might be a sequence of reactions started by just one player moving too early and, concurrently, other players following to compensate for the potential disadvantage. For instance, if an attacker enters the penalty area first in order to get a potential rebound, a defender is probably going to follow in order to compensate for the disadvantage.

Nearly all refereeing decisions were wrong. There are three different scenes a referee and his assistants have to monitor: The penalty kick taker, the goal line (observing the goalkeeper), and the eighteen-yard line (observing the rest of the players). On the one hand, there is one match official focusing on each scene. This actually seems to be an easy task. On the other hand, all match officials need to recognize when the penalty kick taker touches the ball and, at the same time, judge whether another player commits a rule violation. Firstly, this is impossible and secondly, sometimes players only slightly violate the rules in such a way that a human being might not be able to perceive it in real time. Unfortunately, we did not collect information about the amount of time a player misbehaved early, or how far a player entered the penalty area, or how far the goalkeeper left the goal line. This kind of information should be collected in a future study to help in answering this question. In the course of this research, there was the opportunity to stop the video and check each single frame to identify rule violations. As the video assistant referee has been introduced in several leagues today, this opportunity also exists for match officials. However, it seems that the misbehavior during penalty kicks is

TABLE 5 | Correlation coefficient with the inter-point time for metric variables and descriptive statistics of the nominal variables included in the summarized Models 1 and 2.

	Correlation with *Time*	Model 1	Model 2
	R^2 (*t*-value)	Coefficients (*t*-value) *VIF*	
GK_Mean	0.107***		0.961***
	(7.38)		(7.57)
			1.01
Minute	0.001	0.001	0.001
	(0.66)	(0.17)	(0.15)
		1.04	*1.01*
CurrentScore	0.054***	1.01***	0.775***
	(5.09)	(5.95)	(5.10)
		1.27	*1.02*
	Time in seconds Mean ± SD		
PreviousAction < Shot >	$7.78^{cd} \pm 4.84$	2.64***	2.345***
		(5.22)	(6.20)
		1.03	*1.02*
PreviousAction < Cross >	$7.28^{cd} \pm 4.97$	2.43***	
		(4.87)	
		1.03	
PreviousAction < Pass >	$4.64^{ab} \pm 4.15$	−0.121	*base group*
		(−0.19)	
		1.03	
PreviousAction < Other >	$4.76^{ab} \pm 3.73$	*base group*	
MatchLocation < Home >	5.55 ± 4.59	−1.31**	−0.853*
		(−3.16)	(−2.25)
		1.19	*1.01*
MatchLocation < Away >	6.27 ± 4.49	*base group*	*base group*
Goalkeeper Dummies		Included	excluded
Intercept		2.79*	−0.497***
		(2.53)	(−0.59)
		Goodness of fit	
F (df, n)		5.24***	28.0***
		(29,428)	(5,452)
R^2		0.262	0.236
Adjusted R^2		0.212	0.228

** significant on 0.05 level; ** significant on 0.01 level; *** significant on 0.001 level. [a] significantly different from <Shot> (on 0.05 level); [b] significantly different from <Cross> (on 0.05 level); [c] significantly different from <Pass> (on 0.05 level); [d] significantly different from <Other> (on 0.05 level).*

still there, but this should be part of further research as the data of the *penalty study* was recorded before the introduction of the video assistant.

Similar to Berman's (2011) arguments in his tennis research, referees could misjudge misbehavior during penalty kicks to keep the flow of the game, which might be an even bigger issue in an invasion game like football. Further, a team gets a penalty kick to compensate for a disadvantage. Having a penalty kick should be an advantage for a team and, therefore, it should profit from this situation. Since in 80% of the cases a penalty kick results in a goal (Kropp and Trapp, 1999; Bar-Eli et al., 2007; Wright et al., 2011), referees might render the misbehavior as no longer relevant in these situations.

Regarding the *six-seconds study*, we found that in almost 40% of the observed ball-in-hand incidents the goalkeepers held on to the ball for more than six seconds. For almost one third of these violations the ball was not released until the permitted time interval had elapsed twice over. As expected we found indications that the ball-in-hand situations, in which the goalkeeper cannot be challenged by an opponent, is used to delay the game. If the goalkeeper's team has the lead, the average ball-in-hand time is 7.07 s, compared to 4.23 s when the team is trailing. The amount of rule violations increases from 25.4 to 46.2%. A strategy that is not surprising, considering the systematic underestimation of the additional time (Siegle and Prüßner, 2013). In contrast, the elapsed game time influenced neither the dependent variable nor the share of rule violations.

PreviousAction showed the highest correlation with the ball-in-hand time among our context variables. If the goalkeeper had to save a shot or intercept a cross, the ball-in-hand time increased by 2.7 s and the number of situations in which the six-seconds maximum is exceeded increased by 22%. Further, significant parts of the variance in time were affected by the variance of the goalkeepers and by the match location (whether the match was played at home or away). Further, we want to note that our model was only able to explain about 23% of the total variance of the dependent variable. Thus, there are further variables that have an impact on the ball-in-hand time. One that probably has an impact on the time the goalkeeper controls the ball with his hand is the spatial distribution of his teammates and opponents. The goalkeeper could perceive a potential tactical advantage by releasing the ball quickly or, alternatively, conclude that it would be a disadvantage to speed up the game in a particular situation. Another condition that could affect the ball is the status of the involved teams. Some teams might be satisfied with a tie, for example underdogs or teams that have suffered a red card. It needs to be mentioned that, in contrast to the *penalty study*, the results are limited to patterns in the German Bundesliga, as we were not able to collect this data for other European leagues.

In general, for both situations covered in this paper, the referees are more or less expected to not penalize the respective rule violations, which makes these situations a typical example of unwritten rules (D'Agostino, 1995). However, this kind of unwritten rules, for which we introduced the term *trivial offenses*, can cause serious problems, as Standen (2013) and Berman (2011) show in their respective papers about temporal variance. Especially, in cases in which erratic rule applications interfere with the main objective of a rule regarding the related athletic skills. The goal in soccer is to score more goals than the opponent in a defined amount of time. Controlling the ball with the hand for a longer time than the permitted six seconds (again: the goalkeeper cannot be challenged when he controls the ball with his hands) takes away a share of this time in which the opponent can try to tie or win the game based on their athletic skills. For penalties there can be a huge shift in the preconditions set by these skills as well, especially if the goalkeeper shortens the distance to the penalty mark.

Accepting minor rule violations, even if it might increase the entertainment value, would counteract IFAB's goal of protecting the integrity of the game. Thus, we claim that the IFAB needs to step in and either prompt the referees to enforce the respective rules according to the Laws of the Game or change the respective rules. For example, the IFAB could prolong the time permitted for goalkeepers to hold on to the ball to eight seconds after shots or crosses or change the penalizations for rule violations during penalty kicks. The latter would make sense if the current penalization is seen as too much of a disadvantage for the offensive team. This would need further evaluations, including surveys of the opinions of various stakeholders. To sum up, the IFAB needs to change the rules or the refereeing behavior if it wants to protect the integrity of its rules. Using tools and methods of performance analysis, this study not only provided empirical proof of the existence of the trivial offenses, but also additional information about the respective situations which can contribute to the process of changing the way these situations are umpired.

AUTHOR CONTRIBUTIONS

MS performed the penalty study. OK performed the six-seconds study and provided the theoretical framework for trivial offenses. Both authors contributed to the manuscript, with emphasis on their respective studies.

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REFERENCES

Bar-Eli, M., Azar, O. H., Ritov, I., Keidar-Levin, Y., and Schein, G. (2007). Action bias among elite soccer goalkeepers: the case of penalty kicks. *J. Econ. Psychol.* 28, 606–621. doi: 10.1016/j.joep.2006.12.001

Berman, M. N. (2011). Let 'em Play" A study in the jurisprudenceof sport. *Georgetown Law J.* 99, 1325–1369.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd Edn. Hillsdale, NJ: Lawrence Erlbaum.

D'Agostino, F. (1995). "The ethos of the game," in *Philosophic Inquiry in Sport*, eds W. J. Moran and K. V. Meier (Champaign, IL: Human Kinetics), 48–49.

Dohmen, T., and Sauermann, J. (2015). Referee bias. *J. Econ. Surv.* 30, 679–695. doi: 10.1111/joes.12106

IFAB (2018). *Laws of the Game*. Available at: http://static-3eb8.kxcdn.com/documents/661/065042_170818_LotG_18_19_EN_DoublePage_150dpi_Korr.pdf (accessed June 1, 2018).

Kicker, D. E. (2018). *16 der 20 Elfmeter am WM-Sonntag Waren Irregulär*. Available at: http://www.kicker.de/726742/artikel_16-der-20-elfmeter-am-wm-sonntag-waren-irregulaer.html (accessed July 2, 2018).

Kolbinger, O., and Link, D. (2016). The use of vanishing spray reduces the extent of rule violations in soccer. *Springerplus* 5, 1–7. doi: 10.1186/s40064-016-3274-2

Kropp, M., and Trapp, A. (1999). *35 Jahre Bundesliga-Elfmeter*. Kassel: Agon Sportverlag.

Landis, J. R., and Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics* 33, 159–174. doi: 10.2307/2529310

Michailidis, Y., Michailidis, C., and Primpa, E. (2013). Analysis of goals scored in European Championship 2012. *J. Hum. Sport Exerc.* 8, 1–9. doi: 10.4100/jhse.2012.82.05

R Development Core Team (2015). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Reid, H. L. (2012). *Introduction to the Philosophy of Sport*. Plymouth: Rowman & Littlefield Publishers, Inc.

Scoppa, V. (2008). Are subjective evaluations biased by social factors or connections? An econometric analysis of soccer referee decisions. *Empir. Econ.* 35, 123–140. doi: 10.1007/s00181-007-0146-1

Siegle, M., and Prüßner, R. (2013). Additional time in soccer. *Int. J. Perform. Anal. Sport* 13, 716–723. doi: 10.1080/24748668.2013.11868683

Standen, J. (2013). Foot faults in crunch time: temporal variance in sports law and antitrust regulation. *Pepperdine Law Rev.* 41, 349–396.

Suits, B. (1988). Tricky triad: games, play, and sport. *J. Philos. Sport* 15, 1–9. doi: 10.1080/00948705.1988.9714457

Unkelbach, C., and Memmert, D. (2010). Crowd noise as a cue in referee decisions contributes to the home advantage. *J. Sport Exerc. Psychol.* 32, 483–498. doi: 10.1123/jsep.32.4.483

Wright, C., Atkins, S., Polman, R., Jones, B., and Sargeson, L. (2011). Factors associated with goals and goal scoring opportunities in professional soccer. *Int. J. Perform. Anal. Sport* 11, 438–449. doi: 10.1080/24748668.2011.11868563

Yiannakos, A., and Armatas, V. (2006). Evaluation of the goal scoring patterns in European Championship in Portugal 2004. *Int. J. Perform. Anal. Sport* 6, 178–188. doi: 10.1080/24748668.2006.11868366

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The Relationship Between Cognitive Functions and Sport-Specific Motor Skills in Elite Youth Soccer Players

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The aim of the present study was to examine the relationship between basic cognitive functions and sport-specific motor skills in elite youth soccer players. A total of 15 elite youth soccer players aged 11–13 years performed a computer-based test battery measuring the attention window (AW), perceptual load (PL), working memory capacity (WMC), and multiple object tracking (MOT). Another set of tests was used to asses speed abilities and football-specific technical skills (sprint, change of direction, dribbling, ball control, shooting, and juggling). Spearman's correlation tests showed that the diagonal AW was positively associated with dribbling skills (r_S = 0.656) which indicates that a broader AW could be beneficial for highly demanding motor skills like dribbling. WMC was positively related to dribbling (r_S = 0.562), ball control (r_S = 0.669), and ball juggling (r_S = 0.727). Additionally, the cumulated score of all cognitive tests was positively related to the cumulated motor test score (r_S = 0.614) which supports the interplay of physical and psychological skills. Our findings highlight the need for more, and especially longitudinal, studies to enhance the knowledge of cognition-motor skill relationships for talent identification, talent development, and performance in soccer.

Keywords: elite, youth, cognitive functions, soccer, motor skills, sport-specific skills

INTRODUCTION

High-demand sports require extraordinary physiological capacities combined with outstanding abilities in the areas of motor control, perception, and cognitive functioning. Two recent meta-analysis (Voss et al., 2010; Scharfen and Memmert, 2019) showed small to middle effects of basic cognitive functions in experts and elite-athletes which may point at their superiority in terms of basal cognitive functions. Besides the physiological abilities, previous research mostly focused on the cognitive skills of elite adult athletes (Mann et al., 2007; Voss et al., 2010; Scharfen and Memmert, 2019). In terms of elite youth athletes, especially soccer players, current research mainly studied – on the one hand – the physical or physiological prerequisites of elite youth soccer players (Unnithan et al., 2012; Waldron and Murphy, 2013; Abade et al., 2014; Murr et al., 2018) or – on the other hand – the psychological prerequisites, that is the cognitive functions of elite youth soccer players (Verburgh et al., 2014, 2016; Balakova et al., 2015; Huijgen et al., 2015; Vestberg et al., 2017) in isolation. To the best of our knowledge, the combination of both motor (i.e., soccer-specific motor skills) and basic psychological (i.e., cognitive functions) has not yet been examined. Therefore, the present study is unique as it connects basic psychological (cognitive functions) with motor (soccer-specific motor skills) aspects of elite youth soccer players.

Cognitive skills refer to the ability to identify and acquire environmental information in order to integrate them with existing knowledge (Marteniuk, 1976). This allows the individual to select and execute the appropriate responses. An especially interesting and important subgroup of these skills are executive functions (EF) which describe cognitive processes that regulate thoughts and actions, especially in non-routine situations (Friedman et al., 2014). The EF are further subdivided into core EF (CEF), which can be defined as working memory, cognitive flexibility and inhibitory control, and higher-level EF (HEF), involving reasoning, problem solving, and planning (Diamond, 2013). These EF skills mature at different ages, as they depend on different prefrontal structures. The neuronal structure underlying HEF is the prefrontal cortex which matures slowly and last in development; full capacity is reached between 20 and 29 years of age (De Luca et al., 2003; Luciana et al., 2005). In contrast CEF develop its total capacity earlier in the lifespan, most often before early adolescence (Crone et al., 2006). We related their motor skills to CEFs [working memory, object tracking, inhibition under perceptual load (PL), and flexibility to widen the attention window (AW)] as these develop earlier than HEFs and may be a key predictor for cognitive functions this early in maturation. Additionally, distinct motor-cognition interactions were proposed with strong mutual influences in terms of (i) functional brain networks (e.g., Leisman et al., 2016; Ptak et al., 2017), (ii) structural brain networks (e.g., Hanakawa, 2011; Koziol et al., 2012; Bigelow and Agrawal, 2015; Gao et al., 2018). More specifically, recent studies show that (1) cognition emerges from motor function in young children (i.e., 1.5–6 years of age) – they predicted several cognitive functions like mental rotation ability (Jansen and Heil, 2010; Lehmann et al., 2014), working memory (Lehmann et al., 2014; Gottwald et al., 2016), inhibition (Gottwald et al., 2016) and (2) that exercise improves cognitive function (Hillman et al., 2009; for review see Tomporowski et al., 2015). Additionally, a review by van der Fels et al. (2015) found weak-to-strong relations between motor and cognitive skills, especially in pre-pubertal children (i.e., under 13 years of age) whereas Hartman et al. (2010) reported correlations between motor performance and EF in children with intellectual disabilities. Grooms and Onate (2016) state that the ability to maintain motor control in the unpredictable sport environment demands a complex central nervous system integration of constantly changing inputs, the processing of which also depends on cognitive functions. However, this study is related to the cognitive skills approach as basic cognitive functions are analyzed. Having the value for talent scouting in mind, the current research sets a focus on youth elite athletes.

However, to the best of our knowledge none of these interactions have been examined on a behavioral level in an elite-sports context yet with children in this development stage (i.e., around 12 years of age). In addition, we are following the call of Leisman et al. (2016) by conducting this examination.

Review of Literature on Cognitive Functions and Skills in Elite Youth Soccer Players

In the following, several studies regarding cognitive functions within similar study designs are described (i.e., cross-sectional, elite-athletes, youth, and age range from 9 to 14 years). Verburgh et al. (2014), conducted a study with the aim to examine a broad range of cognitive skills in elite and sub-elite soccer players (n = 126), with an average age of 11.8 years. They measured cognitive abilities, motor inhibition, alerting and orienting, executive network and executive attention, as well as visuospatial working memory. They used a stop signal task, a modified flanker attention network test, and an adapted Bergman-Nutley task (VTSM forward and backward). They reported heterogeneous results: The elite group outperformed the sub-elite in terms of reaction time in the motor inhibition task as well as in the alerting attention task. No differences were found in orienting attention, executive attention, or working memory capacity (WMC).

In another study, the same research group (Verburgh et al., 2016), carried out a similar investigation of elite and sub-elite soccer players and non-athletes (n = 168, M = 10.5 years of age); they checked for motor inhibition, verbal short-term memory, working memory, and visuospatial short-term memory. The elite players significantly outperformed the sub-elite players and the non-athletes in terms of inhibition, short-term memory, and partially working memory. Furthermore, the sub-elite players outperformed the non-athletes in terms of short-term memory and working memory. Moreover, Vestberg et al. (2017), investigated 30 elite soccer players (M = 14.9) in regard to their cognitive functions. Significant results were found for processing speed, simple attention, and WMC in which the elite players performed highly above the level of the normal population. Additionally, working memory and multiprocessing as well as the combination of both functions positively correlated with scored goals whereas no significant correlation was found between processing speed or attention and scored goals.

In contrast to these findings by Vestberg and colleagues which support superior cognitive functions in youth elite athletes, some other studies did not show this exceptionality. For example, Balakova et al. (2015), studied a wide range of cognitive abilities such as visuospatial short-term working memory, reaction ability, and attention by usage of the Vienna test system in 91 elite soccer players (Mage = 13). No differences were found between talented and less talented players except for the ability of spatial and temporal movement anticipation. Also, Granacher and Borde (2017), reported no significant expertise differences when testing elite youth athletes (Mage = 9.5) and non-athletes regarding concentration and attention. For an overview see **Table 1**.

The Present Research

Reviewing the literature on cognitive skills in elite athletes in general, it is conspicuous that there are much fewer studies on youth elite players – especially in the age range from 9 to 14 – (n = 6) (see **Table 1**) than there are on adult elite players – 18 years of age or older – (n = 23). This unpublished review was conducted by the authors in February 2018 by using following inclusion criteria: cross-sectional study, elite- or expert-athletes, examination of active athletes, statement of a specific type of sport. Additionally, the reviewed literature on cognitive skills in youth elite athletes reveals conflicting results and heterogeneity in terms of the used tests (a comparison of employed cognitive

TABLE 1 | Cognitive measurements of elite youth athletes.

Author	Age	Academy/ Country	Type of sport	Test	Measured cognitive abilities	Results
Granacher and Borde, 2017	9,5	Elite-school of sport Germany	Various sports (including soccer)	d2 test	Concentration and attention	*No sign*. Elite differences
Verburgh et al., 2016	10,6	Professional youth soccer academy Netherlands	Soccer	Stop signal task Digit span forward Adapted version of Bergman-Nutley task (VTSM forward)	Motor inhibition Verbal short-term memory (STM) and working memory (WM) Visuospatial short-term memory	Elite *sign*. better than sub-elite and non-athletes: inhibition, STM, WM (not better than sub-elite) Sub-elite athletes *sign*. outperform non-athletes in STM, WM Time spent in organized sports *sign*. positively correlated with inhibition, STM, WM, lapses of attention
Verburgh et al., 2014	11,8	Professional youth soccer academy Netherlands	Soccer	Stop signal task Modified attention network test Modified Flanker task Adapted version of Bergman-Nutley task (VTSM forward and backward)	Motor inhibition Alerting and orienting Executive network and attention Working memory (visuospatial sketchpad and central executive)	Elite *sign*. better than sub-elite (SSRT) but slower RT on go trials Elite with *sign*. larger gain in RT, no differences in orienting attention *No sign*. Elite differences in executive network and attention, working memory
Balakova et al., 2015	13	Professional youth soccer academy Czechia	Soccer	Vienna test system: Reaction test Corsi Block-Tapping test Long-term selective attention test Visual-pursuit test Stroop test Visual memory test Time/movement anticipation test Determination test Gestalt perception test	Cognitive abilities Ability to react Visuospatial short-term working memory Focused attention Visual perception Color-word interference Short-term memory Spatial/temporal movement anticipation Stress tolerance, reactive Special ability test	*No sign*. Elite differences Except the anticipation test (talented within group *sign*. outperformed less talented group)
Vaeyens et al., 2007	14,7	Professional youth soccer academy Belgium	Soccer	Soccer specific video clips (gaze behavior)	Decision making process	Successful within elite group *sign*. quicker in all conditions than less successful group and more accurate in decision making (except condition 2 vs. 1)
Vestberg et al., 2017	14,9	Professional youth soccer academy Sweden	Soccer	CogStateSports Design fluency (DF) Colorword interference test (Stroop test) Trail making test	Demanding working memory (dWM): Attention, processing speed, learning, working memory Multiprocessing (creativity, response inhibition, cognitive flexibility) Cognitive flexibility, verbal inhibition Scanning ability, multiprocessing, cognitive flexibility, short-term memory	Elite players *sign*. above level of normal population: processing speed, attention and dWM No *sign*. Correlation between processing speed / attention and scored goals *Sign*. positive Correlation between dWM, DF, composite score of DF, DWM, and scored goals

tests is illustrated in the supplemental material). The present study aims to enrich the literature on cognitive functions in youth elite soccer players by studying the interplay between these functions and motor/technical skills for the first time. Therefore, the purpose of our research is to set a starting point and open new pathways for research and discussion in terms of the link between cognition and motor skills in youth elite athletes. Furthermore, this linkage has been depicted only on brain-structural and functional dimensions. Therefore, it should be analyzed on a behavioral level. More specifically, the aim of this study was to investigate the relation between cognitive functions [working memory, PL, multiple object tracking (MOT), and AW] and soccer specific motor skills (sprint, change of direction, dribbling, ball control, and ball juggling) in soccer players aged between 11 and 13. These cognitive tests are used based on previous research depicting their crucial importance in elite soccer: (1) working memory; (2) PL (e.g., Vestberg et al., 2012; Verburgh et al., 2014, 2016; Huijgen et al., 2015); (3) MOT (e.g., Faubert, 2013; Romeas et al., 2016); and (4) AW (Hüttermann et al., 2014). As this is a first of its kind investigation the sample size is quite small, because this first step in a possible opening of new research pathways should analyze whether it is worthwhile in the first place. If so, future studies would need to examine this in larger populations.

MATERIALS AND METHODS

Participants

A total of 19 elite youth soccer players from the talent development program of the youth academy of a professional German soccer club were recruited. The participants were boys born between 2005 and 2006 (M_{age} = 12.72, SD_{age} = 0.45) and had started playing soccer at approximately 5.2 years of age (SD = 1.4). At the time of data collection, their teams were playing at the top level of their respective age group and the players were part of a professional youth academy for an average of 2.75 years (SD = 1.47). Participants were not diagnosed with any behavioral, learning, or medical conditions that might influence cognitive abilities. Four datasets of players had to be excluded, two due to missing motor datasets and two because of their positions as goalkeepers, which highly influenced the motor test in a negative way. Therefore, 15 datasets were used for the study. Written informed consent was obtained from every participant before commencing the experiment. The study was carried out in accordance with the Helsinki Declaration of 1975 and was approved by the ethics committee of the German Sport University Cologne.

Procedure and Materials

Data of the cognitive tests were collected in a separate and quiet room. The cognitive test session was conducted prior to a soccer training and consisted of one session lasting approximately 1 h with two players performing the tests simultaneously. We used a battery of four tasks to explore individual differences in basic cognitive mechanisms. Each task is described below. The order of the cognitive tests and the different conditions within were randomized. Participants were instructed to sit in a comfortable position leaning against the backrest of the chair, so that the distance to the screen (approximately 45 cm) was the same for all the players. One experimenter tested all players in a standardized process and was blind to the hypotheses. Additionally, the motor performance test was acquired in a gym approximately 4 months prior to the cognitive tests. This difference regarding the time point of measurement exists due to the fact that the motor test was not conducted for the purpose of this study solely as this test battery is part of the German Soccer Association (DFB) talent-development program and is conducted twice a year in every professional youth academy and at the DFB bases of the talent-development program. Therefore, all players did know this test battery already. Test leaders were either licensed soccer coaches of the youth academy or the DFB talent-development program. The data of this motor performance test were used, because they were analyzed and confirmed for objectivity, reliability, and validity in large scale study (N = 68,158) by Höner et al. (2015).

Cognitive Tests

For stimulus presentation, E-Prime 1.2 (Psychology Software Tools Inc.) and two 15-inch computer screens with a resolution of 1,024 × 786 pixels were used.

The *attention window task* (AWT) by Hüttermann et al. (2013), was used to assess the individual attention breadth on diagonal axis. During each trial, participants were instructed to fixate a central point [21] and try to spot a white triangle within a circle (1.1° diameter) among square distractors (1.1° × 1.1°). Across trials, the target appeared at varying distances from the fixation point (10°, 20°, and 30°) along one of eight equally spaced radial lines that originated from a square in the center of the display (45° apart). This random display was flashed for 12 ms and was followed by a colorful mask (100 ms). After every mask, subjects were asked to indicate how many white triangles they had just seen in the different locations depending on the orientation of the items. Participants completed 180 trials. This particular task measures how well people can attend to objects appearing far from fixation. The dependent measure was the score of the diagonal AW and dividing the total value by the number of the dimensions (i.e., three).

The well-established *working memory span test* (WM) by Conway et al. (2005), measures the athlete's ability to direct attention toward the current task without getting distracted by other thoughts. More specifically, we used a counting span task (see Kane et al., 2004 for a detailed description), as the simplicity of this processing task makes it usable for almost any type of participants (Conway et al., 2005). The instructions were presented as a written text on the computer screen. The counting span task involved counting specific shapes among distractors and then remembering the count totals for later recall. Each stimulus display contained randomly arranged dark blue circles, green circles, and dark blue squares. The task of the participants was to count aloud the dark blue circles and then name the total count aloud at the end. A recall mask occurred after 2–6 stimulus displays into which participants had to fill their memorized count totals in the exact order they had been displayed in. The participants counting span score was a partial credit load score (cf. Conway et al., 2005) which represents the sum of all correctly recalled elements – whereby a correctly recalled item from a set containing two items receives 2 points, and a correctly recalled item from a set with 6 items receives 6 points – divided by the maximum possible score. The test consisted of 15 trials. The dependent measure was the score of correctly memorized objects in percentage.

The *perceptual load test* (PL) by Beck and Lavie (2005), is a measure of inhibition ability as it determines to what extent participants are distracted by stimuli which are totally irrelevant for their task. Participants performed the soccer-specific PL task (Furley et al., 2013) starting with two example blocks (one high and one low load), followed by eight experimental blocks alternating between blocks with low and high load. All participants started out with the high-load block. A fixation point of 1,000 ms was displayed before each trial located in the center of the screen immediately followed by the task display with the soccer-specific arrangement and distractor. The task displays were presented for 100 ms. Subjects were told to ignore the distractor letter and to indicate as quickly and as accurately as possible to which of the target items (the player) the dot (the ball) was allocated. The distractor always showed up on a fixation point (Beck and Lavie, 2005). Participants responded to the target stimuli either by pressing "n" or "c" on the keyboard. The subjects were instructed to press "n" for an X target and "c" for an O target. A new trial was triggered by the participant's response or response omissions within 2 s. After each trial, feedback about incorrect responses or omissions was given by means of a computer sound. After each block, participants were reminded of the key assignments. The test consisted of 160 trials. The dependent measure was the reaction time of PL related to the condition of low and high distraction.

The *motion object tracking test* (MOT) by Alvarez and Franconeri (2007) measures up to which speed threshold participants are able to track several relevant moving objects. Participants monitored the positions of a set of moving circles on a computer monitor. The display initially contained four green circles and three blue ones (1.1° diameter). After 3 s of resting state, the blue items turned green and were identical to the targets and all circles began moving while participants tried to keep track of the positions of the initially green items. The test is adaptive so speed thresholds and number of trials depend on the players' abilities. After 8 s the circles stopped moving and the participants had to select and mark the initially three blue circles. The dependent measure was the number of correctly tracked and marked circles. This task should reveal individual differences in the ability to divide and maintain attention on multiple independently moving objects.

Motor Performance Test

This diverse test battery consists of six tests (sprint 20-m, acceleration 10-m, change of direction, dribbling, ball control, and ball juggling) which assess the motor skills of soccer athletes (Höner et al., 2015).

The *Sprint test* is used to track the time an athlete needs to run 10 and 20 m as fast as possible. The test structure consists of three light barrier pairs, one pair at the start, one at the 10 m point and one at the 20 m point. The task of the athlete is to run as fast as possible through all light barriers. The dependent measure was time (in seconds) at 10 and 20 m.

The *change of direction test* is used to assess how fast the athlete is able to change directions in a preset running parkour – a fixed positioning of bars to direct the athlete in a certain change of direction. The parkour consists of a 3 m sprint to the first slalom parkour – made of three bars – then again a 3 m sprint to the second slalom parkour and then the last 3 m sprint to the finish. The time needed for this task is measured by light barriers at the starting and end point of the parkour. The dependent measure was the total time needed to absolve the parkour.

The *Dribbling test* measures the ability to dribble as fast and as accurate as possible with a ball through a preset parkour with different direction changes. The parkour and the dependent measure used for this task is the same as in the *change of direction test*.

The *Ball Control test* measures the ability to control and pass the ball in a small square as fast and as accurate as possible. The athlete is standing in the middle of the square (1.5 × 1.5 m) which consists of a bounce-wall on the left and on the right at a distance of 3 m. The task is to pass six passes alternately to the two bounce-walls as fast as possible. The passes have to be executed while standing in the middle zone and by using at least two contacts for each pass. The test is over when the last pass is received in the middle zone. The dependent measure was the total time needed to absolve the six passes.

The Ball Juggling test measures the ability to juggle the ball in a preset parkour. The parkour consists of two adjacent circles (3 × 3 m) shaped like an eight. The player starts standing in the middle of the two circles with the ball in his hand. His task is to juggle as fast as possible through the parkour. He gets a point each time he tackles the parkour without a mistake. A mistake was defined as a situation in which the ball touches the ground. The test lasts about 45 s. The dependent measure was the total number of points for successfully absolving the parkour.

We calculated one cumulated value for all cognitive tests (*Cognition Total*) and one for the motor performance tests (*Motor Total)* by adding up the scores of the dependent measures of each motor performance test and dividing the sum by the number of dependent measure variables. All values were z-standardized prior to this calculation. As reaction times for low and for high load in the PL test constitute different cognitive measures (Beck and Lavie, 2005; Furley et al., 2013), we included both values in the Cognition Total Score. *Motor Total* included the overall score of the motor test battery as well which was stated by the test leaders of the motor performance tests to gather a general impression of the performance. This is important to know, as that overall score of the motor test battery differs from the total score calculated by the authors as the first score does not include the test of acceleration.

Statistical Analyses

Data was analyzed using IBM SPSS Statistics 23.0.0. Shapiro-Wilk test was used for testing for normal distributions. Not all variables were normally distributed, as assessed by Shapiro-Wilk's test ($p < 0.05$). Therefore, the Spearman's correlation coefficient test was used to investigate the correlation between the player's cognitive and motor test results. Moreover, effect sizes (cohen's d) were calculated for every correlation coefficient by transforming the r into a d value according to the formula of Ellis (2010) and values of 0.10, 0.30, and 0.50 represent small, medium and large effect size estimates (Cohen, 1998).

RESULTS

Descriptive statistics of each test are illustrated in **Table 2**.

Firstly, there was a significant correlation between the cumulated score Cognition Total and Motor Total,

TABLE 2 | Descriptive statistics of each cognitive and motor test and their dependent measures.

	Mean value	Standard deviation
AW diagonal	4.01	3.46
MOT	988.73	232.85
PL high rt	−4.93	44.42
PL low rt	17.71	54.98
WMC	0.56	0.14
Speed (20 m)	3.43	0.17
Acceleration (10 m)	1.98	0.10
COD	7.95	0.38
Dribbling	1.44	0.95
Ball control	9.40	1.11
Ball juggling	4.77	3.77
Total score	103.97	1.91

For all measurements, the number of participants was equal (n = 15), AW, attention window in cm; MOT, multiple object tracking in number of correctly tracked targets; PL, perceptual load; RT, reaction time in seconds; WM, working memory in %; COD, change of direction.

r_s (13) = 0.614, p = 0.015. Therefore, superior performance in the cognition tests significantly correlates positively with superior performance in the motor tests. Due to this result we further checked for correlations that cause this finding.

In terms of diagonal AW there were no statistically significant correlations between the motor tests except for the dribbling test [r_s (13) = 0.656, p = 0.008] as depicted in **Table 3**. The MOT task was not significantly associated with any of the other tests. Furthermore, there were no significant correlations between the PL reaction times and all other tests. However, there were significant correlations between the WMC test and the test of Dribbling [r_s (13) = 0.562, p = 0.029], Ball control [r_s (13) = 0.669, p = 0.006], Ball juggling [r_s (13) = 0.727, p = 0.002], and the Total Score [r_s (13) = 0.553, p = 0.033]. Thus, superior performance in the WMC test significantly correlates positively with superior performance in the motor tests.

DISCUSSION

The current study addressed the relationship between cognitive functioning and specific motor abilities in elite youth soccer players. The aim was to expand the knowledge of the relationship between basic cognitive skills and soccer specific motor skills. Results showed that the diagonal AW was positively correlated with dribbling performance. This may suggest that athletes who have a wider AW also have advanced dribbling skills. Moreover, these findings could imply that a broad AW enhances the players' skills regarding highly demanding motor tasks, because they may be able to perceive many optical stimuli in their visual AW. This may enable them to execute early reactions in their sensorimotor system to make their performance more efficient. For example, in a game situation where the athlete is dribbling and simultaneously has to keep an eye on the ball, his teammates and his opponents. In this case a broad AW could be beneficial for example to avoid contact with opponents and dribbling in spaces already covered by teammates. These results are in line with previous meta-analysis (Voss et al., 2010; Scharfen and Memmert, 2019) which implicated superior cognitive abilities in elite athletes. Another positive relationship was reported for WMC and dribbling as well as for ball control, ball juggling, and total score. Especially these findings regarding WMC are in line with studies examining cognitive functions in elite athletes mentioned earlier. Previous research for example indicated (a) that a higher WM capacity is associated with a superior athletic performance as well as (b) that time spent in organized sports positively correlates with WM (e.g., Verburgh et al., 2014, 2016). Nevertheless, there are also other studies which did not indicate this relationship (e.g., Furley and Memmert, 2010; Balakova et al., 2015). Additionally, the missing correlation of the motor tests with the MOT and the PL test could be due to the fact that the motor tasks do not include similar demands. For example, in the motor performance tests used here there is no task in which multiple objects or players need to be tracked simultaneously. Therefore, there is no situation that requires similar skills or has the same task structure like the MOT. Although several studies related to the perception-action coupling approach (Renshaw and Davids, 2004; Pinder et al., 2009; Davids et al., 2013) already proved the link of specific perceptual abilities and performance, this is the first study to our knowledge that shows a positive correlation between the cumulated scores of all basic cognitive and all motor tests which could point at a strong interplay of physical and psychological skills. These results are in line with mutually influencing cognition- and motor-networks on a basic functional (Leisman et al., 2016; Ptak et al., 2017) and structural level (Koziol et al., 2012; Bigelow and Agrawal, 2015; Gao et al., 2018). Furthermore, they could also be a hint for the use of similar neural networks (Hanakawa, 2011) and of the same brain regions (Leisman et al., 2016) when carrying out different cognitive tasks and motor skills. Additionally, these findings are in agreement with Grooms and Onate (2016) who state the ability to maintain motor control in the unpredictable sport environment demands complex central nervous system integration of a constantly changing profile of sensory inputs. Moreover, it is also in consonance with their statement that the incorporation of cognitive elements ranging from dual tasks, responding to stimuli, anticipation, decision making, and programming motion relative to external targets may degrade neuromuscular control relative to movement without such factors. In terms of developmental motor-cognition interactions these findings point at the same direction as previous research did with (1) younger children (Jansen and Heil, 2010; Lehmann et al., 2014; Gottwald et al., 2016), (2) cognitive improvements as a function of physical exercise (Hillman et al., 2009; Tomporowski et al., 2015), and (3) strong motor-cognition relations in pre-pubertal children (i.e., under 13 years of age) (for review see van der Fels et al., 2015).

Although the results are based on a cross-sectional study and await replication in a design that allows causal interpretations, the data unveils a possible explanation for differences in

TABLE 3 | Correlations r_s between cognitive and motor tests.

	Speed (20 m)	Acceleration (10 m)	COD	Dribbling	Ball control	Ball-Juggling	Total score
MAW diagonal							
Correlation coefficient	0.087	−0.014	0.339	0.656**	0.380	0.098	0.395
Sig. (twofold)	0.758	0.961	0.216	0.008	0.162	0.729	0.145
Effect size (d)	0.175	−0.027	0.721	1.74	0.822	0.197	0.860
MOT							
Correlation coefficient	−0.047	−0.126	−0.032	0.125	0.146	0.123	0.175
Sig. (twofold)	0.869	0.656	0.909	0.657	0.603	0.664	0.533
Effect size (d)	−0.093	−0.254	−0.064	−252	−294	−248	0.356
PL high reaction time							
Correlation coefficient	−0.029	−0.143	0.211	0.318	0.425	0.418	0.396
Sig. (twofold)	0.919	0.610	0.449	0.248	0.114	0.121	0.143
Effect size (d)	−0.058	−0.289	0.432	0.671	0.939	0.921	0.863
PL low reaction time							
Correlation coefficient	−0.095	−0.056	−0.409	−0.396	0.075	0.168	0.021
Sig. (twofold)	0.737	0.844	0.130	0.143	0.791	0.551	0.940
Effect size (d)	−0.191	−0.112	−0.895	−0.863	0.150	0.341	0.430
WMC							
Correlation coefficient	−0.260	−0.249	0.197	0.562*	0.669**	0.727**	0.553*
Sig. (twofold)	0.350	0.371	0.480	0.029	0.006	0.002	0.033
Effect size (d)	−0.539	−0.513	0.402	1.39	1.81	2.12	1.33

	Motor total
Cognition Total	
Correlation coefficient	0.614*
Sig. (twofold)	0.015
Effect size (d)	1.56

***The correlation is significant at 0.01 level (twofold). *The correlation is significant at 0.05 level (twofold). For all measurements, the number of participants was equal (n = 15). COD, change of direction; AW, attention window; MOT, multiple object tracking; PL, perceptual load; WMC, working memory capacity.*

performance among elite youth soccer players in terms of their cognitive function and their specific motor skills. WMC and AW may prove relevant for talent identification purposes as they are strongly associated with ball juggling, ball dribbling, and especially the total motor skill score and pace, which are all of major interest in professional soccer clubs. By adding these cognitive tests to the physical ones (those who correlated significantly, i.e., dribbling, ball control, ball juggling, and the total score) the impressions and values derived from the physical tests could be strengthened and, besides, the information about the players' profiles in terms of cognitive function would be extended. In terms of talent development, playing soccer at a high level of performance each day, that is in a talent selection team of a professional soccer club, seems to be associated with the development of most of the cognitive skills. This could indicate that these cognitive skills may be crucial for talent development and could be promoted via these talent programs of professional soccer clubs – a positive reciprocal development. Nevertheless, we cannot draw causal conclusions based on our data as talent development might be influenced by a third variable. However, to the best of our knowledge, this study is the first that examines the combination of several cognitive functions and soccer-specific motor skills in young soccer experts. Future studies are clearly needed to investigate this promising relationship further.

We should also acknowledge limitations of the present study. The used motor test analyzes basic soccer-specific motor skills like dribbling and juggling which are able to distinguish elite from recreational soccer players, but not elite from sub-elite (Meylan et al., 2010). The study, thus, does not cover the whole spectrum of the complex soccer game. One example is that no HEFs were assessed which are crucial for the complex game as well (Vestberg et al., 2017). Therefore, some core tactical abilities, such as MOT in a dynamic surrounding like small-sided games are missing. Furthermore, although the change of direction test is well validated, it is a limitation, as it lacks external stimuli on which the changes of direction depend in a real game situation. The differentiation between change of direction and agility is crucial in this regard (Haff and Tripplet, 2016). There is no situation in the game, in which a player has to change his direction in a preset order. Additionally, a high number of correlations in our study were not significant. Thus, more replication research in this field is clearly needed (Klein et al., 2012). Furthermore, the study lacks highly statistical power as the unique sample is relatively small due to the fact that elite youth soccer players have been examined whose accessibility is strictly limited for most of the time.

Consequently, there are several recommendations for future research derived from limitations of this study. First, linking cognitive test results (especially HEF) to (1) that are able to measure more complex and diverse soccer- and sport-specific skills. This is necessary to expand the knowledge about these correlations (e.g., small-sided games and agility test with external stimuli) and (2), objective performance measurements (e.g., assessment of performance during game play), and to strengthen possible relationships and replicate findings from previous studies (Vestberg et al., 2012, 2017). However, it should be noted that performance objectives like scored goals are difficult to measure in young athletes due to highly varying positions of players and due to the fact that the likelihood of scoring goals varies highly depending on the position. Regarding (1), it will be a challenge to include those tests as there may occur problems in terms of objectivity and reliability. Secondly, longitudinal measurements with a larger number of players are necessary to examine the age-related interaction of cognitive functions, soccer-specific motor skills, and their development. Especially considering the individual timing of maturation of cognitive functions (Best et al., 2009). Moreover, using longitudinal study designs would enable researchers to search for additional influential factors as well as to conclude and uncover for further causal relationships as this possibility is very limited in cross-sectional studies. Finally, investigations of HEFs are needed as well as they are an important aspect of the complex game as well (Vestberg et al., 2017).

To summarize, we found that the cognitive functions AW and working memory are partly associated with some specific and core motor skills, whereas the sum of all cognitive, and all motor skills are strongly correlated as well. Additionally, the cognitive test, MOT and PL test, did not show any relation to the tested motor skills. Although one has to keep in mind that this only a first attempt to understand the relationship between cognitive and motor behavior one may have a look at the direction at which these results could point. Namely, these findings could be important from both a theoretical and a practical perspective. From a theoretical point of view, this may highlight the importance of cognitive training models that are based on neuro-cognitive knowledge as well as the need for more sophisticated models and theories that explain the relationship of movements i.e., technique and cognition. The usage of such training models increases the cognitive functions and possibly the motor technique skills, which is in line with recommendations of van der Fels et al. (2015) and with the results above showing correlations of both abilities. The arising need for these cognitive training models is in line with the increasing evidence that some of these cognitive functions like AW and MOT (Romeas et al., 2016; Savelsbergh, 2017) as well as working memory (Klingberg, 2010) are trainable. Nevertheless, the transfer to the real game is not clearly established for every improvement yet. Furthermore, research suggests that a combination of cognitive and physical training is more beneficial for the athletes in terms of cognitive functions, mental health and neurogenesis than only one of them conducted separately (Curlik and Shor, 2012).

From a practical point of view, knowledge about the relationship between cognition and motor skills, in other words between the brain-muscle interplay, could possibly help sport clubs to be able to scout for talents, and new players in a more effective and holistic way. This sophisticated scouting system could be created by adding a cognitive scouting or test tool to the categories of technique, athletics, and tactics. Adding this cognitive tool is backed up by studies that report a high linkage and overlap between cognitive functions and game intelligence, which is crucial for success in elite sports, and still hardly measurable (e.g., Vestberg et al., 2012, 2017). Additionally, this knowledge may be used by coaches to enhance their players' cognitive abilities and eventually some of their motor skills, as well as improving working memory for general motor skills. Referring to this, individual soccer training programs could be created based on these relationships to enhance soccer performance on the pitch.

Furthermore, as these results may point in the same direction as the perception-action coupling approach, it could perhaps help coaches to create training programs and exercises which do not isolate sport specific perception (i.e., cognitive functions) and action (i.e., motor skills) but rather enhance both in unison as these couplings are required and highly challenged in real game situations. Moreover, training those couplings and incorporating cognitive elements may not only enhance performance (Belling and Ward, 2015; Broadbent et al., 2015; Grooms et al., 2015; Appelbaum and Erickson, 2018; Hadlow et al., 2018) but also prevent athletes from injuries (Grooms et al., 2015; Grooms and Onate, 2016).

Further research should provide more evidence for elite youth athletes as specifically these early years in a player's career are crucial for the development of the athlete's cognitive abilities. The sensitive learning phases occur during this period of time which highlights the importance of this age group for further development of the athlete's skills.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the 'ethics committee of the German Sport University Cologne' with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the 'ethics committee of the German Sport University Cologne'.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

Abade, E. A., Gonçalves, B. V., Silva, A. M., Leite, N. M., Castagna, C., and Sampaio, J. E. (2014). Classifying young soccer players by training performances. *Percept. Mot. Skill* 119, 971–984. doi: 10.2466/10.25.PMS.119c31z8

Alvarez, G. A., and Franconeri, S. L. (2007). How many objects can you track? Evidence for a resource-limited attentive tracking mechanism. *J. Vis.* 7, 1–10. doi: 10.1167/7.13.14

Appelbaum, L. G., and Erickson, G. (2018). Sports vision training: a review of the state-of-the-art in digital training techniques. *Intern. Rev. Sport Exerc. Psychol.* 11, 160–189. doi: 10.1080/1750984X.2016.1266376

Balakova, V., Boschek, P., and Skalikova, L. (2015). Selected cognitive abilities in elite youth soccer players. *J. Hum. Kinet.* 49, 267–276. doi: 10.1515/hukin-2015-0129

Beck, D., and Lavie, N. (2005). Look here but ignore what you see: effects of distractors at fixation. *J. Exp. Psychol.* 31, 592–607. doi: 10.1037/0096-1523.31.3.592

Belling, P. K., and Ward, P. (2015). Time to start training: a review of cognitive research in sport and bridging the gap from academia to the field. *Procedia Manuf.* 3, 1219–1224. doi: 10.1016/J.PROMFG.2015.07.202

Best, J. R., Miller, P. H., and Jones, L. L. (2009). Executive functions after age 5: changes and correlates. *Dev. Rev.* 29, 180–200. doi: 10.1016/j.dr.2009.05.002

Bigelow, R. T., and Agrawal, Y. (2015). Vestibular involvement in cognition: visuospatial ability, attention, executive function, and memory. *J. Vestib. Res.* 25, 73–89. doi: 10.3233/VES-150544

Broadbent, D. P., Causer, J., Williams, A. M., and Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: future research directions. *Eur. J. Sport Sci.* 15, 322–331. doi: 10.1080/17461391.2014.957727

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd Edn. Hillsdale: Erlbaum.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, D., and Engle, R. W. (2005). Working memory span tasks: a methodological review and user's guide. *Psychon. B. Rev.* 12, 769–786. doi: 10.3758/BF03196772

Crone, E. A., Wendelken, C., Donohue, S., van Leijenhorst, L., and Bunge, S. A. (2006). Neurocognitive development of the ability to manipulate information in working memory. *Proc. Natl. Acad. Sci. U.S.A.* 103, 9315–9320. doi: 10.1073/pnas.0510088103

Curlik, D. M., and Shor, T. J. (2012). Training your brain: do mental and physical (MAP) training enhance cognition through the process of neurogenesis in the hippocampus? *Neuropharmacology* 64, 506–514. doi: 10.1016/j.neuropharm.2012.07.027

Davids, K., Araújo, D., Vilar, L., Renshaw, I., and Pinder, R. (2013). An ecological dynamics approach to skill acquisition: implications for development of talent in sport. *Talent Dev. Excell.* 5, 21–34.

De Luca, C. R., Wood, S. J., Anderson, V., Buchanan, J. A., Proffitt, T. M., Mahony, K., et al. (2003). Normative data from the CANTAB. I: development of executive function over the lifespan. *J. Clin. Exp. Neuropsy.* 25, 242–254. doi: 10.1076/jcen.25.2.242.13639

Diamond, A. (2013). Executive functions. *Annu. Rev. Psychol.* 64, 135–168. doi: 10.1146/annurev-psych-113011-143750

Ellis, P. D. (2010). *The Essential Guide to Effect Sizes: Statistical Power, Meta-Analysis, and the Interpretation of Research Results*. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511761676

Faubert, J. (2013). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. *Sci. Rep.* 3:1154. doi: 10.1038/srep01154

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., Defries, J. C., and Hewitt, J. K. (2014). Not all executive functions are related to intelligence. *Psychol. Sci.* 17, 172–179. doi: 10.1111/j.1467-9280.2006.01681

Furley, P., and Memmert, D. (2010). Differences in spatial working memory as a function of team sports expertise: the corsi block-tapping task in sport psychological assessment. *Percept. Mot. Skill* 110, 801–808. doi: 10.2466/pms.110.3.801-808

Furley, P., Memmert, D., and Schmid, S. (2013). Perceptual load in sport and the heuristic value of the perceptual load paradigm in examining expertise-related perceptual-cognitive adaptations. *Cogn. Process.* 14, 31–42. doi: 10.1007/s10339-012-0529-x

Gao, Z., Davis, C., Thomas, A. M., Economo, M. N., Abrego, A. M., Svoboda, K., et al. (2018). A cortico-cerebellar loop for motor planning. *Nature* 563, 113–116. doi: 10.1038/s41586-018-0633-x

Gottwald, J. M., Achermann, S., Marciszko, C., Lindskog, M., and Gredebäck, G. (2016). An embodied account of early executive-function development: prospective motor control in infancy is related to inhibition and working memory. *Psychol. Sci.* 27, 1600–1610. doi: 10.1177/0956797616667447

Granacher, U., and Borde, R. (2017). Effects of sport-specific training during the early stages of long-term athlete development on physical fitness, body composition, cognitive, and academic performances. *Front. Physiol.* 8:810. doi: 10.3389/fphys.2017.00810

Grooms, D., Appelbaum, G., and Onate, J. (2015). Neuroplasticity following anterior cruciate ligament injury: a framework for visual-motor training approaches in rehabilitation. *J. Orthop. Sports Phys. Ther.* 45, 381–393. doi: 10.2519/jospt.2015.5549

Grooms, D. R., and Onate, J. A. (2016). Neuroscience application to noncontact anterior cruciate ligament injury prevention. *Sports Health* 8, 149–152. doi: 10.1177/1941738115619164

Hadlow, S. M., Panchuk, D., Mann, D. L., Portus, M. R., and Abernethy, B. (2018). Modified perceptual training in sport: a new classification framework. *J. Sci. Med. Sport* 21, 950–958. doi: 10.1016/j.jsams.2018.01.011

Haff, G. G., and Tripplet, N. T. (2016). *Essentials of Strength Training and Conditioning*, 4th Edn. Champaign, IL: Human Kinetics.

Hanakawa, T. (2011). Rostral premotor cortex as a gateway between motor and cognitive networks. *Neurosci. Res.* 70, 144–154. doi: 10.1016/J.NEURES.2011.02.010

Hartman, E., Houwen, S., Scherder, E., and Visscher, C. (2010). On the relationship between motor performance and executive functioning in children with intellectual disabilities. *J. Intell. Disabil. Res.* 54, 468–477. doi: 10.1111/j.1365-2788.2010.01284.x

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., and Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience* 159, 1044–1054. doi: 10.1016/j.neuroscience.2009.01.057

Höner, O., Votteler, A., Schmid, M., Schultz, F., and Roth, K. (2015). Psychometric properties of the motor diagnostics in the German football talent identification and development programme. *J. Sport Sci.* 33, 145–159. doi: 10.1080/02640414.2016.1177658

Huijgen, B. C. H., Leemhuis, S., Kok, N. M., Verburgh, L., Oosterlaan, J., Elferink-Gemser, M. T., et al. (2015). Cognitive functions in elite and sub-elite youth soccer players aged 13 to 17 years. *PLoS One* 10:e0144580. doi: 10.1371/journal.pone.0144580

Hüttermann, S., Memmert, D., Simons, D. J., and Bock, O. (2013). Fixation strategy influences the ability to focus attention on two spatially separate objects. *PLoS One* 8:e65673. doi: 10.1371/journal.pone.0065673

Hüttermann, S., Simons, D., and Memmert, D. (2014). The size and shape of the attentional "spotlight" varies with differences in sports expertise. *J. Exp. Psychol.* 20, 147–157. doi: 10.1037/xap0000012

Jansen, P., and Heil, M. (2010). The relation between motor development and mental rotation ability in 5-to 6-year-old children. *Intern. J. Dev. Sci.* 4:6775. doi: 10.3233/DEV-2010-4105

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., and Engle, R. W. (2004). The generality of working memory capacity: a latent variable approach to verbal and visuospatial memory span and reasoning. *J. Exp. Psychol.* 133, 189–217. doi: 10.1037/0096-3445.133.2.189

Klein, O., Doyen, S., Leys, C., Magalhães de Saldanha da Gama, P. A., Miller, S., Questienne, L., et al. (2012). Low hopes, high expectations: expectancy effects and the replicability of behavioral experiments. *Perspect. Psychol. Sci.* 7, 572–584. doi: 10.1177/1745691612463704

Klingberg, T. (2010). Training and plasticity of working memory. *Trends Cogn. Sci.* 14, 317–324. doi: 10.1016/j.tics.2010.05.002

Koziol, L. F., Budding, D. E., and Chidekel, D. (2012). From movement to thought: executive function, embodied cognition, and the cerebellum. *Cerebellum* 11, 505–525. doi: 10.1007/s12311-011-0321-y

Lehmann, J., Quaiser-Pohl, C., and Jansen, P. (2014). Correlation of motor skill, mental rotation, and working memory in 3- to 6-year-old children. *Eur. J. Dev. Psychol.* 11, 560–573. doi: 10.1080/17405629.2014.888995

Leisman, G., Moustafa, A. A., and Shafir, T. (2016). Thinking, walking, talking: integratory motor and cognitive brain function. *Front. Public Health* 4:94. doi: 10.3389/fpubh.2016.00094

Luciana, M., Conklin, H. M., Hooper, C. J., and Yarger, R. S. (2005). The development of nonverbal working memory and executive control processes in adolescents. *Child. Dev.* 76, 697–712. doi: 10.1111/j.1467-8624.2005.00872.x

Mann, D. T., Williams, M., Ward, P., and Janelle, C. (2007). Perceptual-cognitive expertise in sport: a meta-analysis. *J. Sport Exerc. Psychol.* 29, 457–478. doi: 10.1123/jsep.29.4.457

Marteniuk, R. G. (1976). *Information Processing in Motor Skills*. New York, NY: Holt.

Meylan, C., Cronin, J., Oliver, J., and Hughes, M. (2010). Talent identification in soccer: the role of maturity status on physical, physiological and technical characteristics. *Int. J. Sports Sci. Coach.* 5, 571–592. doi: 10.1260/1747-9541.5.4.571

Murr, D., Raabe, J., and Höner, O. (2018). The prognostic value of physiological and physical characteristics in youth soccer: a systematic review. *Eur. J. Sport Sci.* 18, 62–74. doi: 10.1080/17461391.2017.1386719

Pinder, R. A., Renshaw, I., and Davids, K. (2009). Information–movement coupling in developing cricketers under changing ecological practice constraints. *Hum. Mov. Sci.* 28, 468–479. doi: 10.1016/J.HUMOV.2009.02.003

Ptak, R., Schnider, A., and Fellrath, J. (2017). The dorsal frontoparietal network: a core system for emulated action. *Trends Cogn. Sci.* 21, 589–599. doi: 10.1016/j.tics.2017.05.002

Renshaw, I., and Davids, K. (2004). Nested task constraints shape continuous perception-action coupling control during human locomotor pointing. *Neurosci. Lett.* 369, 93–98. doi: 10.1016/j.neulet.2004.05.095

Romeas, T., Guldner, A., and Faubert, J. (2016). 3D-multiple object tracking training task improves passing decision-making accuracy in soccer players. *Psychol. Sport Exerc.* 22, 1–9. doi: 10.1016/j.psychsport.2015.06.002

Savelsbergh, G. J. (2017). *Football IntelliGym Efficacy Analysis: PSV Eindhoven and AZ Alkmaar Football Academies*. Genève: Zenodo, doi: 10.5281/zenodo.268696

Scharfen, H.-E., and Memmert, D. (2019). Measurement of cognitive functions in experts and elite-athletes: a meta-analytic review. *Appl. Cogn. Psychol.* 1–18. doi: 10.1002/acp.3526

Tomporowski, P. D., McCullick, B., Pendleton, D. M., and Pesce, C. (2015). Exercise and children's cognition: the role of exercise characteristics and a place for metacognition. *J. Sport Health Sci.* 4, 47–55. doi: 10.1016/j.jshs.2014.09.003

Unnithan, V., White, J., Georgiou, A., Iga, J., and Drust, B. (2012). Talent identification in youth soccer. *J. Sport Sci.* 30, 1719–1726. doi: 10.1080/02640414.2012.731515

Vaeyens, R., Lenoir, M., Williams, A. M., and Philippaerts, R. M. (2007). Mechanisms underpinning successful decision making in skilled youth soccer players: an analysis of visual search behaviors. *J. Mot. Behav.* 39, 395–408. doi: 10.3200/JMBR.39.5.395-408

van der Fels, I. M. J., Te Wierike, S. C. M., Hartman, E., Elferink-Gemser, M. T., Smith, J., and Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4-16 year old typically developing children: a systematic review. *J. Sci. Med. Sport* 18, 697–703. doi: 10.1016/j.jsams.2014.09.007

Verburgh, L., Scherder, E. J., Van Lange, P. A., and Oosterlaan, J. (2014). Executive functioning in highly talented soccer players. *PLoS One* 9:e91254. doi: 10.1371/journal.pone.0091254

Verburgh, L., Scherder, E. J., Van Lange, P. A., and Oosterlaan, J. (2016). Do elite and amateur soccer players outperform non-athletes on neurocognitive functioning? A study among 8-12 years old children. *PLoS One* 11:e0165741. doi: 10.1371/journal.pone.0165741

Vestberg, T., Gustafson, R., Maurex, L., Ingvar, M., and Petrovic, P. (2012). Executive functions predict the success of top-soccer players. *PLoS One* 7:e34731. doi: 10.1371/journal.pone.0034731

Vestberg, T., Reinebo, G., Maurex, L., Ingvar, M., and Petrovic, P. (2017). Core executive functions are associated with success in young elite soccer players. *PLoS One* 12:e017084. doi: 10.1371/journal.pone.017084

Voss, M. W., Kramer, A. F., Basak, C., Prakash, R. S., and Roberts, B. (2010). Are expert athletes 'expert 'in the cognitive laboratory? A meta analytic review of cognition and sport expertise. *Appl. Cogn. Psychol.* 24, 812–826. doi: 10.1002/acp.1588

Waldron, M., and Murphy, A. (2013). A comparison of physical abilities and match performance characteristics among elite and subelite under-14 soccer players. *Pediatr. Exerc. Sci.* 25, 423–434. doi: 10.1123/pes.25.3.423

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Performance Streaks in Elite Beach Volleyball - Does Failure in One Sideout Affect Attacking in the Next?

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This study explores the influence of sideout failure on performance in the next sideout in beach volleyball. The sample comprises 965 elite matches in the FIVB World Series 2012–2016 and in the Olympic Games 2012/2016 including 28,974 sideout sequences (12,755 for men and 16,219 for women). A sideout sequence consists of two sideouts by the same player during the same set in a timeframe of four rallies. The first sideout in this sequence is referred to as the previous sideout and the second sideout as the next sideout. After misses, χ^2-tests indicate a significantly higher technique alternation rate (from spike to shot or vice versa) in the next sideouts for both men (+32.7%) and women (+40.4%) than the next sideouts after hits. After shot misses, the share of shots in the next sideouts was −12.9% lower for men and −8.3% lower for women than the next sideouts after shot hits. After spike misses, the share of shots in the next sideouts by female players was +5.5% significantly higher, and shot hit rate was −6.5% lower than the next sideouts after spike hits. These findings support the belief that tactical decisions and performance in top-level beach volleyball are influenced by failure in the previous sideouts. They might support coaches and players when analyzing matches and developing game strategies.

Keywords: performance analysis, notational analysis, psychological momentum, performance streaks, action sequences

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INTRODUCTION

Beach volleyball is a clearly structured game with two basic situations. In a typical *sideout*, one team receives the opponent's serve, passes the ball, and tries to score with an attack (Koch and Tilp, 2009a). The attacking player can usually choose between a hard-driving *spike* and a soft *shot*, which is preferably played over the block to the open part of the court. The serving team is in *defense* and tries to defend the attack by blocking/digging the attack and to score itself. The winner of a rally will be the next to serve, so that sideout and defense switch continuously between the teams (FIVB, 2017). While the serving player must be alternated every time this occurs, the player that receives the serve can be the same in each sideout of a team.

Recent years have seen many studies on beach volleyball covering different aspects of the games. Research has dealt with the efficiency of game actions and techniques with regard to age, gender, and player's role (Jimenez-Olmedo et al., 2012; Medeiros et al., 2014; Palao and Ortega, 2015; Šimac et al., 2017). Other studies have focused on perception and anticipation (Cañal-Bruland et al., 2011; Güldenpenning et al., 2013; Klostermann et al., 2015;

Noël et al., 2016) and the influence of rule changes (Giatsis, 2003; Ronglan and Grydeland, 2006; Palao et al., 2012). Research has also examined physical workload (Palao et al., 2014; Hank et al., 2016) and the biomechanical aspects of beach volleyball (Tilp et al., 2008; Giatsis et al., 2018).

One question, which has not been investigated so far, is whether failure in a sideout affects the behavior of players in the next sideout. In elite beach volleyball, a team is more likely to score from a sideout situation than from a defense situation (Koch and Tilp, 2009b; Giatsis et al., 2015; Sicoli et al., 2016). The reason is that reception of a serve is much easier and more controllable than defending an attack (Costa et al., 2011) because the ball is hit closer to the net and reaction time is less. A rally won by the serving team is therefore called a "break," which is in contradistinction to many other sports (e.g., tennis). When a player does not score from sideout, there is an increased need and may be a psychological pressure to convert the next sideout. Since there are only two players per team in beach volleyball and substitutions are not allowed, the responsibility of each player is higher than other team sports such as volleyball. For this reason, many athletes and coaches believe that players make different tactical decisions after sideout failures when compared to successful ones.

Related questions have already been addressed for other sports under the headline of "hot-hand" research. The hot hand in sports refers to the belief that success breeds success in a sequence of actions. Gilovich et al. (1985) were the first to ask in relation to basketball if the probability of a hit after a sequence of successful shots is higher than after misses. Subsequently numerous studies have tried to find evidence for the existence of the hot-hand phenomena in various sports, including archery (Medeiros Filho et al., 2008), baseball (Vergin, 2000), bowling (Yaari and David, 2012), cycling (Perreault et al., 1998), dart (Stins et al., 2018), golf (Clark, 2003), tennis (Jackson and Mosurski, 1997), and volleyball (Raab et al., 2012).

Results provide an inhomogeneous picture. One group of studies finds evidence against the existence of hot hand (e.g., Gilovich et al., 1985; Vergin, 2000; Bocskocsky et al., 2014; Csapo and Raab, 2014), whereas a second group maintains the contrary (e.g., Raab et al., 2012; Bocskocsky et al., 2014; Miller and Sanjurjo, 2014; Stins et al., 2018). Meta-studies provide comprehensive overviews of results and associated methodological issues and mostly agree that evidence for the hot-hand phenomena is controversial and fairly limited (Bar-Eli et al., 2006; Avugos et al., 2013; Iso-Ahola and Dotson, 2014). To our knowledge, only one previous study has focused on negative streaks, the so-called "cold hand" (Köppen and Raab, 2012). Here, the authors reported that volleyball playmakers passed fewer balls to a player who performed a sequence of misses. For beach volleyball, no studies on the hot hand or cold hand exist. There are some studies dealing with the sequence effects in a broader sense – influence of rally length and reception quality on attacking performance (Koch and Tilp, 2009a; Sánchez-Moreno et al., 2015) – but these do not examine failure and dependencies between rallies.

This study examines whether failure in a sideout attack affects attacking performance in the next sideout by the same player. Three related subsidiary questions are asked: (1) does sideout failure affect probability of changing attacking technique, (2) does sideout attacking failure increase probability of a further attacking failure ("cold hand"), and (3) are these effects influenced by the attacking technique used? Answering these questions promises benefits for coaches and players, since this could underpin psychological interventions. In addition, many beach top-level volleyball teams perform match analysis in order to uncover typical patterns in opponents' tactical behavior (Link, 2014). Scientific evidence for the general existence of sequence effects would provide an argument for looking for such streaks when developing match strategies. Therefore, the discussion also includes a single case example of how this can be conducted in practice.

MATERIALS AND METHODS

Sample

In line with the objectives of the study, a non-participative observational approach was applied. The sample comprises 965 matches (413 men and 552 women) in the FIVB World Series 2012–2016 and the 2012 and 2016 Olympic Games. Since each player agreed to the video recording of matches on signing their player license, an ethics approval was not required as per applicable institutional and national guidelines. Nevertheless, all procedures performed in the study were in strict accordance with the Declaration of Helsinki as well as with the ethical standards of the local ethics committee.

Performance Variables

For the purpose of this study, a *regular sideout* was defined as a sequence of three ball contacts (reception, set, and attack) directly after a serve. All other rallies, e.g., including service winners, attacks on the second ball contact or free balls, where a ball is passed over the net because an attack was not possible, were excluded. A *sideout sequence* consists of two regular sideouts by the same receiving/attacking player during the same set in a timeframe of four rallies, without being interrupted by a timeout. The first sideout in this sequence will be referred to as the *previous sideout* and the second sideout to as the *next sideout* (**Figure 1**).

For each sideout in a sideout sequence, the performance parameters *Technique* and *Outcome* were collected. Technique indicates whether the attacker hit the ball in a downward direction toward the floor (*spike*) or softly directed the ball to an open area of the court (*shot*). Outcome indicates whether the attacker scored a direct point or the opposing team was not able to touch the ball more than once (successful or *hit*). Otherwise, the sideout is designated as an *unsuccessful* or a *miss*. A miss does not imply that the sideout team did not win really, since there is still the option to defend the counterattack and to score. The variables *Technique Previous Sideout* and *Outcome Previous Sideout* refer to performance

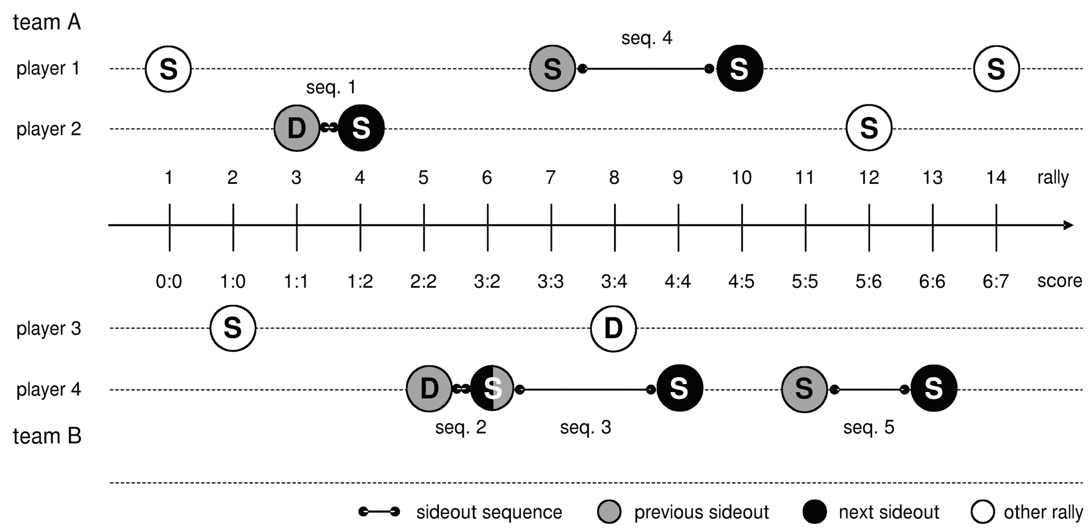

FIGURE 1 | Concept of sideout sequences. Example showing all five sideout sequences (seq.) during the first 14 rallies (circles) in a match. Capital letters indicate whether the sideout team (S) or the serving/defending (D) team scored. In rally 3, the sideout is played by player 2, the serving team scored, and player 2 received the next service in rally 4. Therefore, sequence 1 consists of the previous sideout 3 and next sideout 4. Sequence 4 aggregates the previous sideout in rally 3 and the next sideout in rally 10 by player 1. Rallies 8 and 9 do not interrupt sequence 4 because the length of the time window is three rallies only. One sideout can also be part of two sequences. For example, sideout in rally 6 is the next sideout in sequence 2 as well as the previous sideout in sequence 3. Sideouts in rallies 1 and 3 are not a sequence because they were played by different players. Sideouts in rallies 10 and 14 are also not a sequence, although they were played by the same player. The reason is that the time window between them is more than three rallies. The same applies to the pairs 1/7, 2/8, and 4/12.

parameters in the previous sideout, *Technique Next Sideout* and *Outcome Next Sideout* to the next sideout.

All data were annotated by professional beach volleyball analysts by using custom-made observation software (Link, 2014). Observations based on self-made video recordings were taken by a single camera located behind the court. Data were a part of a more detailed dataset, which was used to prepare Germany's national teams for their competitions. Cohen's κ statistics showed substantial to perfect agreement between two observers based on a subset of 121 sequences (κ = 0.93 up to 1.0).

Statistical Analysis

The analysis uses sideout sequences as statistical units. Data are presented as incidence rates (#) and hit rates (Hit) of sideouts (in %) by the factor *Gender* (men and women). First, the *incidence base rate* ($\#_{base}$) and the *hit base rate* (Hit_{base}) of all sideouts in the categories of Technique are analyzed. $\#_{base}$ is calculated as the number of sideouts in a category divided by the number of all sideouts, and Hit_{base} as the number of hits divided by the number of sideouts in this category. Second, the influence of Outcome Previous Sideout on *technique alternation rate* ($\#_{alter}$) and *technique* alternation *hit rate* (Hit_{alter}) is reported. For each category, $\#_{alter}$ is defined as the number of sequences, where Technique Previous Sideout and Technique Next Sideout differ, divided by the number of all sequences in this category. Hit_{alter} is calculated as the number of successful next sideouts, in which technique is alternated, divided by the number of all next sideouts of this kind. Third, the analysis reports effects of Technique Previous Sideout × Outcome Previous Sideout on the next sideouts played as shots. S*hot rate* ($\#_{shot}$) represents the number of next sideouts played as shots divided by the number of all next sideouts, and *shot hit rate* (Hit_{shot}) the number of successful next sideouts played as shots divided by the number of next sideouts played as shots. In other words, $\#_{shot}$ indicates the share of next sideouts played as shots (and not as spikes), and Hit_{shot} describes how successful these shots are. For next sideouts played as spikes, *spike rate* ($\#_{spike}$) and *spike hit rate* (Hit_{spike}) were calculated in a similar way.

When comparing two rates between conditions, their difference (Δ) (in ± %) of the reference value is reported. To test the significance of differences between rates, χ^2-tests are conducted. Cramer's v is used to describe the effect size of significant differences. Before using parametric statistical test procedures, the assumption of normality was verified. The α-level was set to 0.05. The Holm-Bonferroni method was applied to counteract the problem of multiple comparisons. All statistical analyses were performed using *R* (v3.5).

RESULTS

In the sample, there were 79,422 rallies in total, including 28,974 sideout sequences (12,755 for men and 16,219 for women). Analysis of incident base rates in the categories of Gender × Technique indicates more spikes than shots in men's beach volleyball (Δ = +53.2%, χ^2 = 272.3, $p < 0.001$, $v = 0.10$; **Figure 2A**). In women's matches, no quantitative differences

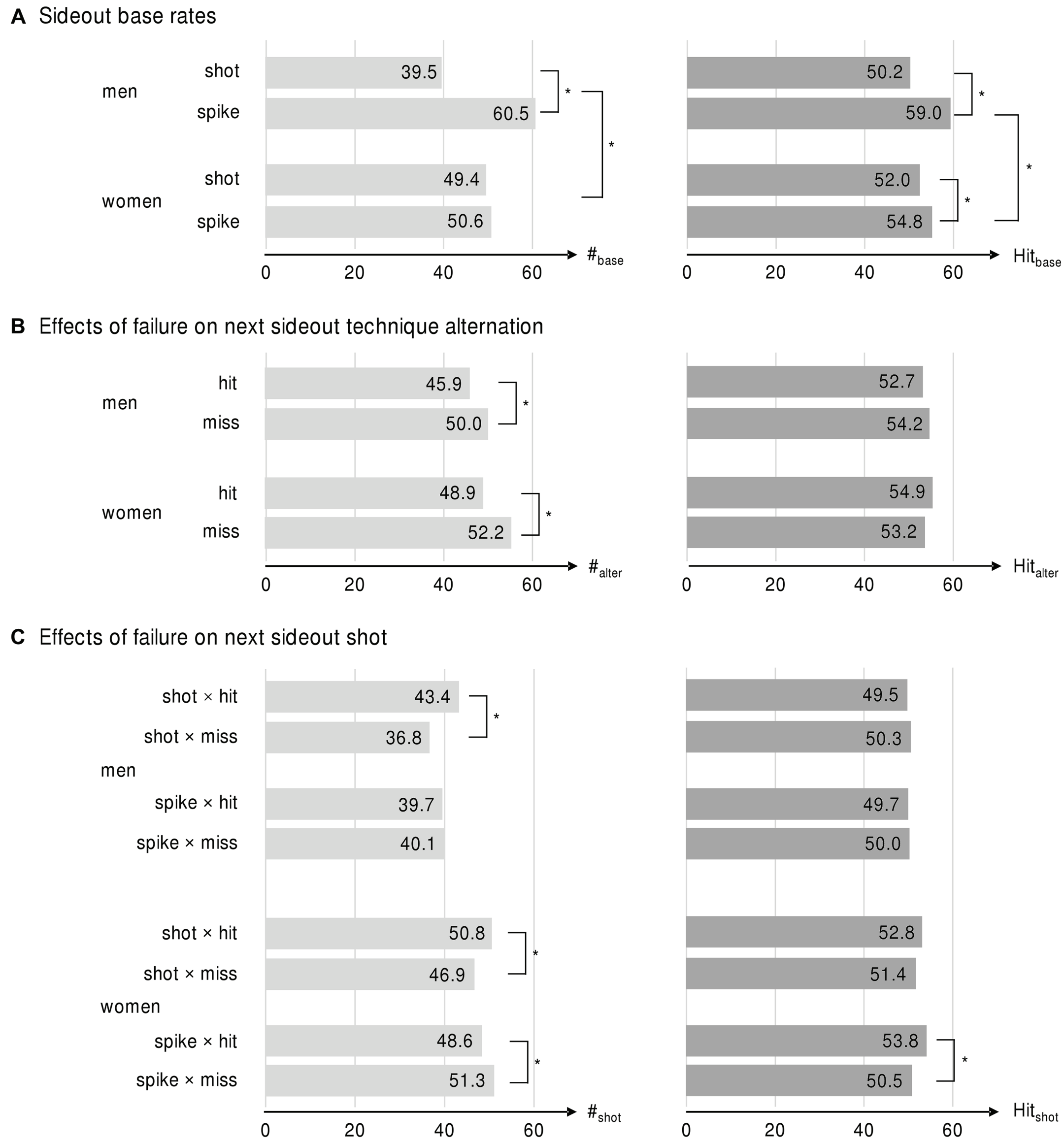

FIGURE 2 | Part **(A)** shows base incidences rates ($\#_{base}$) and base hit rates (Hit_{base}) of shots and spikes in sideouts grouped by Gender. Part **(B)** reports technique alternation rate ($\#_{alter}$) in next sideouts and hit rates (Hit_{base}), in next sideouts, in which technique is alternated, grouped by Gender and Outcome Previous Sideout. Part **(C)** shows incidence rates of shots ($\#_{shot}$) and hit rates of shots (Hit_{base}) in next sideouts grouped by Gender, Technique Previous Sideout and Outcome Previous Sideout. * indicates significant differences between conditions.

in the use of techniques were found. For men, the hit base rate of spikes was +17.5% higher than shots (χ^2 = 98.8, p < 0.01, v = 0.09), and female players were +5.4% more successful when playing spikes (χ^2 = 13.4, p < 0.01, v = 0.03). The hit base rate of spikes was +7.7% higher in men's matches than women's matches (χ^2 = 27.8, p < 0.01, v = 0.05). No significant differences in hit rates of shots were found between men and women. In addition, no differences in base rates were found between the previous and next sideouts for either gender.

Analysis of performance in the categories of Gender × Outcome Previous Sideout shows a higher technique alternation rate in the next sideouts for male and female players after misses than the next sideouts after hits (men: Δ = +32.7%, χ^2 = 61.0, p < 0.01, v = 0.07; women: Δ = +40.4%, χ^2 = 117.1, p < 0.01, v = 0.08; **Figure 2B**). The technique alternation hit rate did not differ between hits and misses in the previous sideouts.

Significant Gender × Technique Previous Sideout × Outcome Previous Sideout interactions were found for sideouts played as shots (**Figure 2C**). After shot misses, shot rate in the next sideouts was −17.9% lower for men and −8.3% lower for women than the next sideouts after shot hits (men: $\chi^2 = 22.1$, $v = 0.07$, $p < 0.01$; women: $\chi^2 = 11.9$, $v = 0.04$, $p < 0.01$). After shot misses, no differences in shot hit rates were found for men and women when compared to sideouts after.

After spike misses, shot rate of female players in next sideouts was +5.5% higher ($\chi^2 = 5.80$, $v = 0.03$, $p < 0.05$) and shot hit rate was −6.5% lower than the next sideouts after spike hits ($\chi^2 = 21.9$, $v = 0.07$, $p < 0.01$). In men's matches, there was no difference between these conditions. Analysis of the previous sideouts played as spikes shows no significant differences in spike rates and spike hit rates between any subgroup. Therefore, these results are not reported in **Figure 2C**.

DISCUSSION

Discussion of Methods

The aim of the study was to answer the question whether sideout failure influences performance in the next sideouts. The definition of a miss includes not only direct errors like out or blocked balls but also defended attacks in which the ball was somehow controlled by the defending team (operationalized by two ball contacts). The idea behind this definition is that top-level teams will likely score when they are able to control the ball in defense (Giatsis et al., 2015), and therefore, the sideout player is expected to try to score with the first chance. Against this, one could argue that the psychological effect of direct errors might be higher than defended attacks because here scoring is still possible. The analysis is limited by the fact that it only studied outcome and technique of the next sideout. Failure could also affect other game actions such as service, block, reception, and setting or the direction of the attack.

By analyzing pairs of sideouts, the question is only whether failure in one sideout affected the next sideout. A different option would be to use streaks of more than one unsuccessful sideout (e.g., three, as proposed by Csapo and Raab, 2014). One argument for longer streaks might be that the effect of failure in beach volleyball is larger or even occurs after many misses in a row. On the other hand, this would lead to a much smaller number of sequences and decrease statistical power. The grounds for using a timeframe maximum of four rallies between two sideouts are that this produces the largest effects. Shorter timeframes exclude more sideouts in which the effect of failure was still present, whereas longer timeframes include more sideouts, which were not influenced by misses. Further studies could vary the timeframe and the streak length to explore the influence of these factors.

The statistical analysis of sequences uses probabilities between the conditions miss and hit (Raab et al., 2012). A different option would have been to treat attacks as continuous sequences and to analyze them by auto correlation and run test, as in the initial study by Gilovich et al. (1985) and many others. However, this approach would not be able to take proper account of confounding factors like timeouts, new sets, and longer timespans in which a player has no sideout. When calculating conditional probabilities, all players are treated as one group (e.g., Stern, 1995). Since this approach masks individual conditions, the results refer to the average performance of players only. Future studies could analyze the rate of players, which are affected by negative streaks and make statements on the range of effect sizes. For practical purposes in particular, it is also necessary to analyze players on an individual level (see paragraph "Discussion of Application").

Discussion of Results

The analysis of base rates suggests that the tactical decision for a particular technique was influenced by its success rate. Since spikes were more successful in men's beach volleyball than shots, athletes might have used this technique more often, whether consciously or unconsciously. In women's matches, the almost similar incidence base rates of spikes and shots are in line with their equal chance of success. The higher hit base rate of spikes in male competitions than women can be explained by motoric and anthropometric differences between genders (Thomas and French, 1985). This also implies that higher physical performance leads to bigger advantages for attacking than for defending actions.

The analysis of sideout pairs indicates that failure in a previous sideout leads to a general tendency to alternate attacking technique (question 1) in the next sideout for both men and women (**Figure 2B**). A lower hit rate after misses was found only in women's beach volleyball (question 2). This is in line with Raab et al. (2012), who also reported a "cold-hand" effect in indoor volleyball but without differentiating between genders, technique, and sideout/defense situation. The effects only occur in particular constellations (question 3). Both, men and women, show a tendency not to play shot again when the previous shot was a miss (**Figure 2C**). We assume that athletes did not wanted to give the opponent a chance to run for a shot and therefore used a hard driven spike more often. This effect was higher in men's beach volleyball than women, which is reasonable from a tactical perspective since hit rates in spike were higher in men's matches (**Figure 2A**).

Women show a lower hit rate when playing a shot after they were not successful in playing a spike. One explanation could be that these shots were played less precise – either by playing less riskily to prevent a direct error or because of higher psychological pressure caused by failure in the previous sideout. A second cause could be that the defending teams anticipated the shots and consequently adapted their tactics – e.g., using a fake block or a different starting position in defense. In men's beach volleyball, there was no effect of misses on hit rate of next sideouts maybe because shots play a less important role.

Effect sizes in the study are quite small. This is less surprising since performance streaks in general are infrequent, weak events are difficult to detect (Iso-Ahola and Dotson, 2014). Tactical decisions in complex sports like beach volleyball depend on a number of additional factors such as the quality of the players themselves and the pairs, situational awareness, tactical agreements, quality of setting, individual preference, climatic conditions, set time, the set number, or anthropometric factors, especially concerning the attacker and the blocker. Clearly, it is also the goal of every player to act as variably and unpredictably as possible. The elite athletes in the sample are at the level they are because they are able to put this into practice. Elite players must also have a high mental performance and stability, which reduces effects of failure. Nevertheless, sequence effects in beach volleyball are found, which support the existence of psychological momentum in this sport.

Discussion of Application

We think that the application of action sequences in practical game analysis needs additional performance variables, e.g., the attacking direction. **Figure 3** shows a single case analysis similar to those that were used by the German teams during the 2012 and 2016 Olympics. The visualization includes data of sideout sequences of one top-level female player in eight matches in which the previous sideout was played with a spike. The three courts in the left column show the number of spikes played diagonal, mid, and line in the previous sideouts. The other courts show the number of smashes (straight line with arrow) and shots (curved line with arrow) in the next sideouts also grouped by their target zone. The courts in the second column show data of the next sideouts after hits, the courts in the third column after misses.

As far as we interpret the data, the player has a tendency to play two diagonal spikes in a row after she was successful with the first (11 diagonal spike in 39 sideouts, 28.2%). When she was not successful with the first diagonal spike, she repeated this technique only in 4 of 28 (14.3%) sideouts. Instead, she uses more spikes in the mid area of the court (7 mid spikes in 28 sideouts, 25.0%), compared to sideouts after hits (5 mid spikes in 39 sideouts, 12.8%). Consequently, teams who play against this player could try to adapt their defense, e.g., by trying to cover more of the central area of the court while blocking – without of course revealing this too early. After spikes played line or in the middle of the court (second and third row), the player shows no differences in attacking behavior between hits and misses.

It is easy to accept that these kinds of analytics can only provide first quantitative hints, which require confirmation using qualitative video analysis (Gréhaigne et al., 2001; Wilson, 2008). In addition, this information does not guarantee the correct prediction of individual behavior, since success in previous rallies is only one factor, which might affect performance. Validity depends on many considerations, e.g., if data were collected in balanced and high important matches in which the player was under pressure. In the final analysis, action sequences are only an additional information source for improving teams' success probability. However, based on our experience, winning one or two points per match in top-level beach volleyball using this information makes the approach rewarding.

CONCLUSION

The findings support the belief that attacking failure influences the choice of attacking technique in the next sideout in elite

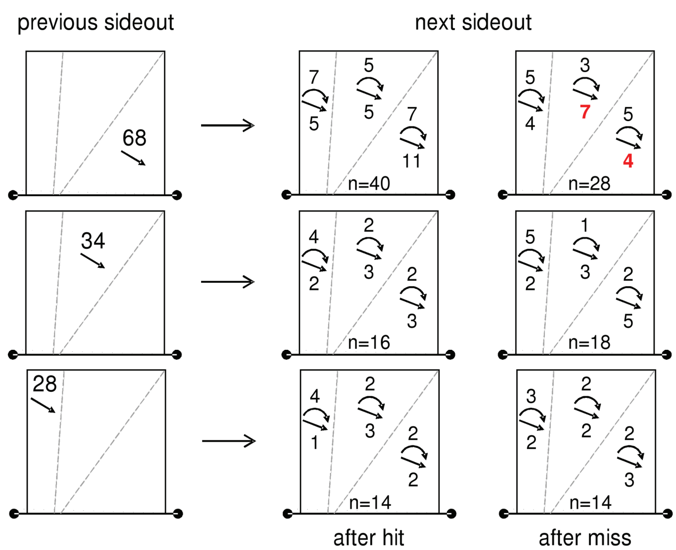

FIGURE 3 | Match report used for supporting German national beach volleyball teams. It shows the profile of one female player in eight matches. Data include sideout sequences in which the previous sideout was played with a spike. The three courts in the left column show the number of spikes played diagonal (n = 68), mid (n = 34), and line (n = 28) in the previous sideouts. The other courts show direction (line, mid, diagonal) and technique (curved line with arrow ≙ shot, straight line with arrow ≙ spike) of attacks in the next sideouts after successful sideouts (second column) and after failure (third column). In this structure, e.g., the second court in the third row shows data of all sideouts after successful line spikes.

beach volleyball. In women's beach volleyball failure has a negative impact on the hit rate in the next sideout, which provides supporting evidence for a cold-hand phenomena under certain conditions. In men's beach volleyball players show a tendency to switch attacking technique after misses, but this does not influence the hit rate. Analysis of streaks on an individual level holds potential for practice, since the knowledge about behavioral stereotypes is a precondition for overcoming them by training and assisting a player in acting more unpredictably. They can also be used for developing match strategies, e.g., by better anticipating an opponent's behavior after misses.

ETHICS STATEMENT

Since each player agreed to the video recording of matches on signing their player license, an ethics approval was not required as per applicable institutional and national guidelines. Nevertheless, all procedures performed in the study were in strict accordance with the Declaration of Helsinki as well as with the ethical standards of the local ethics committee.

AUTHOR CONTRIBUTIONS

DL contributed to the conception, design of the study, and statistical analysis and wrote the manuscript. SW worked on data processing and data analysis. All authors contributed to manuscript revision, as well as reading and approving it for publication.

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REFERENCES

Avugos, S., Köppen, J., Czienskowski, U., Raab, M., and Bar-Eli, M. (2013). The "hot hand" reconsidered: a meta-analytic approach. *Psychol. Sport Exerc.* 14, 21–27. doi: 10.1016/j.psychsport.2012.07.005

Bar-Eli, M., Avugos, S., and Raab, M. (2006). Twenty years of "hot hand" research: review and critique. *Psychol. Sport Exerc.* 7, 525–553. doi: 10.1016/j.psychsport.2006.03.001

Bocskocsky, A., Ezekowitz, J., and Stein, C. (2014). "The hot hand: a new approach to an old "fallacy"" in *Paper presented at MIT Sloan Sports Analytics Conference* (*SSAC14*). (Boston, USA: MIT Sloan).

Cañal-Bruland, R., Mooren, M., and Savelsbergh, G. J. P. (2011). Differentiating experts' anticipatory skills in beach volleyball. *Res. Q. Exerc. Sport* 82, 667–674. doi: 10.1080/02701367.2011.10599803

Clark, R. D. (2003). An analysis of streaky performance on the LPGA Tour. *Percept. Mot. Skills* 97, 365–370. doi: 10.2466/pms.2003.97.2.365

Costa, G., Conselheiro Joaquim Caetano, R., Neiva Ferreira, N., Junqueira, G., Afonso, J., Plácido Costa, R., et al. (2011). Determinants of attack tactics in youth male elite volleyball. *Int. J. Perform. Anal. Sport* 11, 96–104. doi: 10.1080/24748668.2011.11868532

Csapo, P., and Raab, M. (2014). "Hand down, Man down." analysis of defensive adjustments in response to the hot hand in basketball using novel defense metrics. *PLoS One* 9:e114184. doi: 10.1371/journal.pone.0114184

FIVB (2017). *Official beach volleyball rules 2017–2020: Approved by the 35th FIVB Congress 2016*. (Lausanne, Switzerland: Fédération Internationale de Volleyball (FIVB)).

Giatsis, G. (2003). The effect of changing the rules on score fluctuation and match duration in the FIVB women's beach volleyball. *Int. J. Perform. Anal. Sport* 3, 57–64. doi: 10.1080/24748668.2003.11868275

Giatsis, G., Lopez Martinez, A., and García, G. (2015). The efficacy of the attack and block in game phases on male FIVB and CEV beach volleyball. *J. Hum. Sport Exerc.* 10, 537–549. doi: 10.14198/jhse.2015.102.01

Giatsis, G., Panoutsakopoulos, V., and Kollias, I. A. (2018). Biomechanical differences of arm swing countermovement jumps on sand and rigid surface performed by elite beach volleyball players. *J. Sports Sci.* 36, 997–1008. doi: 10.1080/02640414.2017.1348614

Gilovich, T., Vallone, R., and Tversky, A. (1985). The hot hand in basketball: on the misperception of random sequences. *Cogn. Psychol.* 17, 295–314. doi: 10.1016/0010-0285(85)90010-6

Gréhaigne, J. F., Mahut, B., and Fernandez, A. (2001). Qualitative observation tools to analyse soccer. *Int. J. Perform. Anal. Sport* 1, 52–61. doi: 10.1080/24748668.2001.11868248

Güldenpenning, I., Steinke, A., and Koester, D. (2013). Athletes and novices are differently capable to recognize feint and non-feint actions. *Exp. Brain Res.* 230, 333–343. doi: 10.1007/s00221-013-3658-2

Hank, M., Malý, T., Zahálka, F., Dragijský, M., and Bujnovský, D. (2016). Evaluation of the horizontal movement distance of elite female beach volleyball players during an official match. *Int. J. Perform. Anal. Sport* 16, 1087–1101. doi: 10.1080/24748668.2016.11868950

Iso-Ahola, S., and Dotson, C. O. (2014). Psychological momentum: why success breeds success. *Rev. Gen. Psychol.* 18, 19–33. doi: 10.1037/a0036406

Jackson, D., and Mosurski, K. (1997). Heavy defeats in tennis: psychological momentum or random effect? *Chance* 10, 27–34. doi: 10.1080/09332480.1997.10542019

Jimenez-Olmedo, J., Penichet-Tomás, A., Saiz-Colomina, S., Martinez-Carbonell, J. A., and Jove-Tossi, M. A. (2012). Serve analysis of professional players in beach volleyball. *J. Hum. Sport Exerc.* 7, 706–713. doi: 10.4100/jhse.2012.73.10

Klostermann, A., Vater, C., Kredel, R., and Hossner, E.-J. (2015). Perceptual training in beach volleyball defence: different effects of gaze-path cueing on gaze and decision-making. *Front. Psychol.* 6:1834. doi: 10.3389/fpsyg.2015.01834

Koch, C., and Tilp, M. (2009a). Analysis of beach volleyball action sequences of female top athletes. *J. Hum. Sport Exerc.* 4, 272–283. doi: 10.4100/jhse.2009.43.09

Koch, C., and Tilp, M. (2009b). Beach volleyball techniques and tactics: a comparison of male and female playing characteristics. *Kinesiology* 41, 52–59.

Köppen, J., and Raab, M. (2012). The hot and cold hand in volleyball: individual expertise differences in a video-based playmaker decision test. *Sport Psychol.* 26, 167–185. doi: 10.1123/tsp.26.2.167

Link, D. (2014). A toolset for beach volleyball game analysis based on object tracking. *Int. J. Comp. Sci. Sport* 13, 24–35.

Medeiros Filho, E. S., Moraes, L. C., and Tenenbaum, G. (2008). Affective and physiological states during archery competitions: adopting and enhancing the probabilistic methodology of individual affect-related performance zones (IAPZs). *J. Appl. Sport Psychol.* 20, 441–456. doi: 10.1080/10413200802245221

Medeiros, A. I. A., Mesquita, M. I., Marcelino, O. R., and Palao, J. M. (2014). Effects of technique, age and player's role on serve and attack efficacy in high level beach volleyball players. *Int. J. Perform. Anal. Sport* 14, 680–691. doi: 10.1080/24748668.2014.11868751

Miller, J. B., and Sanjurjo, A. (2014). A cold shower for the hot hand fallacy. SSRN IGIER working paper no. 518.

Noël, B., Hüttermann, S., van der Kamp, J., and Memmert, D. (2016). Courting on the beach: how team position implicitly influences decision-making in beach volleyball serves. *J. Cogn. Psychol.* 28, 868–876. doi: 10.1080/20445911.2016.1194847

Palao, J. M., and Ortega, E. (2015). Skill efficacy in men's beach volleyball. *Int. J. Perform. Anal. Sport* 15, 125–134. doi: 10.1080/24748668.2015.11868781

Palao, J. M., Valadés, D., Manzanares, P., and Ortega, E. (2014). Physical actions and work-rest time in men's beach volleyball. *Motriz. Rev. Ed. Fis.* 20, 257–261. doi: 10.1590/S1980-65742014000300003

Palao, J. M., Valadés, D., and Ortega, E. (2012). Match duration and number of rallies in men's and women's 2000–2010 FIVB world tour beach volleyball. *J. Hum. Kinet.* 34, 99–104. doi: 10.2478/v10078-012-0068-7

Perreault, S., Vallerand, R. J., Montgomery, D., and Provencher, P. (1998). Coming from behind: on the effect of psychological momentum on sport performance. *J. Sport Exerc. Psychol.* 20, 421–436. doi: 10.1123/jsep.20.4.421

Raab, M., Gula, B., and Gigerenzer, G. (2012). The hot hand exists in volleyball and is used for allocation decisions. *J. Exp. Psychol. Appl.* 18, 81–94. doi: 10.1037/a0025951

Ronglan, L. T., and Grydeland, J. (2006). The effects of changing the rules and reducing the court dimension on the relative strengths between game actions in top international beach volleyball. *Int. J. Perform. Anal. Sport* 6, 1–12. doi: 10.1080/24748668.2006.11868351

Sánchez-Moreno, J., Marcelino, R., Mesquita, I., and Ureña, A. (2015). Analysis of the rally length as a critical incident of the game in elite male volleyball. *Int. J. Perform. Anal. Sport* 15, 620–631. doi: 10.1080/24748668.2015.11868819

Sicoli, M., Rocha, G., and Vinci, G. (2016). *What the 2016 Olympic Games Tought Us About Beach Volleyball Statistics and Benchmarks*. Available at: https://www.avca.org/res/uploads/media/2017-AVCA-Beach-Stats-in-Rio.pdf (Accessed December 16, 2018).

Šimac, M., Grgantov, Z., and Milić, M. (2017). Situational efficacy of top croatian senior beach volleyball players. *Acta Kinesiol.* 11, 35–39.

Stern, H. S. (1995). "Who's hot and who's not: runs of success and failure in sports" in *Proceedings of the section on statistics in sports* (Orlando, USA: American Statistical Association), 26–35.

Stins, J. F., Yaari, G., Wijmer, K., Burger, J. F., and Beek, P. J. (2018). Evidence for sequential performance effects in professional darts. *Front. Psychol.* 9:591. doi: 10.3389/fpsyg.2018.00591

Thomas, J. R., and French, K. E. (1985). Gender differences across age in motor performance: a meta-analysis. *Psychol. Bull.* 98, 260–282. doi: 10.1037/0033-2909.98.2.260

Tilp, M., Wagner, H., and Müller, E. (2008). Differences in 3D kinematics between volleyball and beach volleyball spike movements. *Sports Biomech.* 7, 386–397. doi: 10.1080/14763140802233231

Vergin, R. C. (2000). Winning streaks in sports and the misperception of momentum. *J. Sport Behav.* 23, 181–197.

Wilson, B. D. (2008). Development in video technology for coaching. *Sports Technol.* 1, 34–40. doi: 10.1080/19346182.2008.9648449

Yaari, G., and David, G. (2012). "Hot hand" on strike: bowling data indicates correlation to recent past results, not causality. *PLoS One* 7:e30112. doi: 10.1371/journal.pone.0030112

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Running Performance of Soccer Players During Matches in the 2018 FIFA World Cup: Differences Among Confederations

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With the purpose of quantifying the differences in the running performance of soccer players during matches from different continental confederations, data of 1508 match observations generated from 559 players in 59 matches at the 2018 FIFA World Cup held in Russia were analyzed. Generalized mixed linear modeling was carried out to estimate the effect of confederations on each of the selected thirteen match running performance related variables (total distance covered, top speed achieved, number of sprints, distance covered and time spent in walking, jogging, low-speed running, moderate-speed running, and high-speed running), controlling the effects of match result, competition phase, and team and opponent strength. Results showed that the differences in the match running performance of UEFA and CONMEBOL players were trivial (ES between 0.04 and 0.14); players from AFC, CAF, and CONCACAF covered less total distance (ES between 0.26 and 0.54), spent less playing time, and covered less distance in jogging and low-speed running (ES between 0.20 and 0.53), whereas they spent more time walking (ES between 0.27 and 0.41) as compared with players from UEFA and CONMEBOL; top speed achieved, number of sprints made, and time spent and distance covered in the moderate- and high-speed running intensity zones by players from all confederations were similar (ES between 0.01 and 0.15), with an exception that high-speed-running distance covered by CONCACAF players was less than that by CAF players (2.0 ± 1.5 m/min vs. 2.3 ± 1.7 m/min, ES = 0.23, ±90% CL: ±0.21).

Keywords: football, physical performance, match analysis, performance analysis, running distance

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INTRODUCTION

Being one of the most popular sports, soccer (association football) is believed to be a "universal language" (Sarmento et al., 2013). However, due to differences in the geographical, cultural, historical, and social aspects, soccer teams from different countries and continents are often characterized by different particularities of match-play (Sarmento et al., 2013; Sapp et al., 2018).

On the basis of a qualitative analysis, (Sarmento et al., 2013) discussed the differences in the preferred strategy and tactics, players' characteristics, and coaches' philosophy existing among the English Premier League, Italian *Serie A*, and Spanish *La Liga.* It was concluded that English Premier

League teams prefer the direct playing style, Italian teams are characterized by their rigid tactical requirement and defensive organization, whereas Spanish teams prioritize the technical beauty of the game and prefer to control the game by passing.

Apart from that, many quantitative studies compared the differences between major European leagues in aspects of anthropometric data, refereeing, player recruitment, injury pattern, competitive balance, and technical and physical match performance. Bloomfield et al. (2005) found that, in the "big five" European soccer leagues (English Premier League, French *Ligue 1*, German *Bundesliga,* Italian *Serie A,* Spanish *La Liga*), players from the *Bundesliga* had the greatest stature, body mass, and BMI, while *La Liga* players had the shortest stature, while the *Serie A* players had the least body mass and BMI. Sapp et al. (2018) indicated that the English Premier League is the most aggressive league with the lowest number of yellow and red cards per match, supporting the notion of the most lenient refereeing in the "big five." Littlewood et al. (2011) identified that teams from the *Bundesliga* and Premier League are the biggest recruiter of foreign players, while *La Liga* and *Serie A* teams host the most indigenous home-grown players; while *Ligue 1* teams have the most non-indigenous home-grown players. Waldén et al. (2005) showed that the risk of match injury was significantly higher in the English and Dutch teams than in the teams from France, Italy, and Spain. Pawlowski et al. (2010) demonstrated that Italian *Serie A* was the most unbalanced competition in the "big five," whereas French *Ligue 1* was the most balanced competition during the 2001–2008 period. Oberstone (2011) investigated the technical match performance of the English Premier League, Italian *Serie A,* and Spanish *La Liga*, and found that teams from the English Premier League had a significantly lower percentage of shots on target than teams from the other two leagues, whereas *Serie A* teams had the highest percentage of successful tackles among the three leagues. Dellal et al. (2011) compared both the physical and technical match performance of soccer players in the English Premier League and Spanish *La Liga*. Their main findings included that the total distance covered by players from the English Premier League and *La Liga* was non-significant, but Premier League players generally covered greater distances in sprinting, while players from both leagues performed a similar proportion of successful passes.

The FIFA World Cup is the highest-level international soccer tournament contested by national teams throughout the world. It provides an ideal sample to study the match performance of soccer players from different continental confederations. Thus, the current study aims to analyze the running performance of soccer players during matches in the 2018 FIFA World Cup held in Russia to identify if there is a "continental difference" in the context of modern soccer.

MATERIALS AND METHODS

Data Resource

Match data were retrieved from the official website of FIFA (FIFA, 2018). The original data were collected using a real-time optical tracking system operated at 25 frames per second that provided details of players' activities on the field. The accuracy of the tracking system has been verified by the Centre for Football Research, Liverpool John Moores University[1]. The updated tracking system has been recently tested by Linke et al. (2018) and has an acceptable reliability. For previous applications of FIFA's database, refer to the examples given by Da Mota et al. (2015) and Nassis et al. (2015). The research committee of the local university approved this study. The committee believed that the object investigated in this study was match-performance data generated by soccer players, which did not involve direct human or animal subjects; hence, no written informed consent was required.

Sample and Variables

There were thirty-two teams from five different continental confederations that participated in the sixty-four matches of the 2018 FIFA World Cup. These five confederations are: Asian Football Confederation (AFC, five teams), Confederation of African Football (CAF, five teams), Confederation of North, Central American and Caribbean Association Football (CONCACAF, three teams), Confederación Sudamericana de Fútbol (CONMEBOL, 5 teams) and the Union of European Football Associations (UEFA, fourteen teams). In line with Da Mota et al. (2015), we selected fifty-nine of sixty-four matches from the tournament for our analysis, excluding the five matches in which extra time was played. Observations generated from all out-field players who participated in these fifty-nine matches were selected as our sample (including the full-match, substituted-on, and substituted-out players). Match data of goalkeepers were excluded because of the specificity of this position. The final sample included 1508 match observations generated by 559 players (see **Table 1** for more details). On the basis of the availability of data, thirteen variables were selected to quantify the running performance of players during matches. Detailed operational definitions of these variables can be found in **Table 2**. The running intensity intervals were set by the FIFA official tracking system (FIFA, 2018). Referencing the intervals used by Da Mota et al. (2015) and Nassis et al. (2015), we classified the intensity zones into the following: zone 1, walking; zone 2, jogging; zone 3, low-speed running; zone 4, moderate-speed running; zone 5, high-speed running.

PROCEDURE AND STATISTICAL ANALYSIS

Generalized mixed linear modeling was realized with *Proc Glimmix* in the University Edition of Statistical Analysis System (version SAS Studio 3.6). The confederation variables, match result, competition phase, and team and opponent strength were included in the modeling as the fixed effects. Random effects for player name, team identity, and match identity were added to account for repeated measurement on the players, teams, and matches. Separate Poisson regressions were run in the modeling, taking the value of each of the thirteen match running performance-related variables as dependent variables.

[1] www.uefa.com

TABLE 1 | Detailed sample distribution.

	UEFA	CONMEBOL	AFC	CAF	CONCACAF	Total
Number of players	250	87	82	83	57	559
Age[#] (mean ± SD)	27.5 ± 3.8	28.1 ± 3.6	27.9 ± 3.4	26.8 ± 3.6	28.9 ± 4.5	27.7 ± 3.8
Caps* (mean ± SD)	41.6 ± 31.6	42.9 ± 33.6	42.2 ± 32.4	29.2 ± 21.6	61.6 ± 37.7	42.0 ± 32.3
Match observations (min-max)	730 (1–7)	259 (1–5)	194 (1–4)	194 (1–3)	131 (1–4)	1508 (1–7)

*[#]Age on 14th June 2018 (opening day of the 2018 FIFA World Cup) calculated from the birth dates of players. *Number of matches played for the national team. The information of birth date and caps was derived from the "FWC_2018_Squadlists" published on the FIFA official website.*

TABLE 2 | Selected dependent variables.

Variable (unit)	Definition
Total Distance (m·min^{-1})	Total distance covered by a player during match play relativized to per minute
Top Speed (km/h)	Maximum running velocity of a player during match play
Sprint (times·min^{-1})	Efforts of sprint (velocity >20 km/h) achieved by a player during match play relativized to per minute
Time zone 1 (%)	Percentage of time moving at the velocity of 0–7 km/h out of total playing time
Time zone 2 (%)	Percentage of time moving at the velocity of 7–15 km/h out of total playing time
Time zone 3 (%)	Percentage of time moving at the velocity of 15–20 km/h out of total playing time
Time zone 4 (%)	Percentage of time moving at the velocity of 20–25 km/h out of total playing time
Time zone 5 (%)	Percentage of time moving at the velocity of >25 km/h out of total playing time
Distance zone1 (m·min^{-1})	Distance covered at the velocity of 0–7 km/h by a player during match play relativized to per minute
Distance zone2 (m·min^{-1})	Distance covered at the velocity of 7–15 km/h by a player during match play relativized to per minute
Distance zone3 (m·min^{-1})	Distance covered at the velocity of 15–20 km/h by a player during match play relativized to per minute
Distance zone4 (m·min^{-1})	Distance covered at the velocity of 20–25 km/h by a player during match play relativized to per minute
Distance zone5 (m·min^{-1})	Distance covered at the velocity of >25 km/h by a player during match play relativized to per minute

Confederation, match result, and competition phase were all included as nominal predictor variables in the model. Confederation was with five levels (UEFA, CONMEBOL, AFC, CAF, and CONCACAF), match result was with three levels (win, draw, and loss), and competition phase was with two levels (group stage and knock-out stage). The effect of team and opponent strength was estimated by including the difference in the log of the FIFA Ranking as a predictor (Yi et al., 2018). By adding the fixed effects of match result, competition phase, and team and opponent strength, the pure differences among confederations can be more accurately assessed.

Uncertainty in the true effects of the predictors was evaluated using non-clinical magnitude-based inferences as implemented in the spreadsheet accompanying the package of materials for generalized mixed modeling with SAS Studio (Hopkins, 2016). Estimated magnitudes and their confidence limits were expressed in standardized units, and were assessed qualitatively with the following scale: <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, >2.0 very large (Hopkins et al., 2009). Standardization was achieved by dividing the estimated effect by the between-player standard deviation, which was derived from the mixed model by adding the variance for the true differences between players to the team-to-team and match-to-match variance within players before taking the square root. Effects were deemed clear if the 90% confidence interval did not include substantial positive and negative values simultaneously. Clear effects were reported with a qualitative likelihood that the true effect was either substantial or trivial (whichever probability was greater) using the following scale: <0.5% most unlikely, 0.5–5% very unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely (Hopkins et al., 2009).

RESULTS

Descriptive statistics and differences in the running performances of the players during matches from different continental confederations estimated from the generalized mixed linear modeling are presented in **Table 3** and **Figure 1**.

The match running performances of UEFA and CONMEBOL players were similar. The total distance covered by AFC, CAF, and CONCACAF players were substantially less than that covered UEFA and CONMEBOL players to a small magnitude. Players from AFC, CAF, and CONCACAF spent substantially more time walking but less time jogging and low-speed running than did players from UEFA and CONMEBOL. Consequently, AFC, CAF, and CONCACAF players covered less distance in jogging and low-speed running than UEFA and CONMEBOL players. The differences in the top speed achieved, number of sprints made, time spent and distance covered in the moderate- and high-speed running intensity zones by players from all confederations were clearly trivial, with the exception that the high-speed-running distance covered by CONCACAF players was substantially less than that covered by CAF players.

DISCUSSION

The current study quantified the differences in the running performance of soccer players during matches from different continental confederations participating in the 2018 FIFA World Cup held in Russia. Our main results showed that the difference in the running performance of UEFA and CONMEBOL players were trivial; players from AFC, CAF, and CONCACAF covered less total distance, spent less playing time and covered less distance in jogging and low-speed running, while they spent

TABLE 3 | Descriptive statistics of the match running performance of soccer players in the 2018 FIFA World Cup estimated from the generalized mixed linear model.

Variable	UEFA	CONMEBOL	AFC	CAF	CONCACAF
TD	107 ± 12	105 ± 12	102 ± 11	102 ± 11	100 ± 11
Top speed	28.1 ± 2.8	28.2 ± 2.8	28.2 ± 2.8	28.2 ± 2.8	27.8 ± 2.7
Sprint	0.36 ± 0.16	0.35 ± 0.15	0.35 ± 0.15	0.35 ± 0.15	0.34 ± 0.15
Time zone 1	66.3 ± 6.0	66.5 ± 6.0	68.4 ± 6.2	68.2 ± 6.2	68.8 ± 6.2
Time zone 2	25.4 ± 4.6	25.3 ± 4.6	23.9 ± 4.4	24.1 ± 4.4	23.4 ± 4.3
Time zone 3	5.4 ± 1.8	5.4 ± 1.8	5.0 ± 1.7	5.1 ± 1.7	4.9 ± 1.7
Time zone 4	1.69 ± 0.77	1.64 ± 0.75	1.64 ± 0.75	1.64 ± 0.75	1.66 ± 0.76
Time zone 5	0.32 ± 0.67	0.32 ± 0.66	0.33 ± 0.67	0.39 ± 0.74	0.36 ± 0.72
Distance zone 1	37.7 ± 3.8	37.1 ± 3.7	37.9 ± 3.8	37.4 ± 3.8	37.0 ± 3.7
Distance zone 2	44.5 ± 8.3	44.0 ± 8.2	41.6 ± 7.8	41.8 ± 7.9	40.3 ± 7.6
Distance zone 3	15.1 ± 4.9	14.9 ± 4.9	13.8 ± 4.6	14.1 ± 4.6	13.9 ± 4.6
Distance zone 4	6.1 ± 2.5	6.1 ± 2.5	5.9 ± 2.4	5.9 ± 2.5	5.8 ± 2.4
Distance zone 5	2.1 ± 1.6	2.1 ± 1.6	2.2 ± 1.6	2.3 ± 1.7	2.0 ± 1.5

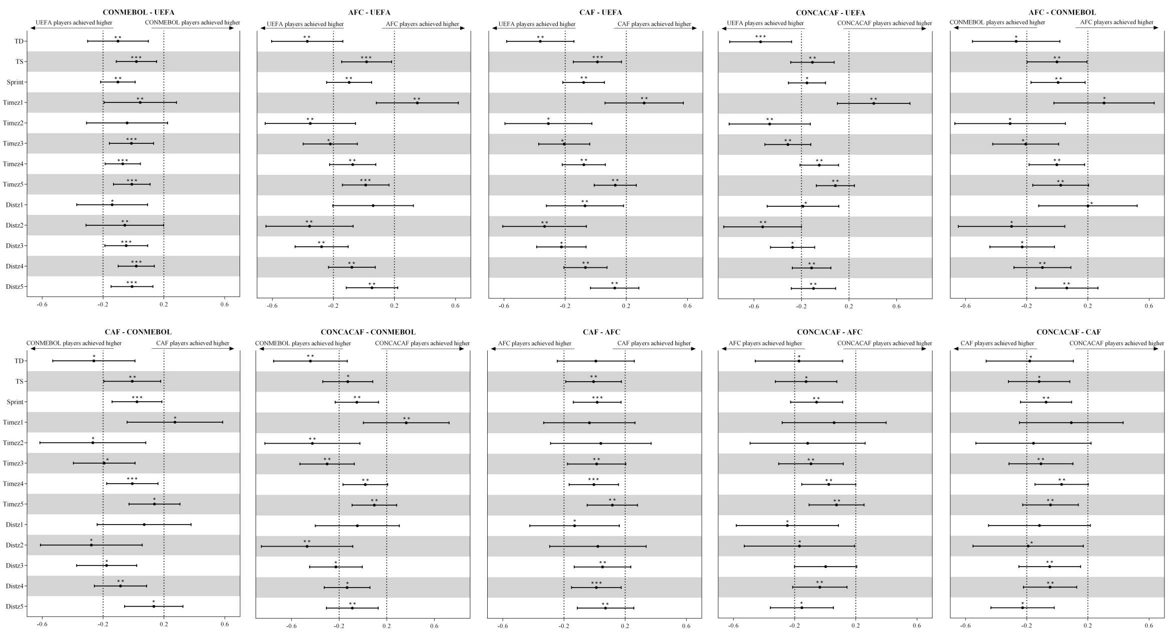

FIGURE 1 | Standardized differences among running performance of players from different continental confederations. Bars are 90% confidence intervals. Asterisks indicate the likelihood for the magnitude of the true difference as follows: *possible; **likely; ***very likely. Asterisks located in the area between –0.2 and 0.2 denote for trivial differences.

more time in walking than players from UEFA and CONMEBOL; top speed achieved, number of sprints made, time spent and distance covered in the moderate- and high-speed running intensity zones by players from all confederations were similar, with an exception that high-speed-running distance covered by CONCACAF players was less than CAF players.

It has been generally accepted that soccer players and teams from different leagues, countries, and confederations are always attributed to different characteristics (Crolley et al., 2000; Wong, 2008). Previous studies investigating these differences mainly focused on comparing the European domestic leagues. Major results indicated that soccer teams from the English Premier League prefer the direct playing style with a special emphasis on the physical aspect, Italian teams are especially characterized by their rigid tactical requirement and defensive organization, while Spanish teams prioritize the technical beauty of the game and players have better ability to control the game (Oberstone, 2011; Sarmento et al., 2013; Sapp et al., 2018). Dellal et al. (2011) analyzed the running performance of soccer players during matches from the English Premier League and Spanish *La Liga*, and concluded that there was no overall difference between these two leagues in total distance covered. However, not much is known about the differences in soccer players among different continental confederations (Wong, 2008), especially when it comes to the running performance during matches. An early study (Rienzi et al., 2000) reported that the total distance covered in matches by professional soccer players from South America was about 1500 m (8638 m vs. 10104 m) less than that of players from the English Premier League. While it contrasts with the result of Barros et al. (2007) who revealed that the mean total distance covered (10012 m) by Brazilian First Division soccer players was similar to European soccer players. Our results are in accordance with Dellal et al. (2011) and Barros et al. (2007), the total distance covered, as well as distance covered and match time spent in different speed zones, by UEFA players are analogous to CONMEBOL players.

High-intensity running is one of the most crucial elements in elite soccer match performance (Di Salvo et al., 2009; Dellal et al., 2011). The comparative analysis of Dellal et al. (2011) revealed that English Premier League players performed a substantially greater distance in high-intensity running than *La Liga* players. Nevertheless, our results showed that top speed achieved, number of sprints made, and time spent and distance covered in the moderate- and high-speed running intensity zones by players from nearly all confederations were similar in matches at the 2018 FIFA World Cup in Russia. Previous research on the 2010 and 2014 FIFA World Cup showed that players competing in this type of tournament may adopt a "pacing strategy" by modifying their match behaviors to maintain their ability to execute technical actions at a high level and to preserve their capacity to achieve high intensity activities by generating the peak running speeds (Nassis, 2013; Nassis et al., 2015; Chmura et al., 2017). One of the most common pacing strategies is that players spare low-intensity activities such as walking and jogging so as to preserve essential high-intensity running (Bradley and Noakes, 2013). According to our results which showed that AFC, CAF, and CONCACAF players spent more playing time walking, while they spent less time and covered less distance in jogging and low-speed running than players from UEFA and CONMEBOL, we can find that there was a difference in the pacing strategies executed by players from UEFA and CONMEBOL and players from the other three confederations. AFC, CAF, and CONCACAF players had to spare their jogging and low-speed running time and distance to guarantee their high intensity running activities, while UEFA and CONMENBOL players were able to achieve the same by saving their playing time by walking. Considering the truth that UEFA and CONMENBOL teams were superior in terms of FIFA rankings and the fact that teams from these two confederations took 14 out of the 16 qualified positions in the FIFA, 2018 World Cup, players of UEFA and CONMENBOL can be attributed to having the highest quality (Collet, 2013). Hence, the results from this study could reveal a trend that all elite soccer players can preserve that capacity to accomplish the essential high intensity activities reaching their top running speeds in different match contexts, while the best players can achieve this by recovering from jogging and low-speed running rather than from walking.

Some attention should be paid to the special case that the high-speed-running distance covered by CONCACAF players was less than that by CAF players. This finding may partially be explained by the difference in the age of players from these two confederations. The information of squads of all the teams in the 2018 World Cup (FIFA, 2018) showed that CONCACAF players who appeared in matches of this World Cup were the oldest (28.9 years on average) and the most experienced (61.6 national team caps on average), while the appeared CAF players were the youngest (26.8 years on average) and with the least experience (29.2 national team caps on average). According to Wong (2008), this was also the situation in the 2002 and 2006 editions of the FIFA World Cup. Wong (2008) further pointed out that the young squads of CAF may be due to the fact that the playing style in Africa was high-speed and high-intensity characterized, where younger players could normally perform better than older players.

Practical Applications and Limitations

Results of this study could provide some practical information to soccer practitioners in several ways. On one hand, UEFA clubs that are used to recruiting elite soccer players from CONMEBOL domestic leagues could plan training drills for these newly recruited players, focusing more on the technical and tactical aspects rather than the physical ones, because the match running performance of elite players from these two confederations was analogous. On the other hand, training of elite soccer players should not only emphasize their ability to maintain high intensity activities but should also underline their capacity of recovery from jogging and low-speed running rather than from walking. Furthermore, when a relatively older squad is in hand, average age up to 29 years for example, coaches should be aware that the players may have some limitations to achieving high-speed running activities during the match; thus, a special training plan and match preparations are warranted.

There are some limitations in our study that should be further investigated. Firstly, the well-defined positional difference in the match running characteristics of players should be considered for future analysis. Secondly, the differences in the tactical and technical match performance of players from different confederations were not measured in this study, which are suggested to be combined. Lastly, due to the limitation in the accessibility of data, the sample distribution in this study is not homogeneous; moreover, the sample does not include the matches with extra time, neither does it exclude the matches with red cards. These shortcomings may lead to some bias in the results, which should be avoided in future research.

AUTHOR CONTRIBUTIONS

QT participated in the study design, statistical analysis, data interpretation, and manuscript preparation. LW, GH, and HZ achieved the literature search, data collection, and statistical analysis. HL managed the whole process of study design, literature search, data collection, statistical analysis, data interpretation, and manuscript preparation.

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REFERENCES

Barros, R. M. L., Misuta, M. S., Menezes, R. P., Figueroa, P. J., Moura, F. A., Cunha, S. A., et al. (2007). Analysis of the distances covered by first division brazilian soccer players obtained with an automatic tracking method. *J. Sports Sci. Med.* 6, 233–242.

Bloomfield, J., Polman, R., Butterly, R., and O'Donoghue, P. (2005). Analysis of age, stature, body mass, BMI and quality of elite soccer players from 4 European Leagues. *J. Sport Med. Phys. Fit.* 45:58.

Bradley, P. S., and Noakes, T. D. (2013). Match running performance fluctuations in elite soccer: indicative of fatigue, pacing or situational influences? *J. Sport Sci.* 31, 1627–1638. doi: 10.1080/02640414.2013.796062

Chmura, P., Konefał, M., Andrzejewski, M., Kosowski, J., Rokita, A., and Chmura, J. (2017). Physical activity profile of 2014 FIFA World Cup players, with regard to different ranges of air temperature and relative humidity. *Int. J. Biometeorol.* 61, 677–684. doi: 10.1007/s00484-016-1245-5

Collet, C. (2013). The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. *J Sport Sci.* 31, 123–136. doi: 10.1080/02640414.2012.727455

Crolley, L., Hand, D., and Jeutter, R. (2000). Playing the identity card: stereotypes in european football. *Soccer Soc.* 1, 107–128. doi: 10.1080/14660970008721267

Da Mota, G., Thiengo, C. R., Gimenes, S. V., and Bradley, P. S. (2015). The effects of ball possession status on physical and technical indicators during the 2014 FIFA World Cup Finals. *J. Sport Sci.* 34:1. doi: 10.1080/02640414.2015.1114660

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., et al. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *Eur. J. Sport Sci.* 11, 51–59. doi: 10.1080/17461391.2010.481334

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., and Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *Int. J. Sports Med.* 30, 205–212. doi: 10.1055/s-0028-1105950

FIFA (2018). *FIFA World Cup Russia 2018*. Available at: https://www.fifa.com/worldcup/ (accessed July 30, 2018).

Hopkins, W. G. (2016). SAS (and R) for mixed models. *Sportscience* 20, 1–4.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–13. doi: 10.1249/MSS.0b013e31818cb278

Linke, D., Link, D., and Lames, M. (2018). Validation of electronic performance and tracking systems EPTS under field conditions. *PLoS One* 13:e0199519. doi: 10.1371/journal.pone.0199519

Littlewood, M., Mullen, C., and Richardson, D. (2011). Football labour migration: an examination of the player recruitment strategies of the 'big five'European football leagues 2004–5 to 2008–9. *Soccer Soc.* 12, 788–805. doi: 10.1080/14660970.2011.609680

Nassis, G. P. (2013). Effect of altitude on football performance: analysis of the 2010 FIFA world cup data. *J. Strength Cond. Res.* 27, 703–707. doi: 10.1519/JSC.0b013e31825d999d

Nassis, G. P., Brito, J., Dvorak, J., Chalabi, H., and Racinais, S. (2015). The association of environmental heat stress with performance: analysis of the 2014 FIFA World Cup Brazil. *Br. J. Sports Med.* 49, 609–613. doi: 10.1136/bjsports-2014-094449

Oberstone, J. (2011). Comparing team performance of the English premier league, Serie A, and La Liga for the 2008-2009 season. *J. Quant. Anal. Sports* 7:2.

Pawlowski, T., Breuer, C., and Hovemann, A. (2010). Top clubs' performance and the competitive situation in European domestic football competitions. *J. Sports Econ.* 11, 186–202. doi: 10.1177/1527002510363100

Rienzi, E., Drust, B., Reilly, T., Carter, J. E., and Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *J. Sports Med. Phys. Fit.* 40:162.

Sapp, R. M., Spangenburg, E. E., and Hagberg, J. M. (2018). Trends in aggressive play and refereeing among the top five European soccer leagues. *J. Sports Sci.* 36, 1346–1354. doi: 10.1080/02640414.2017.1377911

Sarmento, H., Pereira, A., Matos, N., Campaniço, J., Anguera, T. M., and Leitão, J. (2013). English premier league, spain's la liga and italy's serie A – What's different? *Int. J. Perform. Anal. Sport* 13, 773–789.

Waldén, M., Hägglund, M., and Ekstrand, J. (2005). UEFA Champions league study: a prospective study of injuries in professional football during the 2001–2002 season. *Br. J. Sports Med.* 39, 542–546. doi: 10.1136/bjsm.2004.014571

Wong, P. (2008). Characteristics of world cup soccer players. *Soccer J. Binghamton Natl. Soccer Coach. Assoc. Am.* 53:57.

Yi, Q., Jia, H., Liu, H., and Gómez, M. Á. (2018). Technical demands of different playing positions in the UEFA champions League. *Int. J. Perform. Anal. Sport* 18, 926–937. doi: 10.1080/24748668.2018.1528524

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Reliability of Judging in DanceSport

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Purpose: The aim of this study was to assess the reliability and validity of the new judging system in DanceSport.

Methods: Eighteen judges rated the 12 best placed adult dancing couples competing at an international competition. They marked each couple on all judging criteria on a 10 level scale. Absolute agreement and consistency of judging were calculated for all main judging criteria and sub-criteria.

Results: A mean correlation of overall judging marks was 0.48. Kendall's coefficient of concordance for overall marks ($W = 0.58$) suggesting relatively low agreement among judges. Slightly lower coefficients were found for the artistic part [Partnering skills ($W = 0.45$) and Choreography and performance ($W = 0.49$)] compared to the technical part [Technical qualities ($W = 0.56$) and Movement to music ($W = 0.54$)]. ICC for overall criteria was low for absolute agreement [ICC(2,3) = 0.62] but higher for consistency [ICC(3,3) = 0.80].

Conclusion: The relatively large differences between judges' marks suggest that judges either disagreed to some extent on the quality of the dancing or used the judging scale in different ways. The biggest concern was standard error of measurement (SEM) which was often larger than the difference between dancers scores suggesting that this judging system lacks validity. This was the first research to assess judging in DanceSport and offers suggestions to potentially improve both its objectivity and validity in the future.

Keywords: DanceSport, ballroom dance, judging system, reliability, validity, aesthetic sports

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INTRODUCTION

DanceSport consists of three different disciplines: Standard dances (Waltz, Tango, Viennese Waltz, Slow Foxtrot, and Quickstep), Latin-American dances (Samba, Cha-Cha-Cha, Rumba, Paso Doble, and Jive) and Ten Dances (five Standard and five Latin-American dances). A dancer's success is determined by technical and tactical skills (Uznović and Kostić, 2005; Howard, 2007; Uznović, 2008; Laird, 2009) morphological and motor abilities (Koutedakis, 2008; Lukić et al., 2011; Prosen et al., 2013), psychological preparation and aesthetics of movement (Lukić et al., 2009; Čačković et al., 2012). Furthermore, efficiency in DanceSport has been suggested as a determining factor for a judge to award marks for the dancers' performance (Bijster, 2013a,b). This is pertinent since judges have a big influence on the rules, judging and, of course, the final result for a dance performance. Judging in DanceSport is characterized by a subjective marking system that is often criticized because of lack of objectivity. Judges are responsible for quickly and accurately discerning the quality of technical elements and overall aesthetic appearance of a dancer's performance based upon their perception of the performance. To make it harder they need to evaluate six or twelve couples on the dance floor in just a minute and a half.

Prior to the introduction of a new judging system in 2013, the judging system in DanceSport had not been changed for many years, in contrast to many other aesthetic sports like gymnastic, figure-skating, etc., where changes had been made during the last decade (Boen et al., 2008; Dallas and Kirialanis, 2010). There have been some criticisms of the old judging system in DanceSport by dancers, coaches, and judges with unsubstantiated suggestions that some dancers were favored over others, there was insufficient time to properly evaluate each dancer and that dancers did not get sufficient feedback on the quality of their performance (Ambrož, 2010; Bijster, 2012; Hurley, 2012; Malitowska, 2013). Whilst these comments are hearsay, the World DanceSport Federation did construct a new judging system using a similar model to figure-skating and presented it in September 2013. The purpose of this new system was, theoretically, to allow more objective and reliable judging and to give better feedback to dancers in regard to specific criteria of their performance. The main differences of the new system are the determination of four main judging criteria, a higher number of judges used and a lower number of dancers dancing at the same time. Dancers perform three dances solo and two dances with six couples on the dance floor at the same time.

Several aspects of judging performance in aesthetic sports have been described (Popović, 2000; Plessner and Schallies, 2005; Leskošek et al., 2010; Bučar Pajek et al., 2011). Studies have shown that changes in the judging system have usually resulted in higher objectivity of judging (Lockwood et al., 2005; Atiković et al., 2011; Leskošek et al., 2013). To date, there is a lack of studies for judging in dance, with consequent concern for the possibility of systematic bias and inconsistency of judging in DanceSport, which could influence competition results. Research into the quality of judging is therefore seen as a necessity. We therefore designed this study to assess the reliability and validity of the new judging system in DanceSport by measuring the agreement and consistency between judges for all criteria.

MATERIALS AND METHODS

Ethics Statement

This study was approved by the Ethics Committee of the Faculty of Sport at the University of Ljubljana. The study's objectives and methods were explained to each participant, before a written, informed consent was obtained.

Participants

Eighteen judges, two national and 16 WDSF international licensed, had an average judging experience of 19.6 ± 9 years. All judges were educated on the new judging system and had participated in seminars and undertaken the annual judging exam. All of them had previously competed as sport-dancers and most were still coaches.

Procedure

The new judging system consists of technical and artistic parts which each have two criteria, the content of which is defined in **Table 1**. Judging involves four groups of three judges, each group judging only one criterion, which is randomly selected. Each of the three judges in each group therefore judge the dancers on the four sub-criteria but only award one mark which is the main criterion score. These three scores are then put into a formula to calculate the final mark awarded for the main criterion. The judging scale offers 10 different quality rating levels, with 0.5 subdivisions (total of 21 points of evaluation). A description of performance is defined for each level (0–10). Dancers perform three dances solo and two dances with six couples on the dance floor at the same time.

For this study judges rated the 12 best placed adult dancing couples (over 19 years of age) competing at an international competition, the International Open 2012 in Ljubljana, Slovenia. Judges viewed the dances from video (filmed from the same position as judges would be standing at the competition) projected onto a big screen. Judges had 1 min to mark one couple on all four sub-criteria for one main criterion on a 10 levels scale, as would be the case for the real competition. However, whereas in a competition a judge would not need to give a mark for each sub-criteria, i.e., only the main criterion, in this study they were asked to award marks for all sub-criteria also. The order of judging criteria and dancing couples were randomly selected for each judge.

Data Analysis

Basic distributional parameters and Pearson *r* correlation coefficient were computed for all marks for each individual judge. A Total mark was also computed as the mean of the marks for the four main criteria. Inter-rater reliability was evaluated by *MeanCor* (average *r* between all 18 judges in each main and sub-criteria), Kendall's *W* coefficient of concordance and ICCs (intra-class correlation coefficients). Using the notation of Shrout and Fleiss (1979) the following ICCs were computed:

TABLE 1 | Judging criteria issued by the World DanceSport Federation (2013).

Technical part		Artistic part	
Technical qualities	**Movement to music**	**Partnering Skills**	**Choreography and performance**
Posture and hold	Timing	Couple position	Choreography
General principles	Shuffle timing	Leading	Creativity, personal style
Basic actions	Specific rhythm requirements	Basic action – partnering	Expression, interpretation
Specific principles	Personal interpretation	Line Figures – partnering	Characterization

ICC(2,1), ICC(2,3), ICC(3,1), and ICC(3,3), i.e., single and average measures for both two-way random (consistency) and fixed (agreement) effects. ICC(2,3) and ICC(3,3) were computed from ICC(2,1) and ICC(3,1) using Spearman–Brown prediction formula. Additionally, SEM (standard error of measurement) was calculated as SD*$[1\text{–ICC}(2,3)]^{1/2}$, where SD is standard deviation of competitors scores for a criterion. All calculations were performed with *irr* and *psych* libraries of R software (The R project for statistical computing, 2015).

RESULTS

Overall marks (average of marks for technical qualities, movement to music, partnering skills and choreography presentation) showed great variability among judges (**Figure 1**). Range widths varied from less than two points (judges #3 and #9) to more than six points (judges #7 and #8). Individual judge's averages varied between being 1.57 points (judge #7) below the average of all judges to being more than 1 point (judges #4, #9 and #12) above. Minimum marks for individual judges were, in most cases, above 4 points (in half of the judges above 6 points), but as low as 1.25 point for judge #7. Similarly, maximum marks vary from 7.75 (judge #6) to 9.50 (judges #4, #12, and #18). Also extreme difference between judges exist in variability of their marks, e.g., between judge #3 (standard deviation $s = 0.51$, coefficient of variation CV = 0.06), and judge #7 ($s = 2.30$, CV = 0.40).

Combining the judges scores resulted in a mean value for the overall mark of 7.33 with mean standard deviation 1.22 (**Table 2**). However, the difference between the minimum and maximum of the lowest and the highest marks was 6.5 and 1.5 points, respectively. Overall judging marks varied for the mean (5.77–8.53) and s (0.67–2.42) with larger differences for mean values for Partnering skills ($M = 5.67$–8.7) than Choreography and performance ($M = 5.53$–8.54), Movement to music ($M = 5.92$–8.71), and Technical qualities ($M = 5.92$–8.5).

A mean correlation of overall judging marks was 0.48 (**Table 3**) with correlations ranging between Partnering skills ($M = 0.46$) and Choreography and performance ($M = 0.49$) to Movement to music ($M = 0.59$) and Technical qualities ($M = 0.60$). However, correlation coefficients ranged between 0.06 and 0.84. For the reliability of judging the Kendall's W coefficient and ICC of a single (x,1) and three (x,3) judges (as used in the new system) were considered. Kendall's coefficient of concordance for overall marks ($W = 0.58$) suggested low agreement among judges. Slightly lower coefficients were found for the artistic part [Partnering skills ($W = 0.45$) and Choreography and performance ($W = 0.49$)] compared to the technical part [Technical qualities ($W = 0.56$) and Movement to music ($W = 0.54$)]. The lowest value was for the sub-criterion Leading ($W = 0.41$). Similar results were found for ICC coefficients with the ICC for overall criteria low for absolute agreement [ICC(2,3) = 0.62] but higher for consistency [ICC(3,3) = 0.80].

Reliability was also estimated separately for the order in which judges evaluated the sub-criteria. Average ICC(1,3) for the 20 criteria were 0.50, 0.56, 0.59, and 0.51, respectively.

All of the judges' marks for the four main criteria were highly correlated with their own sub-criteria (**Figure 2**). However, the correlations between the four main criteria were much lower, especially for some judges (#3, #13, and #15).

DISCUSSION

The relatively large differences between judges' marks (mean values ranged between 5.77 and 8.53) suggest differences in how judges perceived the quality of the dancers or their interpretation of the judging scale. The use of three judges in the new judging system helps reduce inter-judge differences by averaging, thus reducing the effect of extreme scores, evident in the ICC coefficients for three judges compared to for one. The ICC coefficients and Kendall's coefficients of concordance were, however, quite low suggesting poor validity of the new judging system. Since dancing experts, judges, coaches, and dancers contributed to this system a potential solution could be to learn from other sports which have changed their judging systems in a positive way (Boen et al., 2008; Dallas and Kirialanis, 2010; Leskošek et al., 2010).

The relatively high standard errors of measurement (SEM), e.g., 0.54 for the overall marks was higher than the difference between scores for consecutively ranked dance couples in all but one case (0.99 between places 10 and 11) and higher than the difference between "bronze medal" and 9th position. As SEM is only one part of MD (*minimum difference to be considered real*, usually computed as SEM*1.96*$2^{1/2}$; Weir, 2005), it seems that the rank order of pairs is not defensible as the error of measurement is in many cases much higher than the actual differences between pairs.

The present judging scale offers 10 different quality rating levels. Whilst a description of performance is defined for each level (0–10) it may be the case that judges do not adopt these criteria easily (hence the differences in scores) and subconsciously create their own marking scale and continue to rank dancing couples against each other, the opposite of the intention of the new judging system. A comparable judging scale (0 to 10) is used in figure-skating, where the description of each level includes the content of the performed elements along with technical and artistic descriptors. The quality of required elements is specifically defined which also includes possible mistakes in a performance (International Skating Union, 2015). Potentially DanceSport should define a similar scale to that used in skating, where descriptors of quality for each criteria and sub-criteria are defined.

The judging of the technical parts of performance was shown to be more reliable than the artistic parts, which could be a result of more detailed criteria for the technical parts. Lockwood et al. (2005) also found that judging the technical part was more reliable than judging the artistic part in ice-skating. Similarly, Pajek et al. (2014) noted that judging the artistry component in gymnastic showed poor reliability among judges. Vermey and Brandt (2002) suggested that judges rely on their knowledge and ability to recognize artistic qualities,

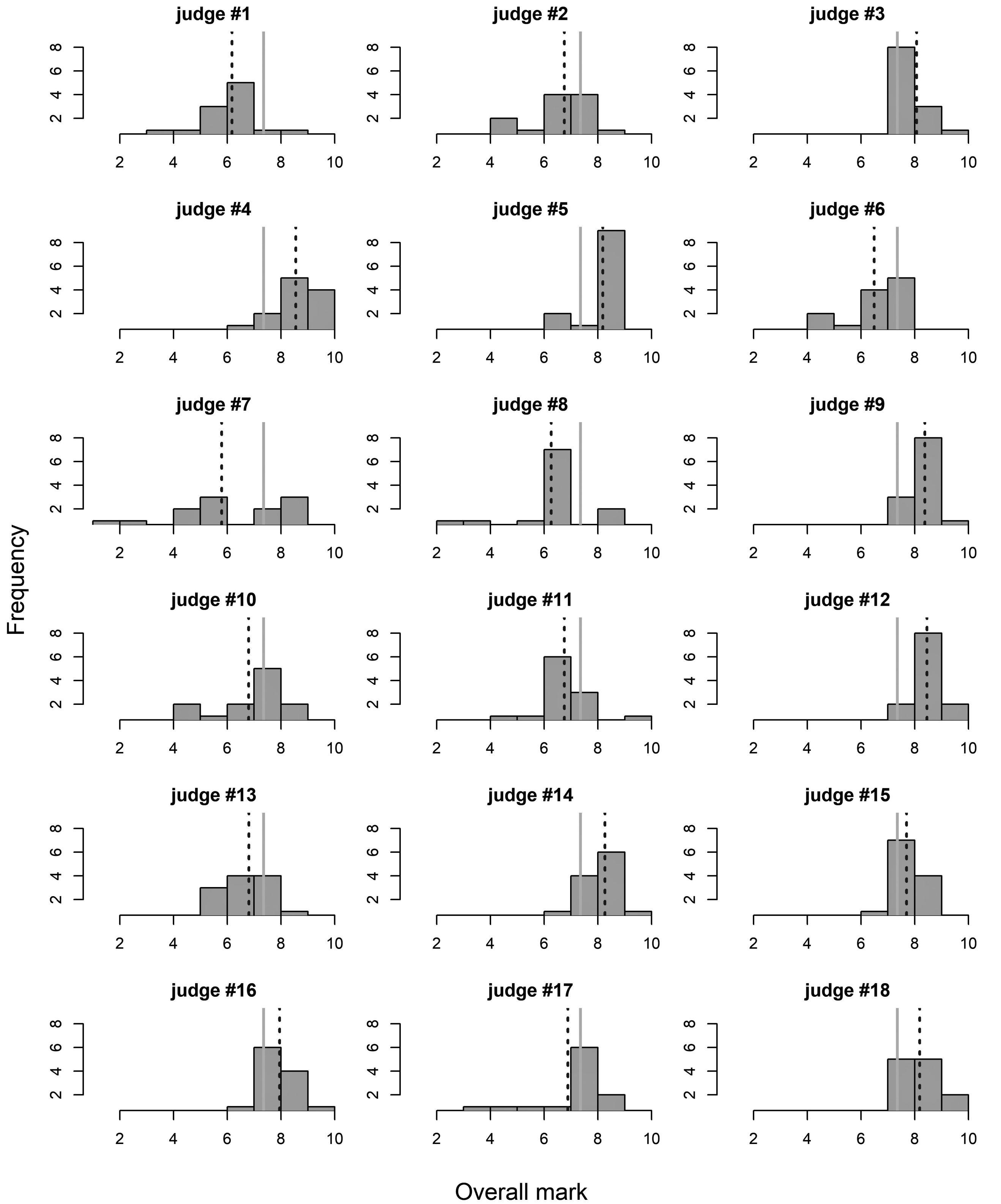

FIGURE 1 | Histograms of the overall marks for competitors (n = 12) by individual judges. Key: solid vertical lines denote grand average (all judges combined), while dotted lines denote averages for individual junges.

TABLE 2 | Mean, average, minimum and maximum values for judging criteria.

Judging criteria	Mean values			Standard deviation			The lowest marks			The highest marks		
	M	min	max	M	min	max	M	min	max	M	min	max
Technical qualities	**7.36**	**5.93**	**8.5**	**1.15**	**0.7**	**2.1**	**5.25**	**1.0**	**7.5**	**8.89**	**8.0**	**9.5**
TQ1 – Posture and hold	7.47	6.04	8.54	1.11	0.66	2.3	5.31	0.5	7.5	8.97	8.5	9.5
TQ2 – General principles	7.35	5.79	8.5	1.21	0.68	2.41	5.08	0.5	7.0	8.94	8.0	9.5
TQ3 – Basic actions	7.31	5.88	8.58	1.18	0.63	2.01	5.14	1.0	7.5	8.97	8.0	9.5
TQ4 – Specific principles	7.23	5.67	8.5	1.2	0.54	2.06	5.08	1.5	7.5	8.89	7.5	9.5
Movement to music	**7.34**	**5.92**	**8.71**	**1.38**	**0.54**	**3.01**	**4.83**	**1.0**	**7.5**	**9.03**	**8.0**	**9.5**
MM1 – Timing	7.56	6.08	8.67	1.29	0.62	2.9	5.11	1.0	7.5	9.17	8.0	9.5
MM2 – Shuffle timing	7.27	5.79	8.63	1.45	0.65	3.06	4.69	1.0	7.5	9.14	8.0	9.5
MM3 – Specific rhythm requirements	7.28	5.67	8.75	1.35	0.54	2.76	4.81	1.0	7.5	8.97	8.0	9.5
MM4 – Personal interpretation	7.17	5.5	8.58	1.53	0.67	3.4	4.47	0.5	7.5	9.14	8.0	10.0
Partnering skills	**7.37**	**5.67**	**8.71**	**1.15**	**0.53**	**2.16**	**5.39**	**1.5**	**7.5**	**8.94**	**7.5**	**9.5**
PS1 – Couple position	7.52	5.92	8.63	1.03	0.48	1.84	5.81	2.0	7.5	9.03	8.0	9.5
PS2 - Leading	7.42	5.63	8.75	1.24	0.52	2.54	5.28	1.0	7.5	9.06	8.0	9.5
PS3 – Basic action – partnering	7.3	5.42	8.71	1.16	0.61	2.17	5.22	2.0	7.5	8.94	7.5	9.5
PS4 – Line Figures – partnering	7.21	5.58	8.58	1.26	0.62	2.8	5.06	0.5	7.5	8.97	7.5	9.5
Choreography and performance	**7.35**	**5.53**	**8.54**	**1.08**	**0.45**	**2.41**	**5.5**	**1.5**	**7.5**	**8.86**	**7.5**	**9.5**
CP1 - Choreography	7.48	5.71	8.63	1.02	0.42	2.35	5.67	1.5	8.0	8.92	8.0	9.5
CP2 – Creativity. Personal style	7.15	5.17	8.54	1.17	0.5	2.59	5.14	1.0	7.5	8.86	7.0	9.5
CP3 – Expression. Interpretation	7.23	5.71	8.46	1.16	0.45	2.35	5.31	3.0	7.5	8.92	7.5	9.5
CP4 - Characterization	7.29	5.46	8.54	1.17	0.48	2.78	5.31	1.0	7.5	8.97	8.0	9.5
Overall marks	**7.33**	**5.77**	**8.53**	**1.22**	**0.67**	**2.42**	**4.00**	**0.5**	**7.0**	**9.36**	**8.5**	**10.0**

TABLE 3 | Reliability of judging of all main and sub-criteria.

Judging criteria	Correlation			Kendall's W coefficient	ICC coefficient				SEM#
					Absolute agreement (AA) (number of judges)		Consistency (C) (number of judges)		
	Mean	Min	Max	Value*	1	3	1	3	3
Technical qualities	**0.60**	**0.24**	**0.83**	**0.56**	**0.37**	**0.63**	**0.55**	**0.78**	**0.56**
TQ1–Posture and hold	0.53	0.15	0.80	0.47	0.33	0.60	0.48	0.74	0.54
TQ2–General principles	0.54	0.17	0.83	0.52	0.34	0.60	0.50	0.75	0.59
TQ3–Basic actions	0.60	0.22	0.81	0.57	0.36	0.63	0.55	0.79	0.58
TQ4–Specific principles	0.53	0.2	0.80	0.53	0.30	0.57	0.48	0.73	0.60
Movement to music	**0.59**	**0.24**	**0.83**	**0.54**	**0.37**	**0.64**	**0.50**	**0.75**	**0.67**
MM1–Timing	0.55	0.16	0.80	0.52	0.38	0.65	0.48	0.73	0.61
MM2–Shuffle timing	0.60	0.30	0.82	0.57	0.36	0.63	0.48	0.74	0.70
MM3–Specific rhythm requirements	0.61	0.28	0.84	0.57	0.37	0.64	0.51	0.76	0.67
MM4–Personal interpretation	0.60	0.28	0.83	0.55	0.36	0.63	0.49	0.75	0.76
Partnering skills	**0.46**	**0.07**	**0.75**	**0.45**	**0.25**	**0.50**	**0.38**	**0.65**	**0.57**
PS1–Couple position	0.46	0.09	0.78	0.45	0.24	0.49	0.38	0.64	0.52
PS2–Leading	0.41	0.22	0.74	0.41	0.24	0.48	0.35	0.62	0.61
PS3–Basic action–partnering	0.45	0.03	0.72	0.44	0.23	0.47	0.37	0.64	0.59
PS4–Line figures–partnering	0.44	0.02	0.76	0.43	0.25	0.50	0.36	0.63	0.63
Choreography and performance	**0.49**	**0.00**	**0.79**	**0.49**	**0.26**	**0.52**	**0.41**	**0.68**	**0.54**
CP1–Choreography	0.42	−0.06	0.76	0.44	0.24	0.48	0.36	0.63	0.50
CP2–Creativity, personal style	0.46	−0.02	0.76	0.45	0.23	0.47	0.39	0.66	0.60
CP3–Expression, interpretation	0.45	−0.01	0.77	0.44	0.26	0.51	0.39	0.65	0.57
CP4–Characterization	0.44	−0.05	0.74	0.46	0.25	0.50	0.37	0.64	0.58
Overall marks	**0.48**	**0.21**	**0.65**	**0.58**	**0.36**	**0.62**	**0.57**	**0.80**	**0.54**

*All Kendall's W coefficients were statistical significant at $p < 0.01$.
#SEM – standard error of measurement [also called typical error, see Hopkins (2000)].*

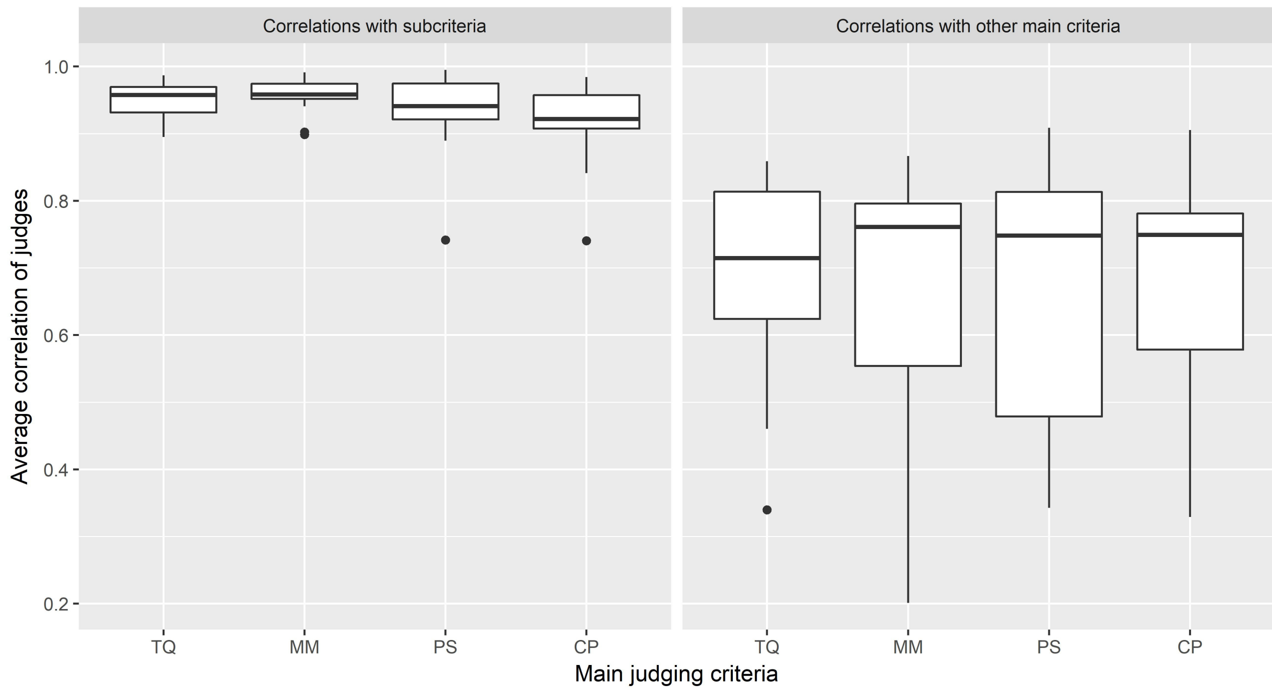

FIGURE 2 | Average correlations between each of the main criteria and it's sub-criteria and between each of the main criteria and other main criteria by judges.

allowing them to ascribe value to a performance. Observers may evaluate aesthetic through cognitive judgment or affective appreciation of dance movement, while others may include their own familiarity and physical ability in their aesthetic appreciation (Chatterjee, 2003; Leder et al., 2004; Cross et al., 2011). Torrents et al. (2013) and Neave et al. (2010) suggested that there were strong associations between higher beauty scores and certain kinematic parameters, especially the amplitude of movement. Choreography in DanceSport is undefined and it is unclear what determines good choreography. Adult dancers have a free choice of choreography and judges interpret the quality of choreography seemingly from a personal perspective. In other aesthetic sports the choreography and its elements are precisely evaluated. For example, the rules of gymnastics for all disciplines describe choreography according to difficulty and correct performance (International Gymnastics Federation, 2015). Hence DanceSport should consider adopting similar descriptions for choreography.

The correlations between each of the main criteria with their sub-criteria were generally high suggesting that judging only four main criteria without including the sub-criteria would have little impact on the overall scores. Lower correlations confirm that judges assess the four main criteria separately whilst higher correlations cannot confirm this as judges could either assess the four criteria correctly as the same or are incapable of separating the criteria. Whilst these findings are ambiguous it is recommended that DanceSport considers using only two criteria, one for the technical component and the other artistic, as used in the figure skating judging system. In this case each criterion could have six judges instead of three, which would contribute to a more reliable judging system allowing for the elimination of extreme values.

Although the judging process includes specific objective criteria, judges may still rely on subjective determinations and perceptions. For example, dancing experts are already warning that the new system brings no improvement and is still too subjective (Bijster, 2012). Subjectivity is bound to reduce the reliability of a judging system unless judges are selected for their personal biases. For example an choreographer might tend to give dancers with excellent choreography higher marks than perhaps the other elements of the dance deserves (Vermey, 1994). Findlay and Ste-Marie (2004) also suggested that subjectivity in rating also biases toward athletes with high reputations. There are also other factors that can potentially influence judging. Ste-Marie (1999) found that judge's education and experience significantly contributed to the evaluation of ice-skater's performance. Fernandez-Villarino et al. (2013) noted that the most valued abilities by the judges are knowledge of the technical parameters of the sport and the capacity to adjust to any level of competition with self-assuredness and self-confidence. Some studies have uncovered order effects, pursuant to which competitors who appear later in a sequence of performances tend to receive higher scores than those who appear earlier (Greenlees et al., 2007). Bruine de Bruin (2006), found that figure skaters who performed later in the first round received better scores in the first and second round. This may be because judges feel uncertain about how to judge the first few performers and to be safe, initially use scores from the middle of the scale, saving more extreme scores for later contestants (Bruine de Bruin, 2005).

A problem or determining an accurate judging system for DanceSport also occurs because there are two organizations overseeing this process. At present the WDC does not use the new judging system whereas the WDSF does with the goal of improving judging to a level acceptable for DanceSport becoming an Olympic sport in 2020. It would seem advisable that these two bodies come together to harmonize opinion as to what constitutes quality in DanceSport.

Whilst this study attempted to provide optimal and comparable conditions to the real competition setting, a limitation of this research was that judges evaluated dancing couples by watching a videotape on a big screen. Whilst they had the same viewing position as the judges had standing at the competition, the unfamiliar surroundings may have had some impact on their judging. They also only judged the top 12 placed dancing couples, because they were the only ones to undertake solo dances. This allowed the judges a better view of each couple compared to if there had been 6 or 12 couples dancing at the same time. However, the lower number of couples and smaller differences in quality between them would tend to lower the intra-class reliability coefficients. It should also be noted that the judges in this study viewed videos of the same couples four times (to judge each main criteria separately), which may have influenced their marking. However, the differences in the reliability for these marks were low suggesting this was not a major concern.

CONCLUSION

The new judging system appears to be too subjective, which would account for a lower than possible reliability rating. This could be solved by determining the content and difficulty for each main and sub-criterion more precisely. Independent criterion should be described and the judging scale should have more precise definitions for each level including perfect presentation and presentation with small or major mistakes. If the judging system is rewritten as suggested the new criteria should be made available to all judges, dancers, and coaches.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Ethics Committee of the Faculty of Sport at the University of Ljubljana, with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethics Committee of the Faculty of Sport at the University of Ljubljana.

AUTHOR CONTRIBUTIONS

JP and BL made substantial contribution to the conception and study design, data acquisition, analysis, and interpretation. GV contributed to the drafting of the manuscript and revised it critically for important intellectual content. NJ contributed to the final approval version of the manuscript.

REFERENCES

Ambrož, N. (2010). New judging system. *World Dancesport Mag.* 4, 36–40.

Atiković, A., Delaš Kalinski, S., Bijelić, S., and Avdibašić Vukadinović, N. (2011). Analysis of judging results from the world championship in men's artistic gymnastics. *Sportlogia* 7, 170–181.

Bijster, F. (2012). *Changing the System of Judging*. Avaliable at: http://www.dancearchives.net/2012/07/24/from-fred-bijster-changing-the-system-of-judging/ (accessed July, 2012).

Bijster, F. (2013a). *Changing the System of Judging*. Available at: http://www.dancearchives.net/2012/07/24/from-fred-bijster-changing-the-system-of-judging/ (accessed July 24, 2012).

Bijster, F. (2013b). *Thoughts on Objective Judging*. Available at: http://www.dancearchives.net/ (accessed July, 2012).

Boen, F., Van Hoye, K., Auweele, V. Y., Feys, J., and Smits, T. (2008). Open feedback in gymnastic judging causes conformity bias based on informational influencing. *J. Sport Sci.* 26, 621–628. doi: 10.1080/02640410701670393

Bruine de Bruin, W. (2005). Save the last dance for me: unwanted serial position effects in jury evaluations. *Acta Psychol (Amst).* 118, 245–260. doi: 10.1016/j.actpsy.2004.08.005

Bruine de Bruin, W. (2006). Save the last dance for me II: unwanted serial position effects in jury evaluations. *Acta Psychol.* 123, 299–311. doi: 10.1016/j.actpsy.2006.01.009

Bučar Pajek, M., Forbes, W., Pajek, J., Leskošek, B., and Čuk, I. (2011). Reliability of real time judging system. *Sci. Gymnast. J.* 3, 47–54. doi: 10.1186/1471-2393-9-46

Čačković, L., Barić, R., and Vlašić, J. (2012). Psychological stress in dancesport. *Acta Kinesiol.* 6, 71–74.

Chatterjee, A. (2003). Prospects for a cognitive neuroscience of visual aesthetics. *Bull. Psychol. Arts* 4, 55–60.

Cross, E. S., Kirsch, L. P., Ticini, L. F., and Schuütz-Bosbach, S. (2011). The impact of aesthetice evaluation and physical ability on dance perception. *Front. Hum. Neurosci.* 5:102. doi: 10.3389/fnhum.2011.00102

Dallas, G., and Kirialanis, P. (2010). Judges' evaluation of routines in men artistic gymnastics. *Sci. Gymnast. J.* 2, 49–57.

Fernandez-Villarino, M. A., Bobo-Arce, M., and Sierra-Palmeiro, E. (2013). Practical skills of rhythmic gymnastics judges. *J. Hum. Kinet.* 39, 243–249. doi: 10.2478/hukin-2013-0087

Findlay, L. C., and Ste-Marie, D. M. (2004). A reputation bias in figure skating judging. *J. Sport Exerc. Psychol.* 26, 154–166. doi: 10.1123/jsep.26.1.154

Greenlees, I., Dicks, M., Holder, T., and Thelwell, R. (2007). Order effects in sport: examining the impact of order of information on attributions of ability. *Psych. Sport Exerc.* 8, 477–489. doi: 10.1016/j.psychsport.2006.07.004

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Med.* 30, 1–15. doi: 10.2165/00007256-200030010-00001

Howard, G. (2007). *Technique of Ballroom Dancing*. Brighton: International Dance Teachers' Association.

Hurley, A. (2012). *To be an Adjudicator*. Available at: http://www.dancearchives.net/2012/04/28/to-be-an-adjudicator/ (accessed April 28, 2012).

International Gymnastics Federation (2015). *Disciplines: Rules*. Available at: http://www.fig-gymnastics.com (accessed April, 2015).

International Skating Union (2015). *Single and Pair Skating – Ice Dancing – Synchronized Skating ISU Judging System: Evaluation of Judging and Technical Content Decisions, Penalties*. Lausanne: ISU.

Koutedakis, Y. (2008). Biomechanics in dance. *J. Dance Med. Sci.* 12, 73–74.

Laird, W. (2009). *The Laird Technique of Latin Dancing*. Brightion: International Corporation.

Leder, H., Belke, B., Oeberst, A., and Augustin, D. (2004). A model of aesthetic appreciation and aesthetic judgments. *Br. J. Psychol.* 95, 489–508. doi: 10.1348/0007126042369811

Leskošek, B., Čuk, I., and Bučar Pajek, M. (2013). Trends in E and D scores and their influence on final results of male gymnasts at European championships 2005-2011. *Sci. Gymnast. J.* 5, 29–38.

Leskošek, B., Čuk, I., Karacsony, I., Pajek, J., and Bučar, M. (2010). Reliability and validity of judging in men's artistic gymnastics at the 2009 University games. *Sci. Gymnast. J.* 2, 25–34.

Lockwood, K. L., McCreary, D. R., and Liddell, E. (2005). Evaluation of success in competitive figure skating: an analysis of interjudge reliability. *Avante* 11, 1–9.

Lukić, A., Bijelić, S., Mutavdžić, V., and Zuhrić-Šebić, L. (2009). Povezanost sposobnosti izražívanja složenih ritmičkih struktura i uspjeh u sportskom plesu. *Međunarodni naučni kongres »Antropološki aspekti sporta, fizičkog vaspitanja i rekreacije«* 4, 191–195.

Lukić, A., Bijelić, S., Zagorc, M., and Zuhrić-Šebić, L. (2011). The importance of strength in Sport Dance preformance technique. *Sportlogia* 7, 115–126.

Malitowska, A. (2013). *Ethics and Adjudication*. Available at: http://www.dancearchives.net/2013/04/08/ethics-and-adjudication-written-by-anna-malitowska/ (accessed April 08, 2013).

Neave, N., McCarty, K., Freynik, J., Caplan, N., Hönekopp, J., and Fink, B. (2010). Male dance moves that catch a woman's eye. *Biol. Lett.* 7, 221–224. doi: 10.1098/rsbl.2010.0619

Pajek, M. B., Kovač, M., Pajek, J., and Leskošek, B. (2014). The judging of artistry components in female gymnastics: a cause for concern? *Sci. Gymnast. J.* 6, 5–12.

Plessner, H., and Schallies, E. (2005). Judging the cross on rings: a matter of achieving shape constancy. *Appl. Cogn. Psych.* 19, 1145–1156. doi: 10.1002/acp.1136

Popović, R. (2000). International bias detected in judging rhythmic gymnastics competition at Sydney-2000 Olympic Games. Facta universitatis-series. *Phys. Educ. Sport* 1, 1–13.

Prosen, J., James, N., Dimitriou, L., Perš, J., and Vučković, G. (2013). A time-motion analysis of turns performed by highly ranked Viennese waltz dancers. *J. Hum. Kinet.* 37, 55–62. doi: 10.2478/hukin-2013-0025

Shrout, P. E., and Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychol. Bull.* 36, 420–428. doi: 10.1037//0033-2909.86.2.420

Ste-Marie, D. (1999). Expert-novice difference in gymnastics judging: an information processing perspective. *Appl. Cogn. Psychol.* 13, 269–281. doi: 10.1002/(sici)1099-0720(199906)13:3<269::aid-acp567>3.3.co;2-p

The R project for statistical computing (2015). *The R Project for Statistical Computing*. Available at: http://www.r-project.org/ (accessed March, 2015).

Torrents, C., Castaner, M., Jofre, T., Morey, G., and Reverter, F. (2013). Kinematic parameters that influence the aesthetic perception of beauty in contemporary dance. *Perception* 42, 447–458. doi: 10.1068/p7117

Uznović, S. (2008). The transformation of strength, speed and coordination under the influence of Sport Dancing. *Facta Univers.* 6, 135–146.

Uznović, S., and Kostić, R. (2005). A study of success in Latin-American sport dancing. *Facta Univers.* 3, 23–35.

Vermey, R. (1994). *Latin: Thinking, Sensing and Doing in the Latin-American Dancing*. Holland: Institution for Dance Development.

Vermey, R., and Brandt, R. (2002). *Artistic Criteria for I.D.S.F. Adjudicators*. Amsterdam: I.D.S.F.

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J. Strength Cond. Res.* 19, 231–240. doi: 10.1519/00124278-200502000-00038

World DanceSport Federation (2013). *Judging System 2.0*. Lausanne: WDSF.

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Using a Situation Awareness Approach to Identify Differences in the Performance Profiles of the World's Top Two Squash Players and Their Opponents

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Purpose: The pressure exerted on a squash player is a consequence of the quality of a shot coupled with the ability of the player to return the ball, namely, the coupling of the two players' situation awareness (SA) abilities. SA refers to an awareness of all relevant sources of information, the ability to synthesize this information using domain knowledge and the ability to physically respond to a situation.

Methods: Matches involving the two best players in the world ($n = 9$) at the 2011 Rowe British Grand Prix, held in Manchester, United Kingdom were recorded and processed using Tracker software. Shot type, ball location, players' positions on court and movement parameters between the time an opponent played a shot prior to the player's shot to the time of the opponent's following shot were captured 25 times per second. All shots (excluding serves and rally ending shots) produced five main SA clusters, similar to those presented by Murray et al. (2018), except a greater proportion of shots were categorized in the greater pressure clusters and less in the lower pressure ones.

Results: Individual matches were presented using cluster performance profile infographics which demonstrated how individual player's performance profiles differed between matches.

Conclusion: It is suggested that it is the coupling, of the two player's behaviors, that makes the examination of tactics so challenging. This inherently means that performance profiles vary in subtle ways, making consistent profiles that are independent of the opponent very unlikely for elite players. This approach should be further modified to determine within match changes in performance.

Keywords: situation awareness, performance profiles, squash shots, movement parameters, tactics

INTRODUCTION

In squash, like all racket sports, the main objective of any shot is to minimize the amount of time available to the opponent to hit their shot. This is optimally achieved by hitting the shot accurately and early, e.g., a volley, forcing the opponent to move quickly over a maximal distance. To counter this pressure, expert players can anticipate where the ball will go (Abernethy, 1990; Triolet et al., 2013) using a split step to initiate movement (James and Bradley, 2004) move efficiently on a well-defined path before lunging to hit the ball. This action also allows a very efficient return to the T area of the court, where winning players have been shown to spend a greater proportion of total playing duration than losers (Vučković et al., 2009). This means that two factors determine the amount of pressure exerted on a player: (1) the quality of a shot, and (2) the ability of the player to move to return the ball which involves knowing where the ball will go as soon as possible, potentially some anticipatory behavior. Triolet et al. (2013) estimated that elite tennis players demonstrated anticipation behaviors only between 6.14 and 13.42% of the situations analyzed, suggesting that, in most situations, tennis players do not need to exceed in anticipation actions, since sufficient ball flight information will enable them to return the ball without any risk. James and Bradley (2004) also found limited use of anticipation in expert squash players as they initiated their first movement toward the ball on average 270 ms (± 0.09 s) after ball contact, assuming a reaction time of approximately 200 ms, this suggested they often utilized ball flight information before moving. However, only relatively easy shots were sampled, to prevent situational probabilities from being used, suggested as a potential confounding variable by Abernethy et al. (2001). Whilst these studies suggested that anticipatory behaviors were not as prevalent as perhaps assumed, it is also possible that players could anticipate but chose not to. This could be because overuse of anticipation could be detected by their opponent and over anticipating could end up counterproductive, or anticipatory behavior simply enables the response to be planned and executed more effectively, often without the need for either an early movement or unnecessary speed.

A fundamental question, albeit difficult to answer, relates to which shot should be played in any situation. Whilst coaches often consider one shot optimal, usually when a player is under some pressure, it would be likely that expert players would usually select this shot. This would mean that discernible patterns of play, i.e., consistent shots played in certain situations, would be evident. Sanderson and Way (1977) tested a hypothesis related to this, i.e., that "an individual exhibits a pattern of play which is relatively stable over time and independent of the opponent." Their results suggested that players showed a higher degree of similarity when winning compared to losing. The concept of a "pattern of play," meaning the relative frequency of each stroke a player made in the matches analyzed, suggests that if players demonstrate a relatively stable playing pattern then opponents can make use of this information to their advantage. However, McGarry and Franks (1996) found that invariant (consistent) patterns of play were difficult to ascertain but suggested that the complexity of discriminating the situation in which the shot was played was a crucial factor. They suggested that the preceding shot alone was unlikely to be sufficient to predict the subsequent shot. In response, Vučković et al. (2014) controlled for previous shot type, time between shots, court location and the handedness of the players. They found that tight shots (played from close to the corners of the court) tending to be more predictable (two or three typical shots played) compared to loose ones (up to seven different shot responses to the same preceding shot when nearer the middle of the court).

Murray et al. (2018) described shot selection in squash from a situation awareness (SA) perspective (Endsley, 1995). SA refers to the awareness of relevant sources of information, the synthesis of this information using domain knowledge gained from past experiences (Abernethy et al., 2001) and the ability to physically respond to the situation. Murray et al. (2018) suggested the relevant sources of information were likely to be related to events previously encountered (historical and within the game being played), opponent movements (visual cues) and probabilistic information such as a heuristic "in this situation it is likely that. . ...." This perspective demonstrates the complexity in deciding which shot to play and raises the question as to what extent individual differences affect this decision-making process. Within this SA perspective the final task of actually playing the shot is important since an inaccurate shot would give the opponent a relatively easy shot under no time pressure and thus offset any advantage gained from having successfully accomplished the first two tasks, e.g., identified the opponent's shot early and been able to volley the ball and hence reduce time.

Previous research has tended to analyze relatively large data sets, grouping individual players according to their level of expertise, e.g., Vučković et al., 2014; and may be inappropriate, e.g., grouping attacking players with defensive ones. This aproach fails to consider individual differences, potentially falling into what Mackenzie and Cushion (2013) identified as a "theory-practice gap," where research findings were suggested to have a lack of transferability and had little or no relevance to practitioners in sport. They advocated that performance analysis research should be for practitioners to utilize the results to improve performance. To address this issue, more discriminating information relating to, processes rather than just outcome measures (James, 2009), and in relation to individual, rather than multiple, players or teams are required.

Murray et al. (2018) presented six shot type clusters, referred to as SA clusters, named to relate to the outcome of a shot ranging from a "defensive" shot played under pressure to create time to an "attempted winner" played under no pressure with the opponent out of position. The important point was these authors used the term SA to reflect the point that the clusters represented both the intention to play a specific shot, based on the situation the player was in, and the outcome of the shot in terms of the effect the shot had on the opponent's movement. They used a two-step cluster analysis using two distance parameters (how far the player moved to return the shot and the distance the player was from the T at the moment the shot was hit) as well as the time and maximum velocity of the player returning the shot (between the shot and the returning shot). They only used shots that were played from selected areas of the court (front, middle, or back) that had achieved their objective, namely the ball was returned from the area of the court aimed for. The logic for this decision being that shots that did not achieve their objective would have, potentially significant, different movement parameters, e.g., when an opponent anticipated a shot and was able to volley the ball or the shot was played badly enough to allow this type of interception. By only analyzing shots that achieved their objective, the authors were able to differentiate different SA clusters for the same shot type from the same court area, suggested as being consistent with players changing the pace and trajectory of the shot because of different objectives (SA tasks). However, this selection process removed around 50% of shots from the analysis, the less accurate shots, and therefore presented a distorted view of overall shot outcomes and an inaccurate evaluation of players' performance. Therefore, this study aimed at presenting a more accurate picture of shot distributions in elite male squash players and also increasing the likelihood of finding between player differences in shot outcomes, since shots that achieved their objective impacted their opponents similarly. The present study had a further purpose to increase the ecological validity of a previous study (Murray et al., 2018), using all shots irrespective of their outcome.

Previous papers have grouped players according to their world ranking (e.g., Hughes and Robertson, 1998; Murray et al., 2016) but we argue that players are always moving up or down the ranking list and their current world ranking may not be an accurate reflection of their ability at the time a match is played. This is particularly obvious for young emerging players or older players moving down the ranking list. Similarly, players may have different strengths and weaknesses meaning that they play with somewhat different approaches, e.g., high tempo risky versus defensive attrition. Grouping these different players together will therefore reduce the accuracy of the analysis. It is the aim of this paper, therefore, to also compare the shot selections, and shot effectiveness, of two elite players, ranked as the top two players in the world at the time of data collection, using shots that both achieved and did not achieve their objective, i.e., where the return shot was played from was not a factor check except for lobs which were returned from the front of the court as this very unusual situation was removed from the analysis. This approach will provide a more detailed analysis of the differences evident between players of very similar ability and provide more practically relevant information.

The methodology used in this paper led to a couple of hypotheses. First we thought that individual players would exhibit different playing patterns between matches, due to not playing at full ability against weaker opponents, rendering grouping players, and matches as meaningless in terms of practical significance. Secondly, we hypothesized that different playing styles would be apparent if an in-depth analysis of shot types was included. Squash pundits and fans consider the game has changed with a more attacking style favored by some, in particular the Egyptians who currently dominate the sport. Our analysis of the World number 1, an Egyptian, was thus thought to be likely to provide evidence of this attacking style of play.

MATERIALS AND METHODS

Participants

Matches at the 2011 (n = 9) Rowe British Grand Prix, held in Manchester, United Kingdom were recorded and processed using Tracker software (Vučković et al., 2014), a newer version of the SAGIT/Squash software (Perš et al., 2008). Ten full-time professional players (age 28.8 years ± 2.95 years), who were ranked in the world's top 64, participated in this study. The Professional Squash Association granted approval for all data capture and analysis of their players for research purposes and ethical approval for the study was provided by the sports science sub-committee of Middlesex University's ethics committee in accordance with the 1964 Helsinki declaration.

Data Collection and Processing

Matches took place on a court set up with a PAL video camera (Sony HDV handy camera HVR-S270, Japan) with a specially adapted 16 mm wide angled lens (Sony NEX SEL16F28) attached to the ceiling above the central part of the court such that the entire floor and part of the walls were within the field of view. A similar camera (used by the Professional Squash Association to record matches) was located on a tripod 15 m behind the court and 5 m above ground level. The camera placement and techniques for transferring video images into Tracker were identical to SAGIT/Squash, i.e., automatic processing with operator supervision, and have been well documented (Vučković et al., 2009). Similarly, the reliability for resultant calculations of distance and speed for each player (Vučković et al., 2010) and positions on court (Vučković et al., 2009) have been published. The exact camera location for the overhead camera (both vertically and horizontally) was not critically important, as subsequent calibration for image capture accounted for its position. Data were collected 25 times per second.

The shot type (n = 24; **Table 1**) and ball location (cell, **Figure 1**) for each shot (denoted player A), excluding serve, return of serve, and rally ending shots (winners, errors, lets and strokes), were recorded along with the same information for both the preceeding shot (B−1) and following shot (B+1). The justification of the cell dimensions was originally presented by Vučković et al. (2014) who suggested that shots near the sides of the court were far more critical than central areas, arguing that the area of the cells should reflect this. They also noted that the ball bounced differently when it hit the sidewall and using this sidewall bounce was a deliberate tactic in elite squash. Whilst this is tactically astute the authors pointed out that the resultant trajectory of the ball tended to finish further away from the sidewall the nearer the ball got to the back wall. A similar observation was made at the front of the court. On this basis the authors argued that cells should not be rectangular in the front and back of the court but should represent typical ball trajectories for these areas. Once the basic shape of the court cells had been identified reliability studies were carried out to determine the optimum area of the cells. These tests resulted in the 15 cells used in this study with the acknowledgment that smaller cells would provide better distinction of shot difficulty but the consequent

TABLE 1 | Operational definitions for shot types used.

Shot type	Variations	Number	Definition
Drive	Straight or crosscourt Groundstroke or volley Hits back wall or not	8	The most prevalent shot in squash is the drive which aims to push the opponent into one of the two back corners of the court. The shot can be hit at different speeds and heights on the front wall primarily determined by the tactical situation.
Boast	Two or three wall Groundstroke or volley	4	The shot is hit onto the side wall prior to the front wall. The objective is to move the opponent into one of the two front corners of the court. The basic two wall boast aims to force the opponent to hit the ball before the ball reaches the opposite side wall. The three wall boast can be aimed for the opposite wall nick (join between wall and floor) and if played well can be a winning shot but the three wall boast can also be played as a very defensive high shot.
Drop	Straight or crosscourt Groundstroke or volley	4	A low soft shot to move the opponent into one of the two front corners of the court. The side wall is usually a secondary target to increase opponent difficulty.
Kill	Straight or crosscourt Groundstroke or volley	4	A low hard shot to move the opponent into one of the two front corners of the court. Hitting hard gives the opponent less time but the side wall has to contribute to the opponent's difficulty otherwise the shot can be poor.
Lob	Straight or crosscourt Groundstroke or volley	4	A high soft shot to move the opponent into one of the two back corners of the court. The main objective is to enable the player to recover the T area before the opponent plays a shot.

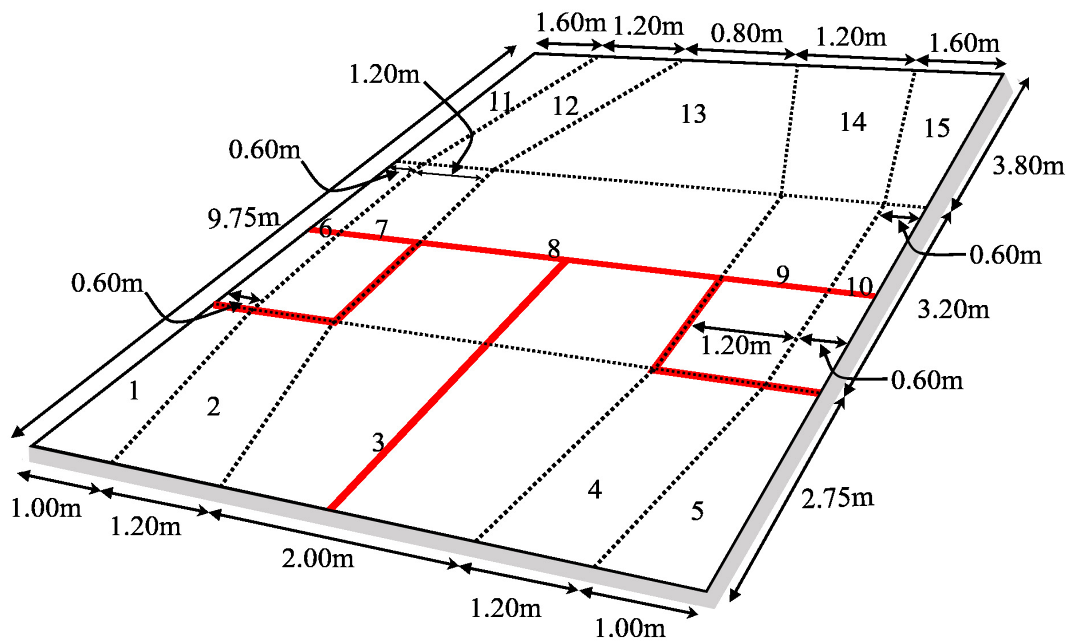


FIGURE 1 | Squash court floor divided into 15 cells.

lowering of reliability meant that for this data collection method smaller cells were not possible.

Additional information regarding time, speed and distance were recorded both between shots and at the time player A hit the ball (see Murray et al., 2018 for original methods who explained how the original list of variables was reduced incrementally by removing the least powerful predictor from an analysis due to poor clusters being formed. This was repeated until clusters deemed fair were found). The resultant information used in this paper was thus both following player A's shot, i.e., variables related to player B's movement, and considered as measures of the shot's effectiveness. Other information both prior to the shot and at the time of the shot, the opponent's position relative to the T area was used in this paper, which may have reflected the player's SA (Macquet, 2009) and hence influenced decision-making. This study did not differentiate the same shot when played from different areas of the court as did Murray et al. (2018), rather shots were classified by type, e.g., straight drive, irrespective of whether it was played from the front or back of the court. This procedure was considered more appropriate since all rally continuing shots were analyzed, rather than only the ones that achieved their objective, as Murray et al. (2018) did. This meant that the variability associated with the variables collected was far greater and this complexity prompted the simplification of the shot classification. One shot was removed from the data (lob from front of the court that was volleyed in the front of the court) as the variables collected suggested this was an attacking shot. This was, however, either a poorly executed defensive shot or a very unusual interceptive movement by the opponent. For elite players, both situations are rare and were hence deemed outliers and removed.

Statistical Analysis

Each shot in squash has an objective, which in simple terms, is to place the opponent under as much pressure as possible given the constraints of the situation. This ranges from applying a lot of pressure when in a good situation to minimizing an opponent's advantage when in a poor situation. Coaches may not always agree on what the objective was, or should be, in every situation, e.g., did a player try to play a winning shot or just apply pressure on an opponent? This would also be determined by the execution of the shot as a well-played shot would have different consequences to a less accurate one. The same cluster analysis of a previous study (Murray et al., 2018) was used for this study. This is a data mining technique that enables the formation of groups within a data set based on maximizing the homogeneity of cases within a group and the heterogeneity between clusters (Hair et al., 1995). Cluster analysis begins with all cases as separate groups and the two "most alike" cases are combined in the first step using the most appropriate distance measure. The two cases with the smallest distance measure will then cluster together and a group mean (cluster centroid) can be calculated and used in the next step. The next two most alike cases (or groups once cases have been clustered) are then combined. This process continues until an optimal cluster solution is obtained, although this may be determined from a practical standpoint as there are no objective methods for determining the optimal number of clusters (Hair et al., 1995).

The two-step cluster analysis, using a probability-based log-likelihood distance measure (SPSS) enabled the same continuous (two distance parameters, time, and maximum velocity) and categorical (shot type) variables to be used in a single analysis. However, when running a cluster analysis on different data, we used all shots rather than Murray et al.'s constrained shots, different clusters were found from those reported by Murray et al. (2018). The cluster parameters in this study, i.e., all players, all shots, were very similar, however, hence we used the same names for the new clusters. The silhouette coefficient, i.e., the measure of cohesion and separation for clusters, was lower (average = 0.2) compared to the 0.35 found in Murray et al. (2018). The importance of each continuous predictor variable was 1.0 with the exception of opponent distance to T which was 0.85. Differences became more marked, however, when individual players were analyzed, necessitating the need to quantify which original cluster each new cluster was most similar to.

Determining Which Was the Most Similar Cluster

Each cluster was determined by the group mean (cluster centroid) based on the four continuous (two distance parameters, time, and maximum velocity) and one categorical (shot type) variable. To determine which cluster (all players, all shots) each individual player cluster most resembled, the absolute differences, between the means for each continuous variable for one individual player cluster and the same variable for all clusters (all players, all shots) were calculated. The cluster which had the lowest sum, of the four absolute differences, was hence deemed the most similar. On this basis, an individual player's clusters were color coded according to the colors of the most similar clusters used for the general, all players, all shots, clusters. Hence, an individual player cluster profile did not always exhibit the same five clusters as for the general profile meaning that different color profiles were often generated.

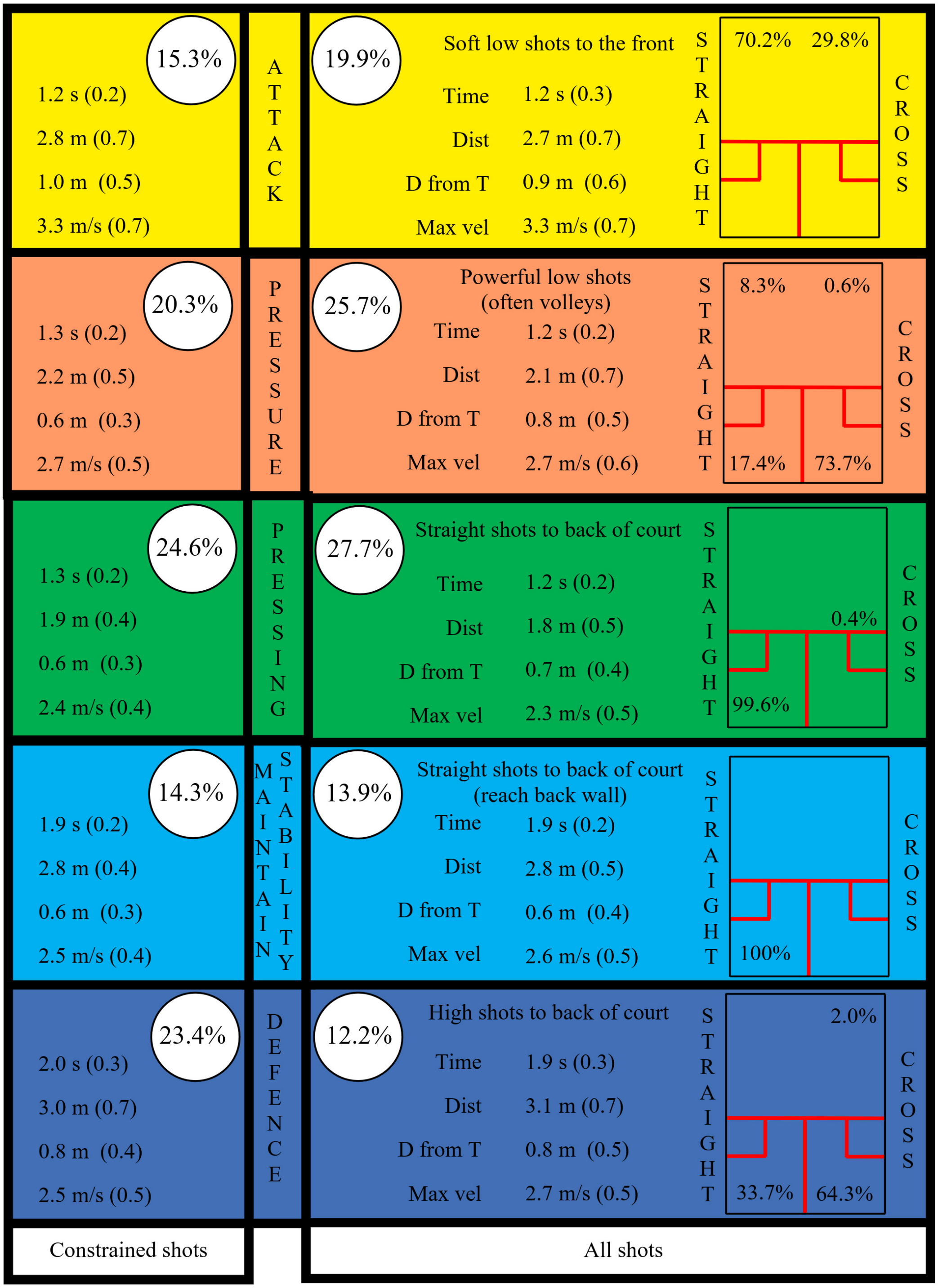
Determining the Degree of Difference Between the Clusters

Having determined which general cluster each individual player cluster was most similar too, and hence color coded the same, the degree of difference between the two clusters was calculated as an additional check that the color coding was appropriate. This was achieved by finding how far the mean for each parameter, for the individual player, was from the mean of each parameter, for all players, in terms of standard deviations, i.e., the z score. The four z scores were then summed, not averaged because scores could be both negative and positive, to give an overall deviation value. The maximum z scores obtained from all clusters presented in this paper were $\pm$ 0.92.

RESULTS

Five SA clusters were named, the same as for Murray et al.'s (2018) constrained shot approach, to relate to the outcome of a shot (**Figure 2**). When all shots from Murray et al.'s (2018) data set were used, the proportion of shots creating the most pressure on the opponent, increased in comparison to the previously used, constrained shot approach. This was primarily due to there being 11.2% less defensive shots and a corresponding increase in offensive shots (4.6% more attack, 5.4% more pressure, and 3.1% pressing). The parameters for each cluster remained very similar, however, with the biggest difference being for maximum velocity in the defense cluster (increase of 0.2 m/s). General descriptors that described the shot types associated with each cluster were added to **Figure 2**, e.g., attacking clusters shots tended to be soft shots to the front, although occasionally a very small proportion of a different shot type was associated with a cluster, i.e., crosscourt shots (0.4% of pressing) and three wall boast (2.0% of defense). Shots in the attacking cluster aim to increase the distance and reduce the time for the opponent, hence the highest maximum velocity of any cluster seen for the opponent. Shots tended to be played straight to the front (70.2%) rather than crosscourt. In comparison, the pressure cluster showed how elite players can use different shots, played to all four corners of the court, to exert similar levels of pressure on the opponent.

In order to present the different clusters relative to each other, whilst also presenting all four variables, a cluster performance profile infographic was created (**Figure 3**). The center of each circle (cluster) is located according to the mean value for time (x) and distance (y), between the shot being played and the return shot. The distance the opponent was from the T at the time of the shot is represented by the length of the T which is drawn relative to the *x* axis. Finally, the diameter of the circle



Key: All movement values are means (standard deviation in brackets)
Dist is distance opponent moved, Time and Max vel (maximum speed of opponent) all from shot being played to return shot
D from T is opponent distance from T when shot played
Court floor indicates where shots within cluster were played to (back, middle or front of court) and whether played straight (shown on left side of court) or crosscourt (right)

FIGURE 2 | Time, distance, and speed parameters for five SA clusters using constrained shots (Murray et al., 2018) compared to all shots (all data from Murray et al., 2018).

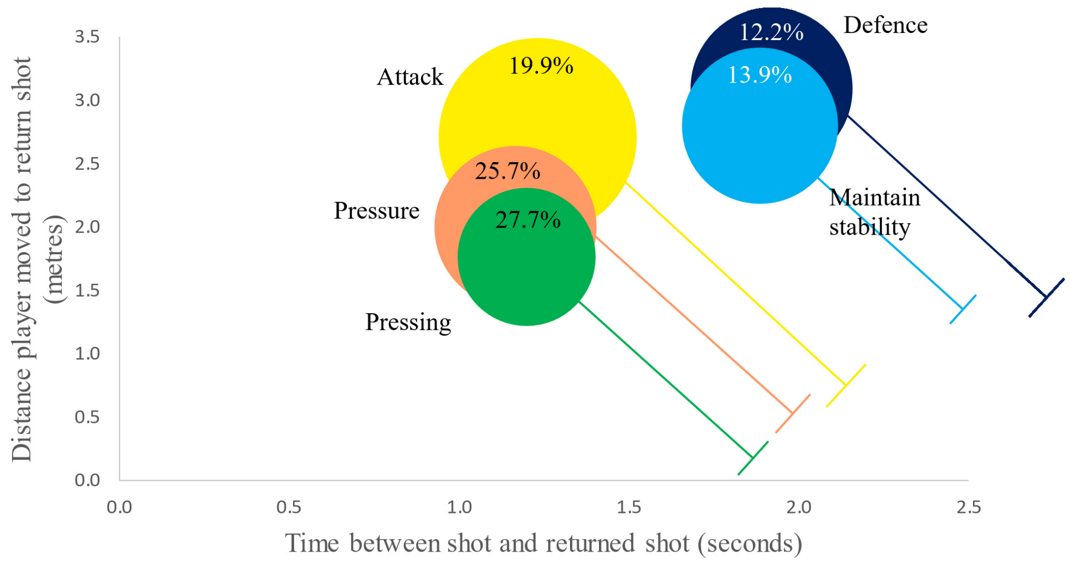


FIGURE 3 | Shot clusters for all shots (all data from Murray et al., 2018).

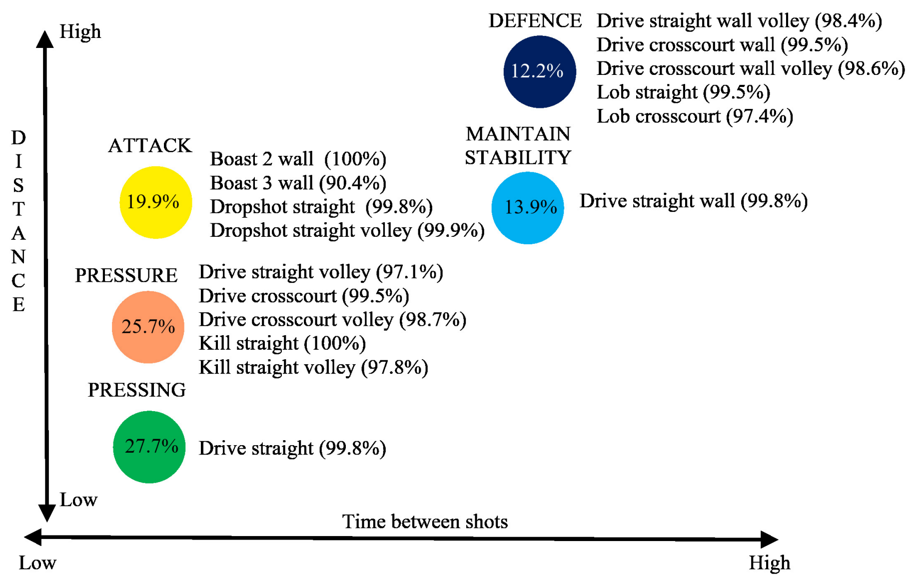


FIGURE 4 | Shot types categorized into different clusters for all shots (all data from Murray et al., 2018).

is proportional to the maximum speed the opponent ran to return the shot. This infographic depicts three attacking (attack, pressure, and pressing) and two defensive (defense and maintain stability) clusters.

The infographic (**Figure 3**) was then used for all nine matches involving the World number 1 and 2 players (their performances in the middle and their opponents outside) culminating in the final played between them (**Figure 4**). Each match demonstrated different cluster patterns (performance profiles) with matches involving the World number 1 displaying a tendency for greater pressure to be exerted as the standard of the opponent increased, 30.9% defensive shots (Ashour, 38% his opponent) against the opponent ranked outside the World's top 24 compared to 22.1% (24.7% opponent) against his top 8 ranked opponent.

In the final (**Figure 5**) the World number 2 forced his opponent to move slightly further with more accurate shots to the back (volleys straight, crosscourt drives) and front of the court (straight kills, volley straight kills) categorized in the pressure cluster whereas these shots were categorized in the pressing cluster for the World number 1. In contrast, the World number 1 gave his opponent less time on shots usually associated with the defense cluster (as they were for world number 2). Hence, 54% of his crosscourt drives that reached the back wall, 89.5% of volleys straight that reached the back wall, 37.5% of 3 wall boasts and

100% of crosscourt lobs were categorized in an attacking cluster. To illustrate the extent to which players can hit shots that achieve different levels of pressure for the opponent an in-depth analysis of the World number 1's shots for the final against the World number 2 is presented (**Figure 6**).

DISCUSSION

Traditional analysis of the tactical behavior of racket sport players has usually assessed the different shots played in different areas of the court. However, this approach has tended to fail to differentiate the small differences between individual elite players and to obtain practically valid differences we considered that a more in-depth analysis was needed. This paper focused on the amount of pressure exerted on an opponent by each individual shot and measured by three movement and one time variable. However, the amount of pressure exerted on a squash player is a consequence of the quality of a shot coupled with the ability of the player to move to return the ball. The categorisation of shot types according to four variables associated with opponent movement therefore encapsulates both the quality of the shot and the opponent's ability to offset the pressure. Murray et al. (2018) focussed more on the former part of this pressure, namely the pressure exerted by the shot, as they only selected shots that achieved their objective. They removed shots where the opponent volleyed the ball in the middle of the court for example, often a consequence of anticipating the ball trajectory. This approach was deemed to discriminate decision-making where the same shot type played from the same court area produced different outcomes (SA clusters) as this was suggested as consistent with players changing the pace and trajectory of the shot because of different objectives (SA tasks).

This study adopted an alternative approach and included shots that did not achieve their objective, in other words shots which were played less accurately or where the opponent was able to anticipate and return the ball early. This approach complicates the analysis as more factors are likely to determine the amount of pressure a player is under but clearly has greater ecological validity in that this is a more accurate reflection of elite squash match play. Murray et al. (2018) named clusters with terms that were representative of the increasing pressure being placed on an opponent. This increased pressure was exhibited by the reduction of time available, differentiating the two defensive clusters and the defensive clusters from the attacking ones, and the increase in speed required of the opponent differentiating the attacking clusters. This quantitative approach derived clusters by the values of the parameters but the cluster names were derived from the squash expertise of the authors who used labels to reflect the aim of the shots (see **Figure 4** for shot types used in each cluster). Utilizing the approach of using all shots (excluding rally ending shots as these require a separate analysis; see also Murray et al., 2018) five main SA clusters were found to be very similar to those presented by Murray et al. (2018). The attempt winner cluster only accounted for 0.6% of shots in this study and was thus not presented (**Figure 2**). The clear impact of using all

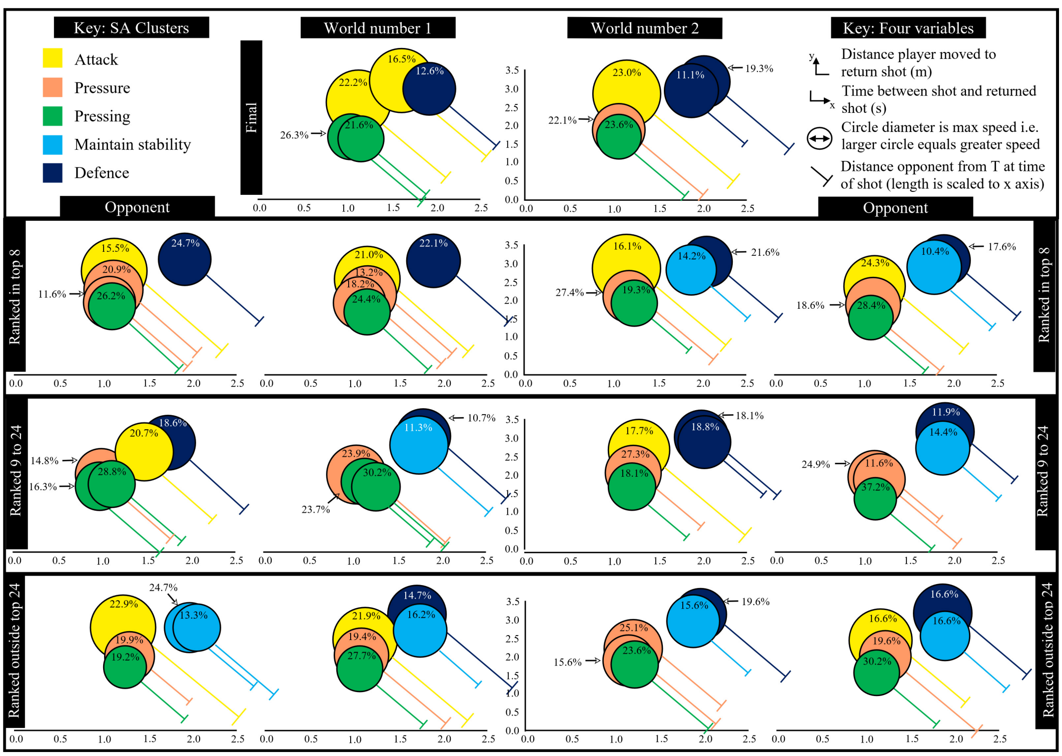


FIGURE 5 | Shots clusters for matches involving Ramy Ashour (World ranked number 1) and Nick Matthew (World ranked number 2).

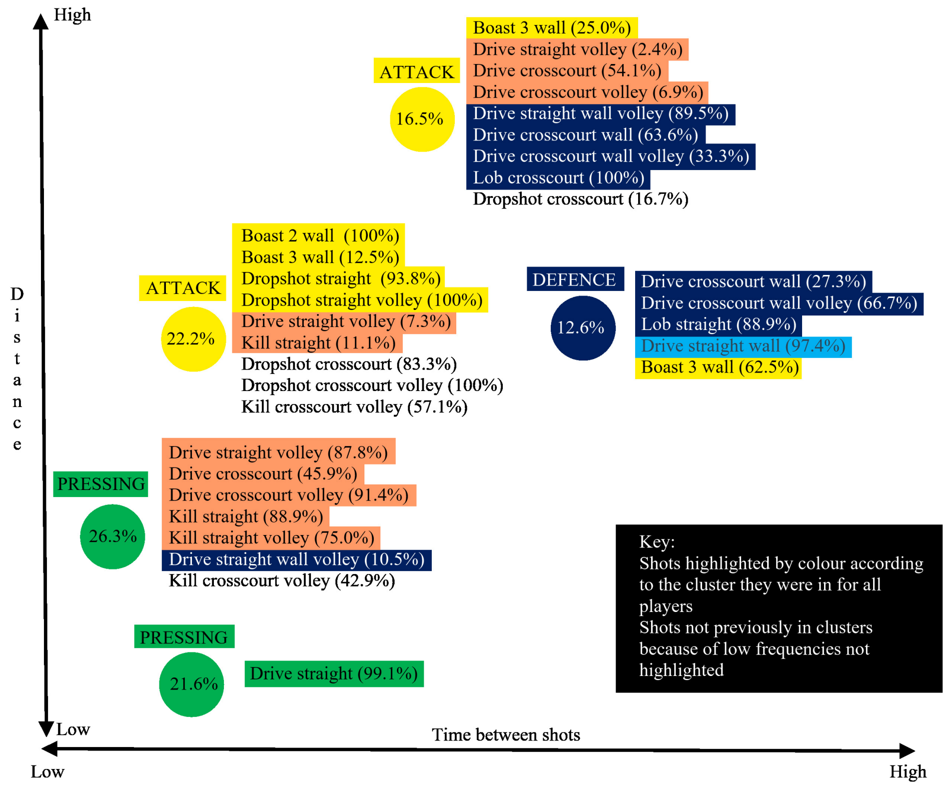


FIGURE 6 | Shot types categorized into different clusters for Ramy Ashour (World ranked number 1) when playing against Nick Matthew (World ranked number 2).

shots was that a greater proportion of shots were categorized in the greater pressure (advantage situation) clusters (pressing, pressure, and attack) and less in the lower pressure (disadvantage or neutral situation) ones (maintain stability and defense). This gives a more realistic view, than Murray et al.'s (2018), of the amount of pressure elite male players tend to be under in match play conditions. In **Figure 2** schematics of the court floor were included to highlight the different types of shot used within each cluster even though the parameters were similar. For example, the attack and pressure clusters exhibited similar values for the parameters but the placement of shots showed quite different approaches, with different shots achieving similar pressure on the opponent. The shots in the attack cluster were to the front of the court, hence less distance for the ball to travel (less time), also the ball tends to stay very tight to the sidewall (more difficult for opponent) for straight shots compared to crosscourt where the ball can easily move toward the center of the court if not played very well.

The relationship between the three movement and one time variables that defined each SA cluster was not clearly presented by Murray et al. (2018) prompting the creation of an infographic in this paper. The challenge of presenting four dimensions was alleviated by using just two dimensions (time and distance) with the other two represented by the size of the circle and length of T. This clearly differentiated two low and three high pressure clusters when all players and all shots were used. However, this overview of multiple players lacks the transferability in relation to individual players, the so called "theory-practice gap" (Mackenzie and Cushion, 2013).

Individual matches were presented to highlight how individual players exhibited different cluster formations in different matches. A fine-grained analysis of the final, played between the two top players in the World at the time, exposed some of the subtle differences, of relevance to practice (Mackenzie and Cushion, 2013), due to spatial and temporal variations within rallies. For example, the World number 1 gave his opponent less time on crosscourt drives and volleys straight (shots categorized in attack clusters, **Figure 4**), including shots which reached the back wall and usually associated with the defense cluster. This can be due to hitting these shots harder, hence reducing the time available. This would predominately be a consequence of the quality of a shot, since the opponent was unable to return the ball early, but other factors, such as opponent positioning, could be contributory. This typically occurs when an opponent moves forward to cover a short shot and is thus slightly out of position for a shot played to the back of the court. This in-depth analysis also showed his overall capability of utilizing more offensive tactics. He used a larger array of attacking shots (**Figure 6**, shots not highlighted in the attack clusters) and was able to exert more pressure for some drive straight volley (7.3%) and kill straight (11.1%) shots at a level consistent with the attack cluster. This was also evident for all shots previously (**Figure 4**) associated with the pressure cluster (highlighted orange in **Figure 6**), but in this match the world number 1's shots produced values more closely associated with attack and pressing clusters. This in-depth analysis clearly identified strategy changes for individual players between matches (**Figure 5**) but also how individual shot types can have different outcomes within a match (**Figure 6**). Whilst **Figure 6** showed the general relationship between each cluster the figure was not scaled perfectly due to the main aim of showing which shots contributed to a cluster. The differences between **Figure 4** (all players multiple matches) and **Figure 6** (World number 1 playing a match against World number 2) demonstrated how a general picture derived from a large data set does not accurately portray the individual differences evident between players or even between matches. One clear advantage of the in-depth match analysis (**Figure 6**) was evident in the fact that the Boast 3 wall was seen in both attack and defense clusters. People knowledgeable in Squash would not be surprised at this as the shot can be played in two polar opposite ways but was only classified as an attacking shot in the general model because of the relatively infrequent use of the shot in defense.

This paper sought to present useful information at the practice level through an in-depth analysis of the world number 1 player in one match, but also sought to present evidence that players do not play the same way againset all players, **Figure 5**, by showing how individual match clusters differed from a general picture of elite male squash. Whilst focusing on the World number 1 in this regard, it was clear that he tended to increase the pressure on opponents as the opponent quality increased. This is suggestive of a strategy of playing within himself when the opponent threat was minimal but when necessary his performance levels increased. This supports the finding of McGarry and Franks (1996) who found consistent patterns of play elusive. However, their work comprised a sample of 8 elite players taken from 10 matches where invariant patterns of play would be less likely than for one player in one match as presented here. The degree of difference, both between and within players, found here suggests that many researchers have previously underestimated the extent that individual differences play in decision-making processes, in this case deciding which shot to play. Equally, the complex coupling of the two players (shots and movements) can lead to differences in shot outcomes, e.g., defensive type shots can result in high pressure for the opponent (classified as an attacking cluster) because of spatial and temporal effects present during the rally. This type of effect can be as a consequence of very small differences in the movement or positioning of a player which, for example, prevents the usual volley return and forces the less advantageous ground stroke response.

Motion and time information was used to elicit small differences between and within players, evident between matches. These methods are applicable for other racket sports and have been used in tennis (Kovalchik and Reid, 2018). Further advances are likely as researchers become more adept at using computer science methods to discern meaningful patterns in complex data sets like these.

CONCLUSION

This paper has further demonstrated the usefulness of analyzing squash from a SA approach but has also demonstrated the inherent variability associated with squash match play. The dynamic between the player trying to put pressure on an opponent by playing accurate shots is offset to some extent by an opponent who move efficiently thanks to an awareness of relevant sources of information and the synthesis of this information using domain knowledge gained from past experiences (Abernethy et al., 2001). It is this coupling, of the two player's behaviors, that makes the examination of tactics so challenging. However, this is exacerbated because player's decision-making abilities are unlikely to be the same between players, can change as a consequence of experience (even within a match) and may be incorrect on occasion. Whilst this approach has identified some of these complexities, highlighting within player differences between matches, within match changes in performance have still not been addressed. Until analysis procedures are sensitive enough to discern these differences it is unlikely that a true understanding of expert performance will be forthcoming.

ETHICS STATEMENT

Ethics approval for the study was provided by the sports science sub-committee of Middlesex University's ethics committee in accordance with the 1964 Helsinki declaration.

AUTHOR CONTRIBUTIONS

JP and RM assisted in the data acquisition, processing, and software development. SM, NJ, and GV designed the study, conducted the analysis, interpreted the data, and wrote the manuscript. All authors read and approved the final manuscript.

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REFERENCES

Abernethy, B. (1990). Anticipation in squash: differences in advance cue utilization between expert and novice players. *J. Sports Sci.* 8, 17–34.

Abernethy, B., Gill, D. P., Parks, S. L., and Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception* 30, 233–252.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Hum. Factors* 37, 32–64.

Hair, J. F., Anderson, R. E., Tatham, R. L., and Black, W. C. (1995). *Multivariate Data Analysis with Readings*, 4th Edn. Englewood Cliffs, NJ: Prentice-Hall.

Hughes, M., and Robertson, C. (1998). "Using computerised notational analysis to create a template for elite squash and its subsequent use in designing hand notation systems for player development," in *Science and Racket Sports II*, eds M. Hughes and I. Maynard (London: E & FN Spon), 227–234.

James, N. (2009). Performance analysis of golf: reflections on the past and a vision of the future. *Int. J. Perform. Anal. Sport* 9, 188–209.

James, N., and Bradley, C. (2004). "Disguising ones intentions: the availability of visual cues and situational probabilities when playing against an international level squash player," in *Science and Racket Sports III*, eds A. Lees, J.-F. Kahn, and I. W. Maynard (Abingdon: Routledge), 247–252.

Kovalchik, S., and Reid, R. (2018). A shot taxonomy in the era of tracking data in professional tennis. *J. Sports Sci.* 36, 2096–2104. doi: 10.1080/02640414.2018.1438094

Mackenzie, R., and Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *J. Sports Sci.* 31, 639–676. doi: 10.1080/02640414.2012.746720

Macquet, A. C. (2009). Recognition within the decision-making process: a case study of expert volleyball players. *J. Appl. Sport Psychol.* 21, 64–79. doi: 10.1080/10413200802575759

McGarry, T., and Franks, I. M. (1996). In search of invariant athletic behaviour in sport: an example from championship squash match-play. *J. Sports Sci.* 14, 445–456.

Murray, S., James, N., Hughes, M. D., Perš, J., Mandeljc, R., and Vučković, G. (2016). Effects of rule changes on physical demands and shot characteristics of elite-standard men's squash and implications for training. *J. Sports Sci.* 10, 129–140. doi: 10.1080/02640414.2016.1216155

Murray, S., James, N., Perš, J., Mandeljc, R., and Vučković, G. (2018). Using a situation awareness approach to determine decision-making behaviour in squash. *J. Sports Sci.* 36, 1415–1422. doi: 10.1080/02640414.2017.1389485

Perš, J., Kristan, M., Perše, M., and Kovačič, S. (2008). "Analysis of player motion in sport matches," in *Computer Science in Sport-Mission and Methods*, eds A. Baca, M. Lames, K. Lyons, B. Nebel, and J. Wiemeyer (Slovenia: Faculty of Electrical Engineering University of Ljubljana),

Sanderson, F. H., and Way, K. I. M. (1977). The development of objective methods of game analysis in squash rackets. *Br. J. Sports Med.* 11:188.

Triolet, C., Benguigui, N., Le Runigo, C., and Williams, A. M. (2013). Quantifying the nature of anticipation in professional tennis. *J. Sports Sci.* 31, 820–830. doi: 10.1080/02640414.2012.759658

Vučković, G., James, N., Hughes, M., Murray, S., Milanović, Z., Perš, J., et al. (2014). A new method for assessing squash tactics using 15 court areas for ball locations. *Hum. Mov. Sci.* 34, 81–90. doi: 10.1016/j.humov.2014.01.002

Vučković, G., Perš, J., James, N., and Hughes, M. (2009). Tactical use of the T area in squash by players of differing standard. *J. Sports Sci.* 27, 863–871. doi: 10.1080/02640410902926412

Vučković, G., Perš, J., James, N., and Hughes, M. (2010). Measurement error associated with the sagit/squash computer tracking software. *Eur. J. Sports Sci.* 10, 129–140.

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Impact of Contextual Factors on External Load During a Congested-Fixture Tournament in Elite U'18 Basketball Players

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An understanding of basketball physical demands during official matches is fundamental for designing specific training, tactical, and strategic plans as well as recovery methods during congested fixture periods. Such assessments can be performed using wearable indoor time motion tracking systems. The purpose of this study was to analyze the time-motion profile of under 18-years of age (U'18) basketball players and compare their physical demands in relation to team ranking, playing position, match periods and consecutive matches during a 7-day tournament. Relative Distance (RD), percentage of High-Intensity Running (%HIR), Player Load (PL), Acceleration (Acc), Deceleration (Dec), Peak Speed (PSpeed), and Peak Acceleration (PAcc) were recorded from 94 players (13 centers, 47 forwards, and 34 guards) belonging to eight elite teams (age: 17.6 ± 0.8 years; height: 1.91 ± 0.08 m; body mass: 82.5 ± 8.8 kg). WIMU PRO™ inertial measurement units with ultra-wide band (UWB) indoor-tracking technology recorded 13 matches during the *Adidas Next Generation Tournament Finals* in the 2016–2017 season. Paired *t*-tests and one-way analyses of variance with omega partial squared (ω_p^2) and Cohen's effect sizes (*d*) were used to analyze for differences between variables. According to team quality, the best teams had lower RD ($p = 0.04$; $d = -0.14$). Guards presented higher RD ($p < 0.01$; $\omega_p^2 = 0.03$), PSpeed ($p < 0.01$; $\omega_p^2 = 0.01$) and PAcc ($p < 0.01$; $\omega_p^2 = 0.02$) compared to forwards and centers. The first quarter showed differences with higher RD ($p < 0.01$; $\omega_p^2 = 0.03$), %HIR ($p < 0.01$; $\omega_p^2 = 0.02$), and PL ($p < 0.01$; $\omega_p^2 = 0.04$) compared to all other quarters. The third match of the tournament presented higher demands in RD ($p < 0.01$; $\omega_p^2 = 0.03$), HIR ($p < 0.01$; $\omega_p^2 = 0.01$) and PL ($p < 0.01$; $\omega_p^2 = 0.02$) compared with the first two matches. This study showed that team quality, playing position, match period, and consecutive matches throughout an U'18 basketball tournament influenced the kinematic demands experienced by players during official competition. Therefore, each of these contextual factors should be considered in managing the load and developing individualized strategies for players in tournament settings.

Keywords: team sports, external load, kinematics, indoor, ultra-wide band

INTRODUCTION

Basketball is considered as a team sport involving intermittent efforts due to the elevated number of instances of high-intensity running alternating with low-intensity periods (Stojanović et al., 2018). Currently, most elite team sport players are exposed to congested fixtures with a high number of matches or competitions within a few days (Ibáñez et al., 2009; Dellal et al., 2013; Rojas-Valverde et al., 2018), and this kind of situation could lead to an increase in fatigue and injury risk (McLean et al., 2018). In fact, in recent years this competitive dynamic has increased the interest of teams' medical and technical staffs to analyze and thus better understand the internal and external physical load of players using objective methods during training and competition (Fox et al., 2017).

Internal load is the physiological reaction and stress experienced when faced with a stimulus (Fox et al., 2018), and it can be measured by heart rate telemetry, rating of perceived exertion, fitness-wellness tests, as well as metabolically, using biochemical, hormonal, and immunological markers (Akubat et al., 2014). On the other hand, external load is considered as the total locomotor and mechanical stress produced by an activity. Load parameters vary among brands or device version (Aughey, 2011; Cummins et al., 2013; Dellaserra et al., 2014), most of them measure: (i) distance covered per minute (m/min), (ii) average speed as an indicator of intensity of movement (km/h); (iii) percentage of high-intensity actions (% HIA), (iv) accelerations and decelerations per minute (acc/min; dec/min), and (v) impacts at different intensities or specific formulas such as PlayerLoad^{TM} (PL^{TM}) (Edwards et al., 2018; Staunton et al., 2018; Svilar et al., 2018).

Analytic techniques have been used previously, employing subjective means, to classify the form and intensity of the activities in order to assess load demands in basketball (Abdelkrim et al., 2007; Matthew and Delextrat, 2009). These procedures could not be so precise and depended on the quality of video capture, the relative size and occlusion frequency of people, and also changes in illumination (Barris and Button, 2008). Standardization in the use of external load measurements, as well as the technological development of tracking systems, have allowed time-motion variables to become one of the most common methods to assess the demands of sport tasks, training sessions and official matches (Fernandez et al., 2016). New tracking technologies using local positioning systems allow the assessment of physical (Ogris et al., 2012; Leser et al., 2014; Bastida Castillo et al., 2018), accelerometrical (Boyd et al., 2011; Gómez-Carmona et al., 2018) and tactical demands (Bastida-Castillo et al., 2019a) in team sports such as basketball in indoor conditions.

Given these possibilities, current hot topics in research are focused on a better understanding of the physical and physiological demands during training and competition in basketball and the effect of contextual variables, including: (i) type of session, higher demands have been reported in official matches compared to training or simulated competition (Fox et al., 2018; Reina et al., 2018); (ii) playing position, guards usually sustained greater workloads than forwards and centers (Abdelkrim et al., 2007; Puente et al., 2017); (iii) match periods, there is evidence of a decrease in physical performance throughout the match quarters (Scanlan et al., 2015b; Staunton et al., 2018); (iv) gender, women develop higher volume loads and men higher intensity demands (Scanlan et al., 2015a); (v) players' levels, the higher-level players performed greater intensity movements while the lower-level players covered a greater volume of distance (Scanlan et al., 2011); (vi) congested fixture periods, there is a higher demand in a competitive period with two matches per week with respect to 1 match per week (Conte et al., 2018). These contextual variables make it possible to establish the specific profile of basketball demands for a better understanding and individualization of training load (Scanlan et al., 2015b).

For these reasons, due to the current characteristics of basketball tournaments with consecutive matches (Ibáñez et al., 2009), considering the key role of intensity as a determinant of performance in team sports (Hills et al., 2018), and also the specific demands of young players at the physical (Oba and Okuda, 2008), technical-tactical (García et al., 2010) level, and relative age effect (Arrieta et al., 2016) compared to adult players, the aims of this study were to: (1) describe the intensity time-motion profile of elite U'18 basketball players and (2) compare their demands in relation to team quality, playing position, match periods and three consecutive matches during an international tournament characterized by congested fixtures.

MATERIALS AND METHODS

Design

A cross sectional design with natural groups was employed in the current study (Ato et al., 2013) to analyze the intensity time-motion profile of elite U'18 basketball players during the *Adidas Next Generation Tournament* (ANGT 16-17) using an ultra-wide band (UWB) tracking system.

Participants

A total of 94 elite under 18-year-old basketball players (see **Table 1**), members of eight teams, were studied during the

TABLE 1 | Anthropometric characteristics of the participants by playing position.

Variable	All participants (*n* = 94)	Guard (*n* = 34)	Forward (*n* = 47)	Center (*n* = 13)
Age (years)	17.6 ± 0.8	17.6 ± 0.8	17.6 ± 0.3	17.5 ± 0.5
Height (m)	1.91 ± 0.08	1.93 ± 0.03	1.89 ± 0.05	1.86 ± 0.04
Body mass (kg)	82.5 ± 8.8	88.2 ± 9.8	78.4 ± 7.1	76.2 ± 5.4
BMI (kg/m^2)	22.7 ± 1.8	24.4 ± 1.8	23.4 ± 1.2	22.5 ± 1

BMI, body mass index; data expressed as mean ± SD.

13th edition of the Euroleague Basketball *ANGT* finals held from May 18 to 21, 2017.

The teams' staffs and tournament managers gave their consent for participation in this research[1]. As all players were over 16 years old, they signed a written consent before the tournament started to give their assent for participation without needing their parents' permission, and approval was given by the Bioethics Commission of the University (Reg. Code 67/2017). The study was conducted according to the Declaration of Helsinki (World Medical Association, 2013) guidelines.

Instruments

To collect time-motion pattern data measurements, all players were equipped with an inertial measurement unit (IMU) with UWB tracking system technology (WIMUPRO^{TM}, RealTrack Systems, Almería, Spain). The sampling frequency for positioning and for accelerometer load was 18 and 100 Hz, respectively. The accuracy (x-axis = 5.2 ± 3.1 cm; y-axis 5.8 ± 2.3 cm) and reliability (x-axis, ICC = 0.65; y-axis, ICC = 0.85) of the indoor tracking system technology on the tournament court has been previous reported in different courses (perimeter, middle line, paint lines, center circle, and 6.75-m line) at a speed of over 15 km/h (Bastida-Castillo et al., 2019b). In addition, the within and between-units reliability of accelerometers in: (a) laboratory (static: with and without stress; dynamic: 10 and 30 Hz vibrations; coefficient of variation = 0.23–0.78%) and (b) field conditions (incremental running treadmill test, coefficient of variation = 2.20%; and SAFT^{90}, coefficient of variation = 2.96%), with (c) the test–retest reliability (p = 0.46–0.98; t = 0.01–0.73; r = 0.86–0.96) has also been analyzed (Gómez-Carmona et al., 2018).

Variables

Time Motion Analysis

In order to compare results among playing positions, quarters, matches and team quality; variables were selected related to playing time per minute: (a) Relative Distance (RD, m/min); High Intensity Running (HIR, % of total distance covered at over 16 km/h); (c) Player Load, accumulated accelerometer load in the three axes of movement (PL, a.u./min); Total Accelerations (Acc, count/min) and Decelerations (Dec, count/min) and Peak Speed (PSpeed, km/h) and Peak Acceleration (PAcc, m/s^2) (Vazquez-Guerrero et al., 2018).

[1]http://www.euroleague.net/final-four/istanbul-2017/news/i/7tcu3xlq5npomb9i/euroleague-basketball-u18-tournament-games-to-be-monitored-using-wimu-pro

Team Quality

The teams which took part of the tournament (in order of final positions) were: CFBB Paris (CFBBP), KK Mega-Bemax-Belgrade (MBB), PBC CSKA Moscow (CSKAM), Real Madrid (RM), FC Barcelona-Lassa (FCBL), Fenerbache Istanbul (FI), KK Crvena Zvezda (CZ), and Žalgiris Kaunas (ZK). For further analysis, the teams were divided by the final tournament ranking into two groups as follow: best teams (1st-to-4th) (n = 513) vs. worst teams (5th-to-8th) (n = 521).

Playing Position

In order to explore differences by playing positions the total sample was grouped in the three regular basketball roles: 13 centers (n = 154), 47 forwards (n = 466), and 34 guards (n = 374).

Match Period

Data from each match were divided into four periods according to official basketball rules: quarter 1 (Q1; n = 263), quarter 2 (Q2; n = 269), quarter 3 (Q3; n = 249), and quarter 4 (Q4; n = 253).

Consecutive Matches Throughout the Tournament

The final round of the ANGT 16-17 was composed of 13 matches that were divided into four rounds. The first, second and third round were part of the Tournament phase, and the fourth round was the final match of the championship. Each round of the tournament phase was composed of four matches (two matches in group A and two matches in group B) (**Figure 1**). The sample analyzed in each round was: round 1 (n = 292), round 2 (n = 327), and round 3 (n = 415); and the last one in the final round (n = 58). The final round has not been considered for analysis as only two teams participated.

Procedures

The tournament lasted 4 days. The eight teams were randomly divided into two groups, all teams played against each other in each group and the first placed team in group A and B at the end of the round played the final. There was a total of 13 matches, and 915 records were obtained from the players. Matches in the tournament round were played in the "Ahmet Comert Arena," except the final round which was played in the "Sinan Erdem Dome" stadium (Istanbul, Turkey) (see **Figure 1** for more details). The matches in the tournament round were randomly held between 8 am and 2 pm; and the final round at 9 am.

The IMU devices were calibrated and the UWB system was installed around the court following a previous study protocol (Bastida Castillo et al., 2018). Firstly, the UWB system was installed on the field as follows: (i) six antennae with UWB technology were fixed 4.5 m from the perimeter line of the field, except for the ones located in the middle line of the field that were fixed at 5.5 m, in this way the antennae formed a hexagon for a better emission and reception of the signal (see **Figure 2**). All of them were located at a height of 3 m and held by a tripod; (ii) once installed, they were switched on one by one making sure that the master antenna was the last, and then a process of autocalibration of the antennae was carried out for 5′; (iii) in a last step, the tracking devices were switched on and a process of recognition

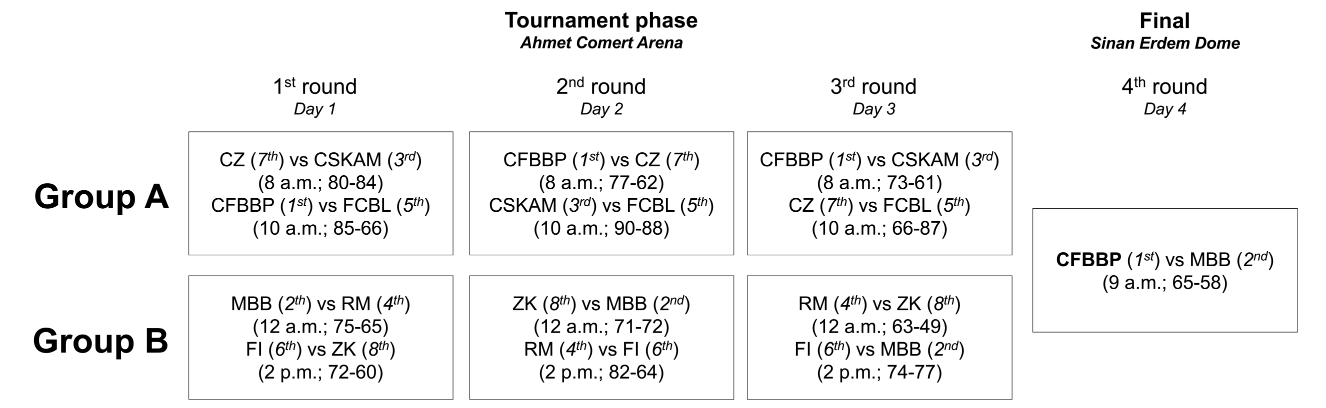

FIGURE 1 | Diagram to show the match distribution throughout the tournament.

and automatic communication with the antennae was carried out during 1′.

Before the match started, IMUs were placed into a specific custom neoprene vest located on the middle line between the scapulae at the C7 level, fitted tightly to the body as is typically used in matches (Svilar et al., 2018; Vazquez-Guerrero et al., 2018).

Raw time-motion data were downloaded and exported in excel format using S PRO specialized software. The players' roster was obtained from the official championship webpage[2] and cross checked with the team staff. The criterion to include players in the statistical analysis was participation in >60% of total playing time per quarter, except time-outs and between-quarter breaks. All within quarter breaks were considered in the analysis (e.g., free-throw, fouls, ball out, changes, and others) in order to explore natural match behavior. This criterion was employed to homogenize the sample considering the player's match participation, especially when the analyzed variables represented the intensity of playing actions (Sampaio et al., 2010).

Statistical Analysis

Mean and standard deviation ($M \pm SD$) of the variables were used to describe the data in the four different variables. Data normal distribution was confirmed using the Kolgomorov–Smirnov test and the homogeneity of variance assumption was made using the Levene Test. Firstly, an independent t-test was performed to compare best (1st-to-4th) and worst teams (5th-to-8th) considering their final tournament positions. Paired magnitude of differences was qualitatively interpreted using Cohen's effect sizes (d) as follows: $d > 0.2$ as *small*, $d > 0.5$ as *moderate*, and $d > 0.8$ as *large* effect size (Cohen, 1988). Three different one-way analyses of variance were performed in order to compare means of PL, HIR, RD, Acc, Dec, PSpeed, and PAcc by (1) playing position, (2) match periods, and (3) consecutive matches throughout the tournament. The magnitude of the differences was qualitatively interpreted using partial omega squared (ω_p^2) as follows: >0.01 *small*; >0.06 *moderate*, and >0.14 *large* (Cohen, 1988). Alpha was prior set at $p < 0.05$. The data analysis was performed using Statistical Package for the Social Sciences (SPSS Statistics, release 22, IBM Corporation, Chicago, IL, United States) and plot design using GraphPad Prism (release 7, La Jolla, CA, United States).

RESULTS

Team Quality

Table 2 shows the descriptive data of the variables analyzed per team in order of their final standings. When comparing best teams (1st-to-4th) vs. worst teams (5th-to-8th), differences with a small effect size were found in: RD ($t = -2.09$, $p = 0.04$; $d = -0.14$ *small effect*). There were no statistical differences in HIR ($t = 0.42$, $p = 0.67$, $d = 0.03$), PL ($t = 0.48$, $p = 0.63$, $d = 0.03$), Acc ($t = -0.12$, $p = 0.90$, $d = 0.01$), Dec ($t = 0.01$, $p = 0.99$, $d = 0$), PSpeed ($t = 1.17$, $p = 0.24$, $d = 0.08$) and PAcc ($t = -0.74$, $p = 0.46$, $d = -0.05$). the best teams had a significant lower RD (see **Figure 3**).

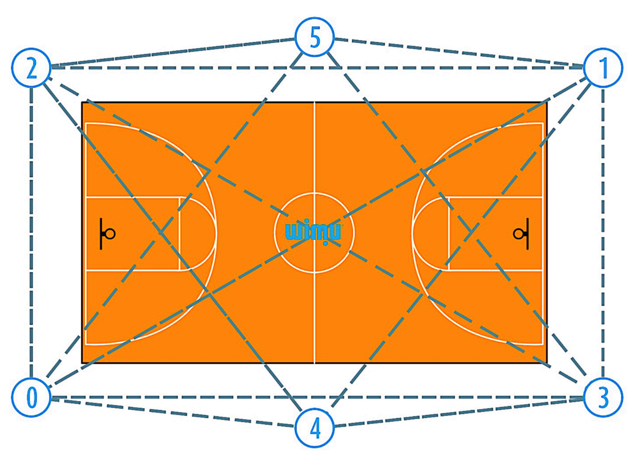

FIGURE 2 | Ultra-Wide Band Antennae court setting/positions.

[2]http://www.adidasngt.com/u18/competition/players

TABLE 2 | Descriptive data (means ± SDs; 95% CIs, in parentheses) of teams by final tournament ranking.

Team ranking	Relative distance (m/min)	High intensity running (%)	Player load (a.u./min)	Acceleration (count/min)	Deceleration (count/min)	Peak speed (km/h)	Peak acceleration (m/s^2)
1st	73.9 ± 15.2	4.1 ± 2.9	1.5 ± 0.4	16.1 ± 2.5	15.6 ± 2.6	18.7 ± 3.6	3.4 ± 0.6
	(71.2–76.8)	(3.6–4.6)	(1.4–1.6)	(15.6–16.5)	(15.1–16.1)	(18–19.4)	(3.3–3.5)
2nd	71.6 ± 10.7	3.5 ± 2.2	1.3 ± 0.2	16.4 ± 1.3	16 ± 1.3	19.2 ± 2.2	3.2 ± 0.4
	(69.5–73.7)	(3.1–3.9)	(1.3–1.4)	(16.2–16.7)	(15.8–16.2)	(18.8–19.6)	(3.2–3.3)
3rd	67.4 ± 16.7	3.5 ± 2.6	1.3 ± 0.3	16 ± 3.5	15.5 ± 3.6	18 ± 4.9	3.2 ± 0.6
	(64.4–\70.4)	(3.1–4)	(1.2–1.3)	(15.4–16.6)	(14.9–16.2)	(17.1–18.8)	(3.1–3.3)
4th	71.7 ± 11.5	3.2 ± 2.3	1.4 ± 0.2	16.5 ± 1.8	16.1 ± 1.8	18.6 ± 3.4	3.1 ± 0.4
	(69.5–74)	(2.7–3.6)	(1.3–1.4)	(16.1–16.8)	(15.8–16.5)	(17.9–19.3)	(3.1–3.2)
5th	79.2 ± 13.2	3.8 ± 2.2	1.4 ± 0.2	16.9 ± 1.3	16.5 ± 1.3	18.8 ± 2.8	3.4 ± 0.3
	(76.7–81.7)	(3.4–4.2)	(1.3–1.4)	(16.6–17.1)	(16.2–16.7)	(18.3–19.4)	(3.3–3.4)
6th	74.4 ± 17.4	3.9 ± 2.9	1.4 ± 0.3	16 ± 2.6	15.5 ± 2.5	18.5 ± 3.5	3.3 ± 0.6
	(71.3–77.5)	(3.4–4.4)	(1.4–1.5)	(15.6–16.5)	(15.1–16)	(17.9–19.1)	(3.2–3.4)
7th	70.6 ± 16.3	3.3 ± 2.5	1.3 ± 0.3	16.2 ± 2.1	15.8 ± 2.2	18.3 ± 3.6	3.3 ± 0.6
	(67.6–73.7)	(2.8–3.7)	(1.2–1.3)	(15.8–16.6)	(15.3–16.2)	(17.6–19)	(3.1–3.4)
8th	68.9 ± 17.2	3.1 ± 2.2	1.2 ± 0.3	15.9 ± 2.8	15.5 ± 2.7	17.6 ± 4.8	3.1 ± 0.6
	(65.8–72.1)	(2.7–3.5)	(1.2–1.3)	(15.4–16.4)	(15–16)	(17.7–18.5)	(3–3.3)

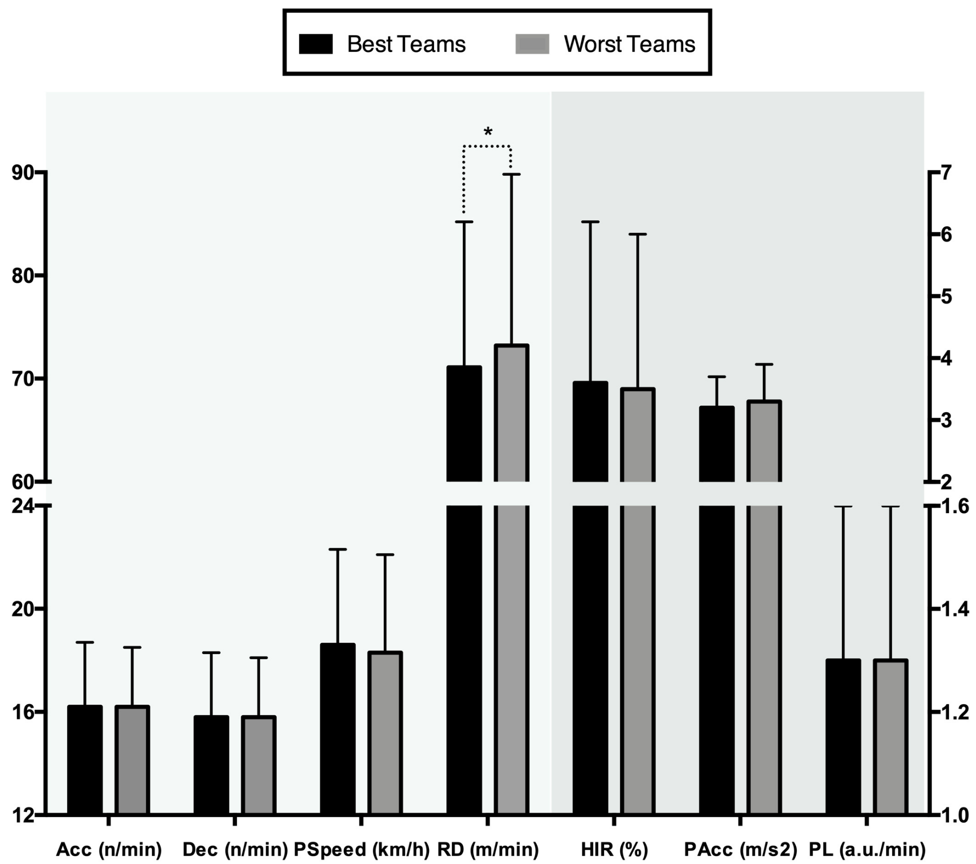

FIGURE 3 | Intensity variables by final tournament ranking (best four teams vs. worst four teams). *$p < 0.05$.

Playing Position

Differences between playing positions were evident in RD ($F = 10.76$, $p < 0.01$, $\omega_p^2 = 0.03$, *small effect*), PSpeed ($F = 7.59$, $p < 0.01$, $\omega_p^2 = 0.02$, *small effect*) and PAcc ($F = 27.23$, $p < 0.01$, $\omega_p^2 = 0.06$, *small effect*); but there were no differences in HIR ($F = 0.44$, $p = 0.65$, $\omega_p^2 = 0$), PL ($F = 2.36$, $p = 0.09$, $\omega_p^2 = 0$),

TABLE 3 | Means ± SDs, 95% *Cis* (in parentheses), one-way ANOVA and pair-wise comparisons with Cohen's effect sizes (d) of basketball time-motion studied demands per playing positions.

Playing position	Guards	Forwards	Centers
Relative distance (m/min)	73.9 ± 13.9¶¶	72.2 ± 15.3¶	66.14 ± 19.8**†
	(72.4–75.5)	(70.7–73.6)	(61.5–69.8)
High intensity running (%)	3.5 ± 2.4	3.6 ± 2.7	3.3 ± 2.9
	(3.3–3.8)	(3.4–3.9)	(2.8–3.9)
Player load (a.u./min)	1.4 ± 0.3	1.3 ± 0.3	1.3 ± 0.4
	(1.3–1.4)	(1.3–1.4)	(1.2–1.4)
Acceleration (count/min)	16.3 ± 2.2	16.1 ± 1.9	16.3 ± 4.2
	(16.1–16.6)	(16–16.3)	(15.5–17.1)
Deceleration (count/min)	15.9 ± 2.2	15.7 ± 2	15.9 ± 4.2
	(15.6–16.1)	(15.5–15.9)	(15.1–16.6)
Peak speed (km/h)	18.8 ± 3.3¶	18.4 ± 3.7¶	17.2 ± 5.2*†
	(18.5–19.2)	(18.1–18.8)	(16.3–18.2)
Peak acceleration (m/s^2)	3.4 ± 0.5¶¶¶†	3.3 ± 0.5*¶¶	2.9 ± 0.7***††
	(3.3–3.4)	(3.3–3.4)	(2.8–3.1)

*ANOVA statistical differences (bold text) ($p < 0.05$). *Statistical differences with guards ($p < 0.05$; effect size: *small, **moderate, ***large). †Statistical differences with forwards ($p < 0.05$; effect size: †small, ††moderate). ¶Statistical differences with centers ($p < 0.05$; effect size: ¶small, ¶¶moderate, ¶¶¶large).*

Acc ($F = 0.52$, $p = 0.60$, $\omega_p^2 = 0$) and Dec ($F = 0.39$, $p = 0.68$, $\omega_p^2 = 0$). Guards presented higher RD, PSpeed and PAcc ($p < 0.01$; guards > forwards > centers). In addition, forwards presented higher RD, PSpeed and PAcc than guards ($p < 0.01$) (see **Table 3**).

Match Periods

There were differences among match periods with a small to moderate effect size in RD ($F = 9.82$, $p < 0.01$, $\omega_p^2 = 0.03$ *small effect*), HIR ($F = 7.19$, $p < 0.01$, $\omega_p^2 = 0.02$ *small effect*) and PL ($F = 12.87$, $p < 0.01$, $\omega_p^2 = 0.04$ *small effect*). No differences were found in Acc ($F = 1.76$, $p = 0.15$, $\omega_p^2 = 0.01$), Dec ($F = 1.59$, $p = 0.19$, $\omega_p^2 = 0.01$), PSpeed ($F = 0.49$, $p = 0.69$, $\omega_p^2 = 0$) or PAcc ($F = 1.318$, $p = 0.267$, $\omega_p^2 = 0$).

All intensity variables tended to decrease across the match periods (see **Table 4**). The change percentage of the first period compared to the fourth period was 10.2% in RD, 24.4% in HIR and 14.28% in PL. In a specific team analysis, the highest percentage changes between the first and fourth periods were found in the tournament champion team (RD: −17.1%; HIR: −38.9%; PL: −23.53%). The first quarter presented higher values in RD ($p < 0.01$; $1^{st} > 3^{rd} > 2^{nd} > 4^{th}$), HIR ($p < 0.01$; $1^{st} > 2^{nd} > 3^{rd} > 4^{th}$), and PL ($p < 0.01$; $1^{st} > 3^{rd} > 2^{nd} > 4^{th}$) compared to the rest of periods (see **Table 4**).

Consecutive Matches Throughout the Tournament

Teams tended to increase the intensity of the match throughout the tournament. There were differences with small effect sizes between matches in RD ($F = 14.98$, $p < 0.01$, $\omega_p^2 = 0.03$), HIR ($F = 4.95$, $p < 0.01$, $\omega_p^2 = 0.01$), PL ($F = 6.54$, $p < 0.01$, $\omega_p^2 = 0.02$), Dec ($F = 6.54$, $p = 0.04$, $\omega_p^2 = 0.02$), PSpeed ($F = 3.2$, $p = 0.04$, $\omega_p^2 = 0.01$) and PAcc ($F = 3.16$, $p = 0.04$, $\omega_p^2 = 0.01$), but there was no difference in Acc ($F = 2.45$, $p = 0.09$, $\omega_p^2 = 0$), The third match presented higher RD ($p < 0.05$; $3^{rd} > 2^{nd} > 1^{st}$), PL ($p < 0.05$; $3^{rd} > 1^{st} > 2^{nd}$), Dec ($p < 0.05$; $3^{rd} > 2^{nd} > 1^{st}$), PSpeed ($p < 0.05$; $3^{rd} > 2^{nd} > 1^{st}$), and PAcc ($p < 0.05$; $3^{rd} > 2^{nd} > 1^{st}$) (**Figure 4**).

TABLE 4 | Means ± SDs, 95% *Cis* (in parentheses), one-way ANOVA and pair-wise comparisons with Cohen's effect sizes (d) of basketball kinematic studied variables per period.

Period	1^{st} Quarter	2^{nd} Quarter	3^{rd} Quarter	4^{th} Quarter
Relative distance (m/min)	75.5 ± 17.5§§	72.1 ± 13.4§	73.2 ± 13§	67.8 ± 16.6**†¶
	(73.2–77.8)	(70.4–73.8)	(71.5–75)	(65.6–70)
High intensity running (%)	4.1 ± 2.7§¶	3.6 ± 2.4	3.3 ± 2.4*	3.1 ± 2.4*
	(3.8–4.5)	(3.3–3.9)	(3–3.6)	(2.8–3.4)
Player load (a.u./min)	1.4 ± 0.3§§†	1.3 ± 0.3*§	1.4 ± 0.3§§	1.2 ± 0.3**†¶¶
	(1.4–1.5)	(1.3–1.4)	(1.3–1.4)	(1.2–1.3)
Acceleration (count/min)	16.1 ± 2.6	16.4 ± 2.4	16.4 ± 1.7	16 ± 2.8
	(15.8–16.5)	(16.1–16.7)	(16.2–16.6)	(15.6–16.4)
Deceleration (count/min)	15.7 ± 2.6	15.9 ± 2.4	16 ± 1.7	15.6 ± 2.8
	(15.3–16)	(15.6–16.2)	(15.8–16.2)	(15.2–16)
Peak speed (km/h)	18.4 ± 4.2	18.6 ± 3.2	18.5 ± 3.5	18.2 ± 4.1
	(17.8–18.9)	(18.2–19)	(18–19)	(17.7–18.8)
Peak acceleration (m/s^2)	3.2 ± 0.6	3.3 ± 0.5	3.3 ± 0.4	3.2 ± 0.6
	(3.2–3.3)	(3.2–3.3)	(3.2–3.3)	(3.1–3.3)

*ANOVA statistical differences (bold text) ($p < 0.05$). *Statistical differences with 1^{st} quarter ($p < 0.05$; effect size: *small, **moderate). †Statistical differences with 2^{nd} quarter ($p < 0.05$; effect size: †small). ¶Statistical differences with 3^{rd} quarter ($p < 0.05$; effect size: ¶small, ¶¶moderate). §Statistical differences with 4^{th} quarter ($p < 0.05$; effect size: §small, §§moderate).*

DISCUSSION

The objectives of this research were to identify the intensity time-motion profile of U'18 basketball players and to compare demands in relation to team quality, specific playing positions, match periods, and consecutive matches throughout the Euroleague Basketball *ANGT* 16-17 finals. The results suggested that the best teams reached a higher intensity during the matches. A decrease in demands was found over the quarters. Differences were evident in relation to playing positions, guards, and forwards performed more movements while centers received more impacts. There was an increase in the volume and high intensity demands throughout the tournament.

High-intensity running is one of the most important performance factors in team sports, and specifically in basketball (Stojanović et al., 2018). Congested fixture conditions are commonly observed during team sport tournaments (Ibáñez et al., 2009; Dellal et al., 2013; Rojas-Valverde et al., 2018),

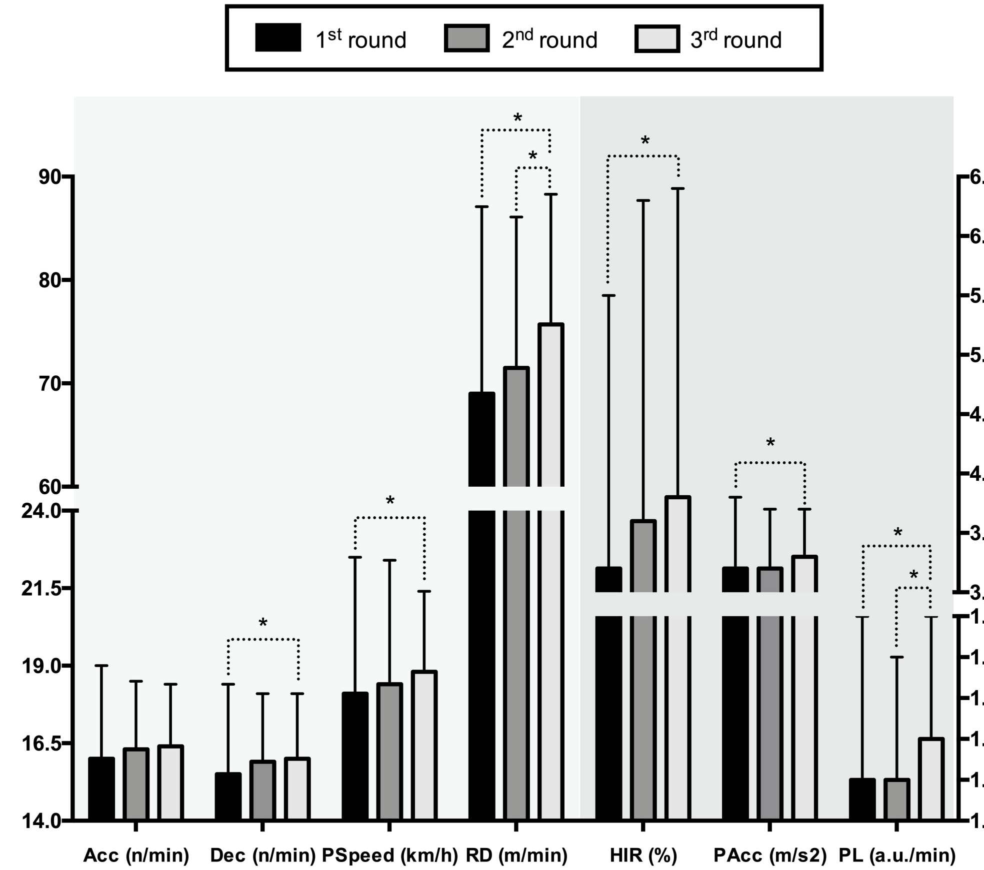

FIGURE 4 | Consecutive match demands variation throughout the tournament. *$p < 0.05$.

and it is important to understand their effects on physical load accumulation and performance decrement (Edwards et al., 2018).

Team Quality

Significant between-team differences were found in RD ($p = 0.04$, $d = -0.14$ *small effect*). Despite there being no differences in variables such as PL, HIR, Acc, Dec, PSpeed and PAcc, the best teams played at a higher intensity (greater values in HIR and PSpeed), while in the rest of variables the demands between the two groups were similar. In addition, the winner of the tournament recorded the highest values in HIR (d = 0.07–0.39 *small effect*) and PL (d = 0.28–0.85 *small-to-large effect*). No previous research has studied physical demands in young players during competition from this approach. Although, in the sport science area, high-intensity activity has been analyzed in basketball during competition at different levels. In contrast to the present study, results considering the differences found in RD (best = 71.1 m/min vs. worst = 73.2 m/min), Scanlan et al. (2011) have reported differences in high-intensity running between elite (2.26% HIR) and sub-elite levels (1.93% HIR), but found no differences in total distance (6390 and 6369 m, respectively).

Similarly, Abdelkrim et al. (2010) found differences between international and national levels in moderate shuffle (14.2 and 19.8% respectively), high shuffle (9.3 vs. 8.1% respectively) and static actions (4.1 vs. 1.5% respectively). From the results obtained, the highest-level teams covered lower RD (more static actions) but performed higher intensity running, this could be explained by their greater efficiency and physical-technical-tactical level (Oba and Okuda, 2008). In this respect, previous studies have found that the best teams' performance could be influenced by individual abilities such as experience (Kioumourtzoglou et al., 1998), technical-tactical (Ibáñez et al., 2009) and fitness player's level (Sampaio et al., 2015).

Playing Position Analysis

Forwards and guards recorded greater RD, PSpeed, and PAcc than centers. However, no differences among playing positions were found in HIR, PL, Acc, or Dec. This topic has been extensively studied in team sports, and specifically in basketball. For example, Scanlan et al. (2011) did not identify differences in RD by playing position (frontcourt vs. backcourt), while the present results found significance differences between forwards and guards compared to centers. On the other hand, Abdelkrim et al. (2007) reported that guards performed more high-intensity activities than forwards and centers, while the present results did not find any differences. Hence, guards recorded the higher values in HIR, in agreement with other studies (Scanlan et al., 2011, 2012). According to previous evidence

(Stojanović et al., 2018) playing position particularities should be considered by basketball practitioners when planning individualized training programs, specifically in intensity actions (PSpeed and PAcc) as evidenced in our study.

Differences in RD, PSpeed, and PAcc could be explained by specificity in playing positions. It was observed in previous research with senior players that guards and forwards had a prevalence in offensive tasks, with emphasis on assists and 3-point field-goals (Sampaio et al., 2006). These indicate that they need to search for free areas outside the three point line, moving around the court from side to side, which explains the distance and speed of their actions (Scanlan et al., 2015a; Reina et al., 2018). However, centers received more impacts, collisions and contacts with opponents, specifically at maximal and supramaximal intensity (Staunton et al., 2018), because their role on the court is related to specific tasks near the basket and into the paint (blocks and defensive/offensive rebounds) (Delextrat et al., 2015). Specific play analysis is needed in order to differentiate the cause of the load and its magnitude, discriminating the high intensity movement actions (guards and forwards) from collisions or contacts (centers).

Match Periods

According to the present results, time-motion demands relative to match periods showed a significant decrease ($p < 0.01$) in the last quarter. Moreover, intensity variables studied during the first quarter were higher than in all other quarters, with the highest effect size found between the first and second quarter in RD and high-intensity running (relative distance: $p < 0.05$, $d = -0.78$ *moderate effect*; %HIR: $p < 0.05$, $d = -0.31$ *small effect*). This great decrease in RD, HIR and PL could be due to physiological fatigue linked to a peak lactate concentration at half time (Abdelkrim et al., 2007), and an increase in match stoppages (fouls, time outs, etc.) that influence the playing rhythms and overestimate the fatigue-induced performance declines (Linke et al., 2018).

Few studies have reported activity data relative to playing period, and the majority was relative to total distance covered (Oba and Okuda, 2008; Abdelkrim et al., 2010; Scanlan et al., 2012) and total activity frequency (total number of actions performed in all activity types related to time) (Caprino et al., 2012; Scanlan et al., 2012). Abdelkrim et al. (2007) showed a decrease in the amount of high-intensity activity in the last quarter in elite under-19-year-old basketball players ($p < 0.01$; 22.41%) which was lower than the present results in HIR ($p < 0.01$; 28.57%). Other studies confirm these findings, but no data comparability was reported (Abdelkrim et al., 2010; Scanlan et al., 2012). Contrasting results were reported by Delextrat et al. (2015) who failed to find differences between quarters, reporting only a small effect size between the first to the third to last quarter ($d = 0.1$). These contrasting results were found in other previous studies, that seem to be all on female players (Matthew and Delextrat, 2009; Scanlan et al., 2012). Our study showed a decrease in all time-motion variables recorded with significant differences in RD, HIR and PL, from the first to the last quarter that could be associated to players' fatigue due to the high competitiveness, but it could also reflect their pacing strategies and strategic decisions by coaches (increased time-outs and free-throws) (García-Rubio et al., 2015).

In this respect, it is interesting that the champion team (CFBBP) presented the higher performance decrement between the first and the last quarter in HIR (40.55%), due to the adoption of an all-out strategy that produced a large points difference against the rival (average point difference per quarter in all matches: Q1 = 13.3 ± 2.5; Q2 = 17 ± 4.4; Q3 = 17.6 ± 2.1; Q4 = 15.3 ± 3.51). Thus, this performance decrease could not only be due to greater efficiency, a better technical-tactical level and physiological fatigue, but also to an attempt to achieve a greater points advantage that allows playing with less intensity (Miñano-Espin et al., 2017; Mancha-Triguero et al., 2018), being accentuated in unbalanced matches (Castellano et al., 2011).

Consecutive Matches Throughout the Tournament

There was a tendency to increase the intensity of the match throughout the tournament. The main finding showed that the intensity increased in the last match of the classification phase ($p < 0.01$). The increase in the intensity of the matches throughout the tournament could be explained due to the eliminatory characteristics of the competition, where the latter games determine the qualification through to finals. To our knowledge, no previous studies have analyzed the match's external load demands during a tournament in basketball, but this aspect has been studied in other team sports such as hockey and soccer.

Jennings et al. (2012) recorded the Australian elite-male hockey national-team that played six matches in 9 days during the Champions Trophy. In soccer, Odetoyinbo et al. (2007) analyzed three matches during a 5-day winter-period in four elite-level Premier League teams and Arruda et al. (2015) assessed an under-15 years soccer team that played five matches in a 3-day championship. Odetoyinbo et al. (2007) and Jennings et al. (2012) did not find significant differences in time-motion variables of performance throughout these congested-fixture periods. Instead, Arruda et al. (2015) found differences in accelerations per minute, body-load impacts, and body load impacts per minute, but did not find differences in total distance, total distance per minute, number of high-intensity runs, distance covered in HIR and peak running speed. Accelerations per minute decreased during the competition while body-load impacts were higher in the final than in all other matches.

Similarly, the most recent results presented by Arruda et al. (2015) in a same-age population are similar, finding higher body-load impacts in the final match of the championship, but are different in that a decrease in accelerations was observed. In the basketball players analyzed, no differences were found in this variable throughout the tournament, a fact that could be due to the unlimited substitutions rule.

Limitations

While the results of this study have provided information about the load demands of high-level players across multiple teams, thanks to the use of an advanced tracking system, and considering multiple contextual factors such as team quality, playing position, match periods and the effect of consecutive matches, some limitations to the study must be acknowledged. Because of limited access to individual player information and testing before the tournament, some alternative data analyses could not be performed (e.g., individualized speed and heart rate thresholds). One of the limitations in this research concerns the sample studied. Due to tactical basketball formations, the total sample was distributed unequally by playing positions. Despite this fact, the authors did not influence the natural dynamics of the competition. Finally, data collection was performed under the same conditions throughout the matches (in indoor stadiums and at same time of the day) but the temperature was not controlled.

CONCLUSION

The first results on load demands obtained by UWB technology during an elite U'18 basketball tournament indicate that players covered 72.9 ± 2.74 m/min, where 3.44% of actions were at high-intensity running (>16 km/h) and experienced a player load of 1.35 ± 0.09 a.u./min. The best teams played with higher intensity while the worst teams performed a greater volume of movement due to not having the initiative in the match and being less efficient. In the specific players analyzed, playing positions revealed similar demands in accelerometer load and high intensity running. Nonetheless, each role has specific playing demands, where guards and forwards performed more movement while the centers experienced higher impacts. Across the quarters, significant declines were evident following the first quarter, with the greatest decline between the first and second quarters. Finally, load demands increased throughout the tournament, reaching the highest values in the last match of the classification phase that is decisive for success in the competition.

Practical Applications

The comprehension of the influence of contextual variables analyzed (individual positioning differences, decrease in physical demands throughout quarters, quality of the team and team's physical behavior throughout the tournament) should be addressed by technical staff for designing conditioning training programs, tactical tasks, match strategy, and recovery protocols during congested fixture periods. Specifically, some practical applications could be considered: (1) Technical staff should study the opponent in order to design the physical load demands in training sessions according to its quality level (a higher-level opponent: more volume of demands; a lower-level opponent: more high intensity actions); (2) Guards and forwards should cover higher distances and reach greater PSpeed and PAcc than centers during training in order to simulate more accurately the match physical requirements; (3) To avoid the effect of fatigue, inter-period recovery strategies should be arranged by medical staff and total playing time should be distributed among the players throughout the match periods; and (4) Technical staff should prescribe correct physical, tactical, and technical demands during the pre-competition period in order to achieve the best performance from the first match of the tournament, since in this research the best performance was shown in the last match of the tournament round.

New devices with microsensor technology are now available for technical staff to quantify the competition and training load demands of athletes. They are non-invasive, reliable, accurate, and portable tools that work in indoor and outdoor conditions. This information is useful for administering individualized training loads, reporting daily feedback data for decision making, and thus achieving optimal performance and maintaining it throughout the season.

ETHICS STATEMENT

The teams' staffs and tournament managers gave their consent for participation in this research. As all players were over 16 years old, they signed a written consent before the tournament started to give their assent for participation without needing their parents' permission, and approval was given by the Bioethics Commission of the University (Reg. Code 67/2017). The study was conducted according to the Declaration of Helsinki (World Medical Association, 2013) guidelines.

AUTHOR CONTRIBUTIONS

JP-O, FN, and SI conception and design of the study, supervision and editing. CG-C, AB-C, and AH-B data collection. DR-V, CG-C, and AB-C software and database organization. DR-V and JG-R formal analysis. DR-V, CG-C, AB-C, and AH-B writing original draft. JP-O, JG-R, FN, and SI writing review. JG-R and SI funding acquisition. All authors approved the submitted version.

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REFERENCES

Abdelkrim, N. B., Castagna, C., Jabri, I., Battikh, T., El Fazaa, S., and Ati, J. E. (2010). Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness. *J. Strength Cond. Res.* 24, 2330–2342. doi: 10.1519/JSC.0b013e3181e381c1

Abdelkrim, N. B., El Fazaa, S., El Ati, J., and Tabka, Z. (2007). Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br. J. Sports Med.* 41, 69–75. doi: 10.1136/bjsm.2006.032318

Akubat, I., Barrett, S., and Abt, G. (2014). Integrating the internal and external training loads in soccer. *Int. J. Sports Physiol. Perform.* 9, 457–462. doi: 10.1123/ijspp.2012-0347

Arrieta, H., Torres-Unda, J., Gil, S. M., and Irazusta, J. (2016). Relative age effect and performance in the U16, U18 and U20 european basketball championships. *J. Sports Sci.* 34, 1530–1534. doi: 10.1080/02640414.2015.1122204

Arruda, A. F. S., Carling, C., Zanetti, V., Aoki, M. S., Coutts, A. J., and Moreira, A. (2015). Effects of a very congested match schedule on body-load impacts, accelerations, and running measures in youth soccer players. *Int. J. Sports Physiol. Perform.* 10, 248–252. doi: 10.1123/ijspp.2014-0148

Ato, M., López-García, J. J., and Benavente, A. (2013). Un sistema de clasificación de los diseños de investigación en psicología. *Anal. Psicol.* 29, 1038–1059. doi: 10.6018/analesps.29.3.178511

Aughey, R. J. (2011). Applications of GPS technologies to field sports. *Int. J. Sports Physiol. Perform.* 6, 295–310.

Barris, S., and Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Med.* 38, 1025–1043.

Bastida Castillo, A., Gómez Carmona, C. D., De la Cruz Sánchez, E., and Pino Ortega, J. (2018). Accuracy, intra- and inter-unit reliability, and comparison between GPS and UWB-based position-tracking systems used for time–motion analyses in soccer. *Eur. J. Sport Sci.* 18, 450–457. doi: 10.1080/17461391.2018.1427796

Bastida-Castillo, A., Gómez-Carmona, C. D., de la Cruz Sánchez, E., and Pino-Ortega, J. (2019a). Comparing accuracy between global positioning systems and ultra-wideband-based position tracking systems used for tactical analyses in soccer. *Eur. J. Sport Sci.* doi: 10.1080/17461391.2019.1584248 [Epub ahead of Print].

Bastida-Castillo, A., Gómez-Carmona, C. D., De la Cruz-Sánchez, E., Reche-Royo, X., Ibáñez, S., and Pino Ortega, J. (2019b). Accuracy and inter-unit reliability of ultra-wide-band tracking system in indoor exercise. *Appl. Sci.* 9, 939. doi: 10.3390/app9050939

Boyd, L. J., Ball, K., and Aughey, R. J. (2011). The reliability of minimaxx accelerometers for measuring physical activity in Australian football. *Int. J. Sports Physiol. Perform.* 6, 311–321.

Caprino, D., Clarke, N. D., and Delextrat, A. (2012). The effect of an official match on repeated sprint ability in junior basketball players. *J. Sports Sci.* 30, 1165–1173. doi: 10.1080/02640414.2012.695081

Castellano, J., Blanco-Villaseñor, A., and Álvarez, D. (2011). Contextual variables and time-motion analysis in soccer. *Int. J. Sports Med.* 32, 415–421. doi: 10.1055/s-0031-1271771

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd Edn. Hillsdale, NJ: Erlbaum.

Conte, D., Kolb, N., Scanlan, A. T., and Santolamazza, F. (2018). Monitoring training load and well-being during the in-season phase in national collegiate athletic association division I men's basketball. *Int. J. Sports Physiol. Perform.* 13, 1067–1074. doi: 10.1123/ijspp.2017-0689

Cummins, C., Orr, R., O'Connor, H., and West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Med.* 43, 1025–1042. doi: 10.1007/s40279-013-0069-2

Delextrat, A., Badiella, A., Saavedra, V., Matthew, D., Schelling, X., and Torres-Ronda, L. (2015). Match activity demands of elite spanish female basketball players by playing position. *Int. J. Perform. Anal. Sport* 15, 687–703. doi: 10.1080/24748668.2015.11868824

Dellal, A., Lago-Peñas, C., Rey, E., Chamari, K., and Orhant, E. (2013). The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team. *Br. J. Sports Med.* 49, 390–394. doi: 10.1136/bjsports-2012-091290

Dellaserra, C. L., Gao, Y., and Ransdell, L. (2014). Use of integrated technology in team sports: a review of opportunities, challenges, and future directions for athletes. *J. Strength Cond. Res.* 2, 556–573. doi: 10.1519/JSC.0b013e3182a952fb

Edwards, T., Spiteri, T., Piggott, B., Bonhotal, J., Haff, G. G., and Joyce, C. (2018). Monitoring and managing fatigue in basketball. *Sports* 6:19. doi: 10.3390/sports6010019

Fernandez, J., Medina, D., Gomez, A., Arias, M., and Gavalda, R. (2016). "From training to match performance: a predictive and explanatory study on novel tracking data," in *Proceedings of the 2016 IEEE 16th International Conference on Data Mining Workshops (ICDMW)*, (Barcelona: IEEE), 136–143. doi: 10.1109/ICDMW.2016.0027

Fox, J. L., Scanlan, A. T., and Stanton, R. (2017). A review of player monitoring approaches in basketball: current trends and future directions. *J. Strength Cond. Res.* 31, 2021–2029. doi: 10.1519/JSC.0000000000001964

Fox, J. L., Stanton, R., and Scanlan, A. T. (2018). A comparison of training and competition demands in semiprofessional male basketball players. *Res. Q. Exerc. Sport* 89, 103–111. doi: 10.1080/02701367.2017.1410693

García, J., Ibáñez, S. J., Parejo, I., Cañadas, M., and Feu, S. (2010). Análisis de los campeonatos del mundo de baloncesto masculino (2002 y 2006): diferencias entre jugadores con diferentes niveles de experiencia (sénior y júnior). *Eur. J. Hum. Mov.* 24, 53–58.

García-Rubio, J., Gómez, M. Á, Cañadas, M., and Ibáñez, J. S. (2015). Offensive rating-time coordination dynamics in basketball. Complex systems theory applied to basketball. *Int. J. Perform. Anal. Sport* 15, 513–526. doi: 10.1080/24748668.2015.11868810

Gómez-Carmona, C. D., Bastida-Castillo, A., García-Rubio, J., Ibáñez, S. J., and Pino-Ortega, J. (2018). Static and dynamic reliability of WIMU PROTM accelerometers according to anatomical placement. *Proc. Inst. Mech. Eng. P J. Sports Eng. Technol.* doi: 10.1177/1754337118816922 [Epub ahead of print].

Hills, S. P., Barwood, M. J., Radcliffe, J. N., Cooke, C. B., Kilduff, L. P., Cook, C. J., et al. (2018). Profiling the responses of soccer substitutes: a review of current literature. *Sports Med.* 48, 2255–2269. doi: 10.1007/s40279-018-0962-9

Ibáñez, S. J., García, J., Feu, S., Lorenzo, A., and Sampaio, J. (2009). Effects of consecutive basketball games on the game-related statistics that discriminate winner and losing teams. *J. Sport Sci. Med.* 8, 458–462.

Jennings, D., Cormack, S. J., Coutts, A. J., and Aughey, R. J. (2012). GPS Analysis of an international field hockey tournament. *Int. J. Sports Physiol. Perform.* 7, 224–231. doi: 10.1123/ijspp.7.3.224

Kioumourtzoglou, E., Kourtessis, T., Michalopoulou, M., and Derri, V. (1998). Differences in several perceptual abilities between experts and novices in basketball, volleyball and water-Polo. *Percept. Mot. Skills* 86, 899–912. doi: 10.2466/pms.1998.86.3.899

Leser, R., Schleindlhuber, A., Lyons, K., and Baca, A. (2014). Accuracy of an UWB-based position tracking system used for time-motion analyses in game sports. *Eur. J. Sport Sci.* 14, 635–642. doi: 10.1080/17461391.2014.884167

Linke, D., Link, D., Weber, H., and Lames, M. (2018). Decline in match running performance in football is affected by an increase in game interruptions. *J. Sports Sci. Med.* 17, 662–667.

Mancha-Triguero, D., Reina, M., Baquero, B., García-Rubio, J., and Ibáñez, S. J. (2018). Análisis de la carga competitiva en jugadores de balonmano de formación en función del resultado final. *J. Sport Sci.* 14, 99–108.

Matthew, D., and Delextrat, A. (2009). Heart rate, blood lactate concentration, and time–motion analysis of female basketball players during competition. *J. Sports Sci.* 27, 813–821. doi: 10.1080/02640410902926420

McLean, B. D., Strack, D., Russell, J., and Coutts, A. J. (2018). Quantifying physical demands in the national basketball association (NBA): challenges in developing best-practice models for athlete care and performance. *Int. J. Sports Physiol. Perform.* 14, 1–22. doi: 10.1123/ijspp.2018-0384

Miñano-Espin, J., Casáis, L., Lago-Peñas, C., and Gómez-Ruano, M. Á (2017). High speed running and sprinting profiles of elite soccer players. *J. Hum. Kinet.* 58, 169–176. doi: 10.1515/hukin-2017-0086

Oba, W., and Okuda, T. (2008). A cross-sectional comparative study of movement distances and speed of the players and a ball in basketball game. *Int. J. Sport Health Sci.* 6, 203–212. doi: 10.5432/ijshs.IJSHS20080336

Odetoyinbo, K., Wooster, B., and Lane, A. (2007). "The effect of a succession of matches on the activity profiles of professional soccer players," in *Science and Football VI*, eds T. Reilly and F. Korkusuz (London: Routledge).

Ogris, G., Leser, R., Horsak, B., Kornfeind, P., Heller, M., and Baca, A. (2012). Accuracy of the LPM tracking system considering dynamic position changes. *J. Sports Sci.* 30, 1503–1511. doi: 10.1080/02640414.2012.712712

Puente, C., Abián-Vicén, J., Areces, F., López, R., and Del Coso, J. (2017). Physical and physiological demands of experienced male basketball players during a competitive game. *J. Strength Cond. Res.* 31, 956–962. doi: 10.1519/JSC.0000000000001577

Reina, M., García-Rubio, J., Feu, S., and Ibáñez, S. J. (2018). Training and competition load monitoring and analysis of women's amateur basketball by playing position: approach study. *Front. Psychol.* 9:2689. doi: 10.3389/fpsyg.2018.02689

Rojas-Valverde, D., Gutiérrez-Vargas, R., Rodríguez-Montero, A., Pereira, L. A., Loturco, I., and Martín-Rodríguez, S. (2018). Reduced muscle contractile function in elite young soccer players after a short-congested fixture period.

Proc. Inst. Mech. Eng. P J. Sports Eng. Technol. doi: 10.1177/1754337118817957 [Epub ahead of print].

Sampaio, J., Drinkwater, E. J., and Leite, N. M. (2010). Effects of season period, team quality, and playing time on basketball players' game-related statistics. *Eur. J. Sport Sci.* 10, 141–149. doi: 10.1080/17461390903311935

Sampaio, J., Janeira, M., Ibáñez, S., and Lorenzo, A. (2006). Discriminant analysis of game-related statistics between basketball guards, forwards and centres in three professional leagues. *Eur. J. Sport Sci.* 6, 173–178. doi: 10.1080/17461390600676200

Sampaio, J., McGarry, T., Calleja-González, J., Jiménez Sáiz, S., Schelling i del Alcázar, X., and Balciunas, M. (2015). Exploring game performance in the national basketball association using player tracking data. *PLoS One* 10:e0132894. doi: 10.1371/journal.pone.0132894

Scanlan, A., Dascombe, B., and Reaburn, P. (2011). A comparison of the activity demands of elite and sub-elite Australian men's basketball competition. *J. Sports Sci.* 29, 1153–1160. doi: 10.1080/02640414.2011.582509

Scanlan, A. T., Dascombe, B. J., Kidcaff, A. P., Peucker, J. L., and Dalbo, V. J. (2015a). Gender-specific activity demands experienced during semiprofessional basketball game play. *Int. J. Sports Physiol. Perform.* 10, 618–625. doi: 10.1123/ijspp.2014-0407

Scanlan, A. T., Tucker, P. S., Dascombe, B. J., Berkelmans, D. M., Hiskens, M. I., and Dalbo, V. J. (2015b). Fluctuations in activity demands across game quarters in professional and semiprofessional male basketball. *J. Strength Cond. Res.* 29, 3006–3015. doi: 10.1519/JSC.0000000000000967

Scanlan, A. T., Dascombe, B. J., Reaburn, P., and Dalbo, V. J. (2012). The physiological and activity demands experienced by Australian female basketball players during competition. *J. Sci. Med. Sport* 15, 341–347. doi: 10.1016/j.jsams.2011.12.008

Staunton, C., Wundersitz, D., Gordon, B., and Kingsley, M. (2018). Accelerometry-derived relative exercise intensities in elite women's basketball. *Int. J. Sports Med.* 39, 822–827. doi: 10.1055/a-0637-9484

Stojanović, E., Stojiljković, N., Scanlan, A. T., Dalbo, V. J., Berkelmans, D. M., and Milanoviæ, Z. (2018). The activity demands and physiological responses encountered during basketball match-play: a systematic review. *Sports Med.* 48, 111–135. doi: 10.1007/s40279-017-0794-z

Svilar, L., Castellano, J., and Jukic, I. (2018). Comparison of 5vs5 training games and match-play using microsensor technology in elite basketball. *J. Strength Cond. Res.* doi: 10.1519/JSC.0000000000002826 [Epub ahead of print].

Vazquez-Guerrero, J., Reche, X., Cos, F., Casamichana, D., and Sampaio, J. (2018). Changes in external load when modifying rules of 5-on-5 scrimmage situations in elite basketball. *J. Strength Cond. Res.* doi: 10.1519/JSC.0000000000002761 [Epub ahead of print].

World Medical Association (2013). World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA* 310, 2191–2194. doi: 10.1001/jama.2013.281053

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Competitive Psychological Disposition and Perception of Performance in Young Female Soccer Players

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The athletes' psychological disposition is a factor that is increasingly considered by researchers as a key to sports performance, even as a mediator between the physical, technical and tactical abilities of the athlete and their competitive performance, thus acquiring great relevance in training and in sports performance. The purpose of this study is to analyze the psychological characteristics of young soccer players and their relation to their performance perception, made both by the player herself and by their coaches. The sample is composed of 108 women (*M* age = 15.53, *SD* age = 1.05), with ages between 13 and 17 years (13 years, $n = 1$, 14 years, $n = 18$, 15 years, $n = 36$, 16 years, $n = 29$, 17 years, $n = 24$), and with a sport practice experience of 7.27 years on average ($SD = 2.64$). For to address this aim, we used the Psychological Characteristics related to the Sport Performance Questionnaire (CPRD) and the Psychological Skills Inventory for Sports (PSIS). In addition, regarding the evaluation of performance perception, an *ad hoc* short questionnaire was created, composed by one question addressed to the player and one directed to the coach. The results indicate that the group of players of the under-16 category obtained higher scores in all the psychological dimensions than the U-18 players, showing significant differences in Team Cohesion ($p < 0.048$). Regarding the degree of congruence between the player's psychological features, and the player's and coach's performance perceptions, the results show statistically significant and negative correlations between the Team Cohesion factor and the athlete's own outcome perception for the match #1 (rxy = −0.479; $p < 0.001$), and match #2 (rxy = −0.402; $p < 0.01$). The results of this study may contribute to establish the differences between different constellations of psychological characteristics according to the categories of competition and their relationship with the perception of performance. This knowledge can be used by sports professionals: coaches, psychologists, physical educators, etc., in order to help athletes to reach their maximum performance.

Keywords: psychological profile, performance perception, mental skills, football, women

INTRODUCTION

Soccer is a high-intensity intermittent team sport that requires technical, tactical and physical skills (Stolen et al., 2005), as well as psychological (Gledhill et al., 2017; Olmedilla et al., 2018b) for optimal performance. Soccer is one of the most researched sports in the scientific literature (Reilly et al., 2000; Datson et al., 2014). However, most of studies have been conducted traditionally with male soccer player samples, and only recent studies have analyzed female soccer player cohorts (Vescovi and McGuigan, 2008). Nowadays, female soccer has a great participation in United States (Markovits and Hellerman, 2003) and begins to be considered an attractive sport by women athletes in Europe and other countries around the world (Wright, 2014). Therefore, a greater research about the main factors related to the female soccer players' performance is clearly required.

Starting from the theoretical model of Gagné (2004) (Differentiated Model of Gift and Talent, GMGT) to work simultaneously with personality traits, acquired skills and psychology requirements for the sports competition, it has been considered that the psychological disposition is one of the factors that have been strongly added to this analysis (Olmedilla and Dominguez-Igual, 2016; González, 2017). Considered as intermediary between players' physical, technical and tactical abilities (Morris, 2000; Castilla and Ramos, 2012; Abdullah et al., 2016; Swann et al., 2017), psychological disposition is one of the keys for the sport performance due to the influence that it would have in the player's competitive success (Anderson et al., 2014; Arthur et al., 2017). In this sense, some studies have found that physiological variables represent between 45 and 48% of the sport performance, and when the psychological variables were added, the proportion of variance explained increased around 79–85% in certain sports like wrestling (Nagle et al., 1975; Silva et al., 1981; Bali, 2015; Abdullah et al., 2016; Olmedilla et al., 2017a).

One of the approaches for studying the role of the psychological variables in sport performance is based on the personality traits (Mahoney and Avener, 1977; Gould et al., 1981; Burnik et al., 2005; Rasmus and Kocur, 2006; Cabrita et al., 2014), as the recent published study by Danielsen et al. (2017) where a relationship was found between the influence of mental toughness and the level of competition in female soccer players. Another approach studies differences between athletes and non-athlete population. For instance, Malinauskas et al. (2014) found higher scores in Consciousness in athletes than in non-athlete population, and greater Extraversion in team sportspeople in comparison with athletes from individual sports. Steca et al. (2018) found that athletes with better success in their careers revealed higher punctuations in all the Big-Five personality dimensions.

Given that these results do not show clearly a specific personality profile to distinguish between athletes and non-athlete population (Weinberg and Gould, 2014), neither result really useful for the sport performance, researchers have focused on the study of the relationship between athletes' mental strategies, abilities and behaviors, and their subsequent performance (Romero et al., 2010; Álvarez et al., 2014; García-Naveira et al., 2015). This approach has been able to provide a better knowledge of the most relevant psychological characteristics for athletes, as well as to explain the differences between diverse sport participants and/or tactical positions in the same sport (Olmedilla et al., 2015). Also as they indicate Baillie et al. (2014, p. 406) "personality may also play a central role in determining the goodness of the fit between an athlete or team and a (psychologist) practitioner," it could serve to distinguish male soccer players from female soccer players, and thus establish working hypotheses about the most appropriated psychological intervention to assist the sport performance; the knowledge of an athlete's psychological profile enables a better understanding, the improvement of the communication procedures with himself and the increase in training effectivity (Martínez-Ferreiro, 2016), and it will result in better mental preparation and better psychological skills acquisition related to the sport success (Bahrololoum et al., 2012; Olmedilla et al., 2018c).

In recent years the number of works that show an especial attention in the study of the relationship between psychological factors and sport performance in female soccer has increased considerably (Danielsen et al., 2017). Specifically, the main psychological factors studied have been self-esteem and anxiety control (Williams, 2017), the prediction of the goal orientations suggesting coach's specific actions (Granero-Gallegos et al., 2015; Domínguez-Escribano et al., 2017), some mental health indicators as depression and anxiety (Junge and Feddermann-Demont, 2016; Olmedilla et al., 2018a), and mood states (Arroyo del Bosque et al., 2016). Thus, it seems interesting the suggestion made by Rutkowska and Bergier (2015), who emphasized the importance of examining the women soccer players' psychological profile due to the relevant information derived from this evaluation for improving training programs, primarily in mental training and in soccer players close to the professional level of performance (Martín-García, 2003).

In summary, sport performance is determined by a physical, technical and tactical systematic practice, necessary to achieve an elite level in soccer (Haugaasen et al., 2014). The same practice should be applied to the psychological training, strengthening the psychological resources for the sport competition; in this sense, the review published by Gledhill et al. (2017) stated 48 social and psychological factors linked to the talent development in soccer (e.g., adaptive lifestyle choices, practice and play behaviors). Similarly, there is a clear need to use women soccer players given the lack of studies that analyze this population in comparison with their male counterparts. Therefore, the main purposes of the current study were: (1) to describe the psychological characteristics of a Spanish sample of female young soccer players, and (2) to determine the differences between under-16 and under-18 age-groups, as well as their relation and congruence with perception of performance by the soccer player herself and her coach.

MATERIALS AND METHODS

Participants

The sample was formed by 108 players that participated in the National Championship of Autonomic Selections of Spain of female soccer, in the categories under-16 and under-18. Mean age was 15.53 ± 1.05 years and mean of years practicing the sport was 7.27 ± 2.64 years, and 1.75 ± 0.92 years of experience in the highest category. The female players train an average of almost 3 sessions a week (2.98), lasting between 1 and 3 h each session, 102.64 ± 17.42 min on average and a total weekly training time of 304.44 ± 74.26 min on average.

Measures

Psychological variables were assessed using the Psychological Characteristics Related to Sport Performance Questionnaire (CPRD, Gimeno et al., 2001), based on the Psychological Skills Inventory for Sports (PSIS, Mahoney et al., 1987; Mahoney, 1989). The questionnaire consists of 55 items graded in a 5-option Likert scale (from totally disagree to totally agree). It also includes a response option "I do not understand" to avoid missing answers.

Characteristics related to the Sport Performance Questionnaire includes five subscales: Stress Control (SC), Influence of Performance Evaluation (IPE), Motivation (M), Team Cohesion (TCOH), and Mental Skills (MSK), showing acceptable values of internal consistency for the total scale (α = 0.85) and for most of the subscales (αSC = 0.88; αIPE = 0.72; αM = 0.67; αTCOH = 0.78; αMSK = 0.34). According to the authors, the low internal consistency of MSK is probably related to it tapping a wide range of different skills but authors still keep the subscale due to the factorials loads showed by the items of this factor.

Stress Control consists of 20 items and refers athlete's responses to potentially stressful situations and other training and competition demands. Higher scores denote athlete has management skills to cope with sport-related stress. IPE consists of 12 items and regards to athlete's responses to situations in which he/she or people close to him/her judges his/her performance. It also includes an assessment about antecedents of athlete's performance judgment. Higher scores mean the athlete can control the impact of performance judgment. M consists of eight items referring to basic motivation to sport performance and achievement, as well as to the regular training and competition activities. Higher scores indicate strong motivation and commitment to competitive sport practice. MSK consists of nine items and assess the use of different mental skills which are related to sport performance. Higher scores express better psychological resources to improve his/her performance. TCOH includes six items and assesses the extension the athlete feels attracted and identified with the sport group. This scale has not been used in this study due to the nature of the target sports.

To assess the perception of performance, an *ad hoc* instrument was created with a question addressed to the player, and a question addressed to the coach, and in both cases they had to answer on a liker scale of 0 (I played very badly) to 10 (I played very well).

Procedure

After the corresponding author's institution IRB approval (UM1551/2017), athletes were contacted by Football Federation of the Region of Murcia (FFRM) and football sport clubs. The researchers explained to both parents and athletes about the objectives and use of the information, and those who voluntarily participated signed an informed consent. In the cases in which the players were under 18 years of age, the signature of the parents was required. The data collection was made during the National Championship of Women's Autonomous Soccer Teams held in Murcia (Spain) in December 2017. In the Championship participated the selections of Balearic Islands, Castilla la Mancha and the Region of Murcia in both categories. Authorization was requested to the Football Federation of the Region of Murcia (organizer of the event) and the coordinators of the different selections were informed about the objectives of the study. The CPRD questionnaire was administered in the accommodation hotel of the selections and during the leisure time between competitions. The evaluation of the perception of the performance was carried out right at the end of each game (from a total of two matches), asking first the players about their performance in the match, and then the coach of each team about the performance of each of their players in the match.

Data Analysis

The analysis of data used have been: measures of tendency of central (means); dispersion measures (standard deviation); frequency analysis; normality tests using the Kolmogorov–Smirnov test; analysis of difference of means for two independent samples by the Mann–Whitney U; mean difference analysis for two correlational samples using the Wilcoxon W statistic; correlational analysis using Spearman's correlation coefficient. Statistical analyzes were carried out using the statistical package SPSS 22.0.

RESULTS

Table 1 shows the descriptive analysis of the total sample of soccer players, and the application of the normality test (Kolmogorov–Smirnov) for the five factors, of which Team Cohesion ($p < 0.001$) and Motivation ($p < 0.01$) are not distributed normally.

Figure 1 shows the scores obtained by the players in each of the factors of the CPRD, compared with and the average scores of a general sample of athletes in the study from Gimeno (1999) with the same tool. It is noteworthy that in all the factors, the scores coming from the group of female soccer players are higher than to those from the general sample, highlighting the Motivation factor (c = 85, M = 23.86, SD = 4.04), Stress Control (c = 65; M = 51.26, SD = 11.15), and Team Cohesion (c = 65, M = 19.94, SD = 2.85), while the Influence of the Performance Evaluation (c = 55, M = 25.83, SD = 6.70) and Mental Ability (c = 55, M = 21.37, SD = 4.09) values are on the average.

Table 2 shows the descriptive values from the players' self-evaluation of the performance in match 1. The answer rate was 81.5% (n = 88), while it was 82.4% for the second match (n = 89). When observing the coaches evaluations, it was initially of 83.3% (n = 90) in the first game, and of 84.3% (n = 91) in the second one. Of these last two evaluation, only 66.67% (n = 72) and 66.76% (n = 73) of valid cases have been finally considered, due to the

TABLE 1 | Descriptive values of the five factors of the CPRD questionnaire and application of the Kolmogorov–Smirnov normality test.

	M	*SD*	Minimum	Maximum.	Centil	K–S	Sig.
SC	51.26	11.16	24.00	80.00	65	0.076	0.155
IPE	25.83	6.70	11.00	44.00	55	0.080	0.085†
M	23.86	4.04	10.00	32.00	85	0.110	0.003**
MSK	21.37	4.09	11.00	33.00	55	0.073	0.200
TCOH	19.94	2.85	4.00	24.00	65	0.186	0.000***

*SC, Stress Control; IPE, Influence of Performance Evaluation; M, Motivation; MSK, Mental Skills; TCOH, Team Cohesion. †p < 0.10; **p < 0.01; ***p < 0.001.*

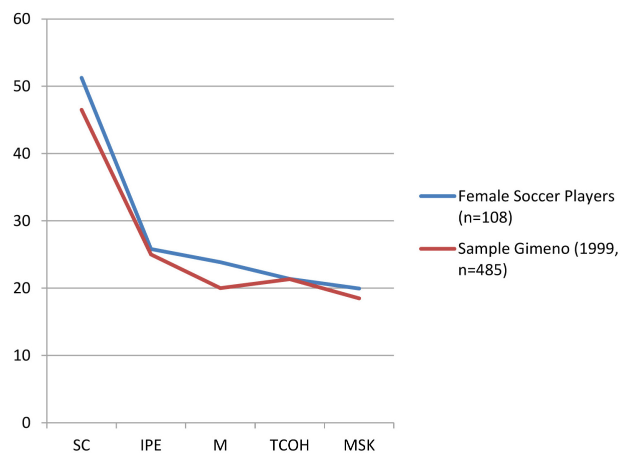

FIGURE 1 | Comparative graph between the average scores of a general sample of athletes (Gimeno, 1999), and the scores of female soccer players in the present study.

elimination of 18 evaluations of match 1 and 18 from the match 2 due to observed answers biases (extreme scores given without discrimination of variability in scores).

We may observe also that the players' self-evaluations are very similar between the two games, although this short difference is significant in favor of the first match ($z = -3.606$, $p < 0.001$). Regarding the evaluations made by the coaches, they are somewhat higher than those made by the athletes, finding significant differences between the performance evaluations made between the first and second match ($z = -2.295$, $p < 0.05$). Unlike athletes, coaches give a better rating to the performance obtained in the 2nd game than the one from the first game.

Table 3 shows the descriptive values and the differences of means between the under-16 and under-18 categories.

The under-16 category players obtain higher scores than the players of the under-18 category in all the factors, although only statistically significant differences appears in Team Cohesion ($p < 0.05$.), and a tendency toward significance in the Motivation factor ($p < 0.05$).

Table 4 shows the players' performance self-evaluations, the coaches' evaluations and the scores obtained in the five factors of the CPRD, considering independently the under-16 category and the under-18 category.

In the under-16 category, only correlations are found between the two coaches' evaluations (match 1 and match 2; rho = 0.500, $p < 0.01$), and a tendency to statistical significance ($p < 0.10$) between the perception of the players in match 1 and the Mental Ability factor. On the contrary, in the under-18 category multiple results with statistical significance appears. There are important correlations between the perception of the players' performance in match 1 and match 2 (rho = 0.702, $p < 0.001$). Also, significant correlations –with medium values- were found between the player's perception of their performance in game 1 and the coaches' perception in that same game (rho = 0.405; $p < 0.05$), obtaining values significantly higher when considering the second match (rho = 0.445; $p < 0.01$).

Regarding to the CPRD factors, the Team Cohesion obtains significant inverse correlations of medium values when correlated with the players' perception in matches 1 (rho = −0.479; $p < 0.001$) and 2 (rho = −0.402; $p < 0.01$). The same factor have a significant negative tendency (rho = −0.273; $p < 0.10$) correlated with coaches' evaluation in match 2. Added to this, there is a positive correlation with tendency to the significance between the Motivation factor and the coach's evaluation in the first game (rho = −0.264; $p < 0.10$).

DISCUSSION

Studying the psychological profile of female soccer players, as was indicated by Rutkowska and Bergier (2015), is extremely important, and also can provide many interesting ideas about the specific nature of women's youth soccer.

It can also show where improvements can be made in sports training programs, specifically in mental training, especially in those players who will soon become part of professional football (MacNamara and Collins, 2017). In this vein, the objectives of this

TABLE 2 | Descriptive values and means differences between players' and coaches' perceptions of performance in the two games (Wilcoxon W).

	N	*M*	*SD*	Minimum	Maximum	Average rank	Total ranks	*Z*	*p*
PP-1	88	7.182	1.2158	4.0	9.5	30.34	1153.00	−3.006	0.000***
PP-2	89	7.006	1.6140	2.0	9.5	20.75	332.00		
N valid	87								
CP-1	72	7.347	1.4551	0.0	9.0	29.08	523.50	−2.295	0.022*
CP-2	73	7.795	1.6726	4.0	10.0	28.22	1072.50		
N valid	71								

*PP, Players' perceptions; CP, Coaches' perceptions. *p < 0.05; ***p < 0.001.*

TABLE 3 | Descriptive values and analysis of means differences of the two subgroups (*n* = 54 each group).

		M	*SD*	Average rank	Total ranks	W Wilcoxon	*Z*	Sig.
SC	Under-16	52.22	12.04969	56.97	3076.50	2809.500	−0.821	0.412
	Under-18	50.30	10.20660	52.03	2809.50			
IPE	Under-16	26.65	6.92591	58.51	3159.50	2726.500	−1.332	0.183
	Under-18	25.02	6.42663	50.49	2726.50			
M	Under-16	24.52	4.00820	59.77	3227.50	2658.500	−1.756	0.079†
	Under-18	23.20	4.00179	49.23	2658.50			
MSK	Under-16	21.74	3.59866	57.53	3106.50	2779.500	−1.008	0.313
	Under-18	21.00	4.53914	51.47	2779.50			
TCOH	Under-16	20.37	2.43633	60.38	3260.50	2625.500	−1.975	0.048*
	Under-18	19.50	3.16675	48.62	2625.50			

SC, Stress Control; IPE, Influence of Performance Evaluation; M, Motivation; MSK, Mental Skills; TCOH, Team Cohesion. †$p < 0.10$; *$p < 0.05$.

TABLE 4 | Correlation values regarding the under-16 category (*n* = 29) and under-18 (*n* = 44) using the Spearman's Rho statistic.

	Under-16				Under-18			
	PP-1	PP-2	PE-1	PE-2	PP-1	PP-2	PE-1	PE-2
PP-1	1.000				1.000			
PP-2	0.286	1.000			0.702***	1.000		
	0.141				0.000			
PE-1	0.126	0.057	1.000		0.405*	0.215	1.000	
	0.516	0.774			0.014	0.207		
PE-2	−0.037	0.118	0.500**	1.000	0.351*	0.445**	0.360*	1.000
	0.850	0.535	0.007		0.036	0.007	0.018	
SC	−0.126	0.231	−0.278	−0.288	0.142	0.242	−0.003	−0.120
	0.514	0.220	0.144	0.123	0.359	0.113	0.987	0.445
IPE	−0.303	0.254	−0.244	−0.086	−0.108	−0.007	−0.081	−0.237
	0.110	0.176	0.202	0.650	0.487	0.966	0.605	0.127
M	0.253	0.125	−0.255	−0.203	−0.040	−0.006	0.264†	−0.162
	0.185	0.510	0.182	0.283	0.798	0.971	0.087	0.299
MSK	0.331†	0.026	0.008	−0.154	−0.173	−0.052	0.038	−0.104
	0.079	0.891	0.969	0.416	0.261	0.738	0.809	0.506
TCOH	0.003	−0.101	0.109	−0.097	−0.479***	−0.402**	−0.101	−0.273†
	0.989	0.595	0.574	0.611	0.001	0.007	0.518	0.076

PP, Players' perceptions; CP, Coaches' perceptions; SC, Stress Control; IPE, Influence of Performance Evaluation; M, Motivation; MSK, Mental Skills; TCOH, Team Cohesion. †$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

study have been to describe the psychological characteristics of young female soccer players, determine the differences between the under-16 and under-18 categories, showing their relationship and congruence with the perception of performance, from both the players and coaches.

The results show that the scores of the young soccer players in the CPRD are higher than those of the general sample of athletes, especially in the scales of M, SC, and TCOH. Specifically in M they have a score that can be considered as quite high, that is, the players in the sample studied seem to have an adequate motivational state to meet the demanding requirements of sports practice and the competition, which coincides with other studies on female soccer players (Muñoz et al., 2018), in which the basic motivation found was intrinsical, related to the game itself and by being part of a team, although these features have fluctuations depending on the competition level (Domínguez-Escribano et al., 2017).

Both in the SC and in TCOH subscales the scores obtained are moderately high, which in principle seems to indicate that the players tend to control well the potential stress inherent to the competition, and that they have a good disposition to work with the team. Regarding the scores obtained in IPE and MSK, the results indicate that they are on the average, which in the first case indicates that the players can be negatively affected by the evaluation that other people (or indeed themselves) make of their performance, and in the second case indicates that the players do not have full consolidated psychological skills, needed for to perform optimally. This last factor affects the need to propose psychological intervention programs tailored to the specific needs and characteristics of athletes, depending on the competition level, gender, etc. In the same vein, Slimani et al. (2016) performed a systematic review finding some very interesting data showing the differences in cognitive/psychological training interventions, and their effectiveness, depending on whether they are directed toward practices or competition, age, competition level and the players' position.

Considering that the players have a similar level of performance in their respective categories, it is clear they show some overestimation of their skills (mainly perceived in the under-16 category), perhaps due to a fewer competitive experience, a lower self-awareness of psychological limitations, and less exposure to experiences related to the performance in competition demands. Also, from an evolutionary perspective, players of 14 and 15 years old are in the middle of the adolescence, where variables such as self-concept and self-knowledge are under construction, and therefore, may have a minor adjustment of their psychological skills to deal with situations of stress and promote self-confidence (Sarkar and Fletcher, 2014; González-Campos et al., 2015; Gómez-Espejo et al., 2017).

On the other hand, with respect to the second objective, the results indicate that the under-16 players obtain higher scores than the under-18 players in all the factors, showing statistically significant differences in TCOH and a tendency to statistical significance in M. In any case, the most relevant differences are in the TCOH scale, where perhaps the younger players have a better disposition to work inside the team, while the U18 players have other aspects of personal competence could work against the teamwork; and on the M scale, which in this case may be better understandable due to other major competitive factors, such as being near the end of the youth stage in the case of the U-18, when some of the players could to be thinking about alternatives outside the practice of competitive football, or that the perceived pressure is inadequately managed, generating anxiety and worry. These data are in accord with what other found in other studies (Pan and Zhu, 2003), where at a higher level of psychological competitiveness, lower is the level of worry and anxiety and better the performance.

Finally, regarding the third objective, and taking into account the whole sample, the results indicate that the players' self-evaluations are very similar between match 1 and match 2, although this difference is significant in favor of match 1. In other words, they perceived that they have played the first match better than the second. Interestingly, the evaluations made by the coaches are somewhat higher than those made by the players themselves, finding significant differences between the assessments made between the match 1 and 2; unlike the players, the coaches give a better rating to the performance obtained in match 2. In this sense, some studies (Møllerløkken et al., 2017) have also found differences between the perception of players and coaches regarding the motivational climate, meaning that players of both sexes perceived that the motivational climate was more oriented toward the performance and less toward the domain compared to coaches. In both cases, these findings may improve our understanding of the coach-player relationship, and may be important in understanding the players' motivational style. Indeed, Reid and Crust (2012) examined the perceptions of elite soccer players and coaches about the psychological drive and how it relates to objective performance, finding that teammates and spectators can have a greater impact on the momentum in female football than with the male soccer.

When analyzing the data by categories, the results indicate that in the under-16 category, only correlations are found between the coaches' evaluation of first and second matches. On the other hand, in the under-18 category there are quite relevant correlations between the perception of the player's performance between the two matches; between the players' and coach performance perception match 1 and the perception, indeed reaching higher significant values when considering the second game. In this last case, the under-18 players' great experience could explain, in part, the correlation of their performance perception with that of their coach, since in the under-16 category that lack of experience could play against a more realistic self-evaluation, differing more with the most experienced coach evaluation.

Furthermore, this fact supports the fact that the TCOH factor obtains significant inverse correlations -of medium values- when is correlated with the player's self-perception both in the first and second matches, and when at the same time obtain a significant negative tendency with the coach's evaluation in the second game. In short, these results indicate that the under-18 players have performance perceptions more adjusted to the expert criterion (from the coaches) than the under-16; the higher experience in the under-18 players' sport practice could explain these differences between these both groups.

Finally, the CPRD questionnaire seems to be a very appropriate instrument to describe the relevant psychological characteristics related to sports performance, and to provide very valuable information, both from a group and individual point of view, serving as a basis for implementing training programs and specific psychological training for the team or individual level. As indicated by Olmedilla et al. (2017a) the knowledge of the psychological characteristics of young athletes can be very valuable so that, together with the physical and anthropometric indicators, they allow their coaches to individualize the training processes and thus optimize them.

The present study provides fundamentally some knowledge about the psychological variables of women's competitive soccer, showing psychological differences in two youth sports categories where the player's experience and age may have great relevance (Ruiz, 2005), as well as the relationships between the load of practice and/or competitions regarding players' mood, psychological well-being and physiological well-being (Lowe, 2017; McFadden et al., 2017; Tharawadeepimuk and Wongsawat, 2017), especially in view of the possibility of evaluating and intervening on a psychological level in women's football teams (Olmedilla et al., 2018b).

The results of this study can help to establish the differences between different constellations of psychological characteristics related with performance levels and their relationship with the subjective perception of performance. This knowledge can be used by sports professionals: coaches, psychologists, physical educators, etc., to help athletes achieve their maximum performance, and to implement effective intervention programs for sports performance (MacNamara et al., 2010; Bennett and Maynard, 2016; Gledhill et al., 2017); personal growth and athletes' dual-career (Llames and García-Dantas, 2017), or even athletes' injury prevention (Olmedilla et al., 2017b).

Limitations and Future Research Directions

In the present study, the participating regional teams have been analyzed in the final phase of the national 11 women's soccer championship in the under-16 and under-18 categories, with 3 teams in each category. The non-randomized selection of the participants, the specific context of the competition and the small sample size of the current research imply that the results obtained cannot be generalized, and that they cannot be compared with other performance levels.

On the other hand, it would be interesting to collect data from a greater number of matches, and perhaps to include practices, in order to determine the differences in the player's and coaches' perception of performance between the two situations. In addition, the coaches' evaluation carried out is individual and not peer-reviewed, and in subsequent studies it should be good to carry out inter-judge analyzes obtaining a more reliable expert criterion regarding the data analysis.

Likewise, there is a great dispersion in the number of hours and days of practice in the players assessed, what is a representation of the reality of female soccer in Spain; so it could be interesting to study more homogeneous groups in future approaches. Regarding future research developments, should be interesting made up studies where specific changes of psychological skills in different female sports teams may be analyzed. Likewise, it would be convenient to establish comparisons with male athletes, aiming to tailoring accurately eventual psychological interventions addressed to each epidemiological segment (such as gender, sport type, athletes' age, and level of performance).

CONCLUSION

The scores of the young soccer players in the CPRD are higher than those of the general sample of athletes, especially in the scales of M, SC, and TCOH.

The under-16 category players' obtained higher scores than the under-18 category players' in all factors, showing statistically significant differences in TCOH, and a tendency to statistical significance in M.

The players' self-perception of their performance is very similar between match 1 and match 2, although the small difference is significant in favor of match 1.

The players' performance made by their coaches is somewhat higher than those made by the players themselves.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Declaration of Helsinki. The protocol was approved by the Comité de Ética de la Universidad de Murcia (reference: UM 1551/2017). All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

AO and AG-M contributed with the conception and design of the study. AO and RR-B organized the database. RR-B and FP performed the statistical analysis. AO wrote the first draft of the manuscript. FP, AG-M, RR-B, and FR-P wrote the sections of the manuscript. FR-P was in charge of the formal aspects of the work. All authors contributed to the revision of the manuscript, and read and approved the presented version.

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REFERENCES

Abdullah, M. R., Musa, R. M., Maliki, A. B. H. M., Kosni, N. A., and Suppiah, P. K. (2016). Role of psychological factors on the performance of elite soccer players. *J. Phys. Educ. Sport* 16:170. doi: 10.7752/jpes.2016.01027

Álvarez, O., Estevan, I., Falcó, C., Hernández-Mendo, A., and Castillo, I. (2014). Perfil de habilidades psicológicas en taekwondistas universitarios y su relación con el éxito en competición. *Cuad. Psicol. Dep.* 14, 13–20. doi: 10.4321/s1578-84232014000300002

Anderson, R., Hanrahan, S. J., and Mallett, C. J. (2014). Investigating the optimal psychological state for peak performance in Australian elite athletes. *J. Appl. Sport Psychol.* 26, 318–333. doi: 10.1080/10413200.2014.885915

Arroyo del Bosque, R., Irazusta, S., and González-Rodríguez, O. (2016). *Impacto del Resultado Post-Partido en el Estado de Ánimo en Jóvenes Jugadoras de Fútbol*. Ph.D. thesis, Universidad del País Vasco País Vasco, SP.

Arthur, R. A., Fitzwater, J., Roberts, R., Hardy, J., and Arthur, C. A. (2017). Psychological skills and "the paras": the indirect effects of psychological skills on endurance. *J. Appl. Sport Psychol.* 29, 449–465. doi: 10.1080/10413200.2017.1306728

Bahrololoum, H., Hassani, A., Reza, M., and Akbari, A. (2012). The relationship between the emotional intelligence and mental skills in iranian elite Male Volleyball Players. I. *J. Acad. Res. Bus. Soc. Sci.* 2, 123–130.

Baillie, P. H. F., Davis, H., and Ogilvie, B. C. (2014). "Working with Elite Athletes," in *Exploring Sport and Exercise Psychology*, 3rd Edn, eds J. van Raalte and B. Brewer (Washington DC: APA), 401–425. doi: 10.1037/14251-018

Bali, A. (2015). Psychological factors affecting sports performance. *Int. J. Phys. Educ. Sports Health* 1, 92–95.

Bennett, J., and Maynard, I. (2016). Performance blocks in sport: recommendations for treatment and implications for sport psychology practitioners. *J. Sport Psychol. Action* 8, 60–68. doi: 10.1080/21520704.2016.1227414

Burnik, S., Jug, S., Kajtna, T., and Tusak, M. (2005). Differences in personality traits of mountain climbers and nonathletes in Slovenia. *Acta Univ. Palacki. Olomuc. Gymn.* 35, 13–17.

Cabrita, T., Rosado, A., de la Vega, R., and Serpa, S. (2014). Relaciones entre identidad atlética y personalidad en el deporte de competición. *Rev. Psicol. Dep.* 23, 247–253.

Castilla, J. F., and Ramos, L. C. (2012). Rendimiento deportivo, estilo de liderazgo y evitación experiencial en jóvenes futbolistas almerienses. *J. Sport Psychol.* 21, 137–142.

Danielsen, L. D., Rodahl, S. E., Giske, R., and Høigaard, R. (2017). Mental toughness in elite and sub-elite female soccer players. *Int. J. Appl. Sports Sci.* 29, 77–85. doi: 10.24985/ijass.2017.29.1.77

Datson, N., Hulton, A., Andersson, H., Lewis, T., Weston, M., Drust, B., et al. (2014). Applied physiology of female soccer: an update. *Sports Med.* 44, 1225–1240. doi: 10.1007/s40279-014-0199-1

Domínguez-Escribano, M., Ariza-Vargas, L., and Tabernero, C. (2017). Motivational variables involved in commitment of female soccer players at different competitive levels. *Soccer Soc.* 18, 801–816. doi: 10.1080/14660970.2015.1067789

Gagné, F. (2004). Transforming gifts into talents: the DMGT as a developmental theory. *High Abil. Stud.* 15, 119–147. doi: 10.1080/1359813042000314682

García-Naveira, A., Ruiz-Barquín, R., and Ortín, F. J. (2015). Optimismo y competitividad en jóvenes atletas de rendimiento. *Rev. Latinoam. Psicol.* 47, 124–135. doi: 10.1016/j.rlp.2014.08.001

Gimeno, F. (1999). *Variables Psicológicas Implicadas En El Rendimiento Deportivo: Elaboración Y Estudios Sobre La Aplicación Del Cuestionario "Características Psicológicas Relacionadas Con El Rendimiento Deportivo" (CPRD).* Doctoral thesis, National Distance Education University, Madrid, SP.

Gimeno, F., Buceta, J. M., and Pérez-Llantada, M. C. (2001). El cuestionario "características psicológicas relacionadas con el rendimiento deportivo" (CPRD): características psicométricas. *Análise Psicol.* 1, 93–133. doi: 10.14417/ap.346

Gledhill, A., Harwood, C., and Forsdyke, D. (2017). Psychosocial factors associated with talent development in football: a systematic review. *Psychol. Sport Exerc.* 31, 93–112. doi: 10.1007/s40279-017-0851-7

Gómez-Espejo, V., Aroca, B., Robles-Palazón, F. J., and Olmedilla, A. (2017). Formación integral en la cantera del real murcia CF: tutorías psicológicas. *Rev. Psicol. Apl. Dep. Ejerc. Físico* 2, 1–11.

González, J. (2017). Diseño del entrenamiento mental del tenista. De lo científico a la aplicado. *Rev. Psicol. Apl. Dep. Ejerc. Físico* 2, 1–14. doi: 10.5093/rpadef2017a5

González-Campos, G., Valdivia-Moral, P., Zagalaz, M. L., and Romero, S. (2015). La autoconfianza y el control del estrés en futbolistas: revisión de estudios. *Rev. Iberoam. Psicol. Ejerc. Dep.* 10, 95–101.

Gould, D., Weiss, M., and Weinberg, R. S. (1981). Psychological characteristics of successful and less successful big ten wrestlers. *J. Sport Psychol.* 3, 69–81. doi: 10.1123/jsp.3.1.69

Granero-Gallegos, A., Gómez-López, M., Abraldes, J. A., and Baena-Extremera, A. (2015). Predicción de las orientaciones de meta en el fútbol femenino. *J. Sport Health Res.* 7, 31–42. doi: 10.1163/9789401202084_005

Haugaasen, M., Toering, T., and Jordet, G. (2014). From childhood to senior professional football: a multi-level approach to elite youth football players' engagement in football-specific activities. *Psychol. Sport Exerc.* 15, 336–344. doi: 10.1016/j.psychsport.2014.02.007

Junge, A., and Feddermann-Demont, N. (2016). Prevalence of depression and anxiety in top-level male and female football players. *BMJ Open Sport Exerc. Med.* 2:e000087. doi: 10.1136/bmjsem-2015-000087

Llames, R., and García-Dantas, A. (2017). Entrenamiento psicológico deportivo aplicado a una estudiante de oposición. *Rev. Psicol. Dep.* 26, 98–103.

Lowe, A. C. (2017). *Physiological and Psychological Well-Being During the Spring Season in Female Soccer Players*. Master's Thesis, Louisiana State University, Lousiana.

MacNamara, A., Button, A., and Collins, D. (2010). The role of psychological characteristics in facilitating the pathway to elite performance part 1: identifying mental skills and behaviors. *Sport Psychol.* 24, 52–73. doi: 10.1123/tsp.24.1.52

MacNamara, Á, and Collins, D. (2017). "Psychological characteristics of developing excellence," in *Sport Psychology for Young Athletes*, eds C. J. Knight, C. G. Harwood, and D. Gould (London: Routledge).

Mahoney, M. J. (1989). Psychological predictors of elite and non-elite performance in Olympic weightlifters. I. *J. Sport Psychol.* 20, 1–12.

Mahoney, M. J., and Avener, M. (1977). Psychology of the elite athlete: an exploratory study. *Cogn. Ther. Res.* 1, 135–141. doi: 10.1007/BF01173634

Mahoney, M. J., Gabriel, T. J., and Perkins, T. S. (1987). Psychological skills and exceptional athletic performance. *Sport Psychol.* 1, 181–199. doi: 10.1123/tsp.1.3.181

Malinauskas, R., Dumciene, A., Mamkus, G., and Venckunas, T. (2014). Personality traits and exercise capacity in male athletes and non-athletes. *Percep. Motor Skills* 118, 145–161. doi: 10.2466/29.25.PMS.118k13w1

Markovits, A. S., and Hellerman, S. L. (2003). Women's soccer in the United States: yet another American "exceptionalism". *Soccer Soc.* 4, 14–29. doi: 10.1177/2325967119829212

Martínez-Ferreiro, J. (2016). *Inteligencia Emocional y Rendimiento Deportivo en el Futbol Femenino de Alta Competición*. Doctoral thesis, Universidad de Valladolid, Valladolid, SP.

Martín-García, G. (2003). La mujer futbolista desde la perspectiva psicológica. *Cuad. Psicol. Dep.* 3, 7–15.

McFadden, B. A., Walker, A. J., Sanders, D. J., Hofacker, M., Bello, M., Poyssick, A., et al. (2017). Workload-related psychological and physiological changes in female college soccer players during a competitive season. *Med. Sci. Sports Exerc.* 49:577. doi: 10.1249/01.mss.0000518503.47781.ba

Møllerløkken, N. E., Lorås, H., and Pedersen, A. V. (2017). A comparison of players' and coaches' perceptions of the coach-created motivational climate within youth soccer teams. *Front. Psychol.* 8:109. doi: 10.3389/fpsyg.2017.00109

Morris, T. (2000). Psychological characteristics and talent identification in soccer. *J. Sports Sci.* 18, 715–726. doi: 10.1080/02640410050120096

Muñoz, S. P., Calle, R. C., Muñoz, A. S., Cayetano, A. R., de Mena Ramos, J. M., Blanco, J. M. F., et al. (2018). ¿Por qué juego al fútbol si soy una mujer?: Motivaciones para jugar al fútbol. *Retos* 34, 183–188.

Nagle, F. J., Morgan, X. P., Hellickson, R. O., Serfass, R. C., and Alexander, J. F. (1975). Sporting success traits in Olympic contenders. *Phys. Sportsmed.* 3, 31–34. doi: 10.1080/00913847.1975.11948293

Olmedilla, A., and Dominguez-Igual, J. (2016). Entrenamiento psicológico para la mejora de la atención y la autoconfianza en un futbolista. *Rev. Psicol. Apl. Dep. Ejerc. Físico* 1, 1–11. doi: 10.5093/rpadef2016a4

Olmedilla, A., García-Mas, A., and Ortega, E. (2017a). Psychological characteristics for sport performance in young players of football, Rugby, and Basketball. *Acci. Psicol.* 14, 7–16. doi: 10.5944/ap.14.1.19249

Olmedilla, A., Rubio, V. J., Ortega, E., and García-Mas, A. (2017b). Effectiveness of a stress management pilot program aimed at reducing the incidence of sports injuries in young football (soccer) players. *Phys. Ther. Sport* 24, 53–59. doi: 10.1016/j.ptsp.2016.09.003

Olmedilla, A., Ortega, E., de los Fayos, E. G., Abenza, L., Blas, A., and Laguna, M. (2015). Perfil psicológico de los jugadores profesionales de balonmano y diferencias entre puestos específicos. *Rev. Latinoam. Psicol.* 47, 177–184. doi: 10.1016/j.rlp.2015.06.005

Olmedilla, A., Ortega, E., Robles-Palazón, F. J., Salom, M., and García-Mas, A. (2018a). Healthy practice of female soccer and futsal: identifying sources of stress, anxiety and depression. *Sustainability* 10:2268. doi: 10.3390/su10072268

Olmedilla, A., Sánchez-Aldeguer, M. F., Almansa, C. M., Gómez-Espejo, V., and Ortega, E. (2018b). Entrenamiento psicológico y mejora de aspectos psicológicos relevantes para el rendimiento deportivo en jugadoras de fútbol. *Rev. Psicol Apl. Deporte Ejerc. Físico* 3, 1–11. doi: 10.5093/rpadef2018a2

Olmedilla, A., Torres-Luque, G., García-Mas, A., Rubio, V. J., Ducoing, E., and Ortega, E. (2018c). Psychological profiling of triathlon and road cycling athletes. *Front. Psychol.* 9:825. doi: 10.3389/fpsyg.2018.00825

Pan, G. P., and Zhu, J. M. (2003). A research on the top female soccer players' psychological characteristics in competition. *Sports Sci. Res.* 24, 32–34.

Rasmus, P., and Kocur, J. (2006). Personality traits and competition skills in adolescent tennis players. *Physic. Educ. Sport* 50, 93–95.

Reid, J., and Crust, L. (2012). "Psychological momentum in elite female soccer: perceptions of players and coaches," in *Proceedings of the BASES Student Conference 2012, 16-17 April 2012*, (London: University of East London).

Reilly, T., Bangsbo, J., and Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *J. Sports Sci.* 18, 669–683. doi: 10.1080/02640410050120050

Romero, A. E., Zapata, R., García-Mas, A., Brustad, R. J., Garrido, R., and Letelier, A. (2010). Estrategias de afrontamiento y bienestar psicológico en jóvenes tenistas de competición. *Rev. Psicol. Dep.* 19, 117–133.

Ruiz, R. (2005). Análisis de las diferencias de personalidad en el deporte del judo a nivel competitivo en función de la variable sexo y categoría de edad deportiva. *Cuad. Psicol. Dep.* 5, 29–48.

Rutkowska, K., and Bergier, J. (2015). Psychological gender and emotional intelligence in youth female soccer players. *J. Hum. Kinet.* 47, 285–291. doi: 10.1515/hukin-2015-0084

Sarkar, M., and Fletcher, D. (2014). Psychological resilience in sport performers: a review of stressors and protective factors. *J. Sports Sci.* 32, 1419–1434. doi: 10.1080/02640414.2014.901551

Silva, J. M., Shultz, B. B., Haslam, R. W., and Murray, D. F. (1981). A psychophysiological assessment of elite wrestlers. *Res. Q. Exerc. Sport* 52, 348–358. doi: 10.1080/02701367.1981.10607882

Slimani, M., Bragazzi, N. L., Tod, D., Dellal, A., Hue, O., Cheour, F., et al. (2016). Do cognitive training strategies improve motor and positive psychological skills development in soccer players? Insights from a systematic review. *J. Sports Sci.* 34, 2338–2349. doi: 10.1080/02640414.2016.1254809

Steca, P., Baretta, D., Greco, A., D'Addario, M., and Monzani, D. (2018). Associations between personality, sports participation and athletic success. a comparison of Big Five in sporting and non-sporting adults. *Pers. Individ. Dif.* 121, 176–183. doi: 10.1519/JSC.0b013e3182719123

Stolen, T., Chamari, K., Castagna, C., and Wisloff, U. (2005). Physiology of soccer: an update. *Sports Med.* 35, 501–536. doi: 10.2165/00007256-200535060-00004

Swann, C., Crust, L., Jackman, P., Vella, S. A., Allen, M. S., and Keegan, R. (2017). Psychological states underlying excellent performance in sport: toward an integrated model of flow and clutch states. *J. Appl. Sport Psychol.* 29, 375–401. doi: 10.1080/10413200.2016.1272650

Tharawadeepimuk, K., and Wongsawat, Y. (2017). Quantitative EEG evaluation for performance level analysis of professional female soccer players. *Cogn. Neurodyn.* 11, 233–244. doi: 10.1007/s11571-017-9427-3

Vescovi, J. D., and McGuigan, M. R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. *J. Sports Sci.* 26, 97–107. doi: 10.1080/02640410701348644

Weinberg, R. S., and Gould, D. (2014). *Foundations of Sport and Exercise Psychology*. Champaign: Human Kinetics.

Williams, K. T. (2017). *Physiological and Psychological Characteristics of First Division Female Football Players*. Doctoral thesis, University of Johannesburg, Johannesburg SA.

Wright, M. D. (2014). Neuromuscular training in girl's football-the challenge of applying evidence based practice in an FA center of excellence. *J. Sports Sci.* 32, s93–s100.

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frontiers in Psychology

ORIGINAL RESEARCH
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The Effect of the Return of Serve on the Server Pair's Movement Parameters and Rally Outcome in Padel Using Cluster Analysis

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Purpose: The pressure exerted on racket sports players by the service has been well documented. Whilst the return of serve has been suggested through qualitative interviews as being of similar importance there is a dearth of quantitative data to support this contention. This study analyzed time, speed, and distance parameters related to the outcome of the return of serve (ROS) in Padel, a sport similar to tennis but played on a court bounded by walls and played in doubles format only.

Methods: Matches (n = 18) at two tournaments, sanctioned by the Valencian Federation, in 2012 were recorded and processed using Tracker software. ROS shot type (flat or lob), ball location, players' positions on court and movement parameters between the ROS and the third shot of the server were captured 25 times per second.

Results: Both lob and flat ROS produced six main clusters, as well as a small proportion of shots deemed outliers. The clusters differentiated shots played by two different level players (National and Regional), whether the ROS was played following a first or second serve, whether the serving pair adopted a conventional or Australian formation and whether the rally ended in a short number of shots (seven or less) or not.

Conclusion: It was suggested that the aim of the ROS in Padel was to prevent the serving pair winning the rally quickly, since the advantage of the serve diminished after around 6 to 8 shots. This was best achieved by good depth on lobs, regardless of the direction, and pace on low shots, predominately aimed toward the server. This approach should be further modified to include the time between serve and ROS and consideration could be given to classifying attacking and defending positions.

Keywords: cluster analysis, performance analysis, padel, return of serve, movement parameters

INTRODUCTION

Padel is a complex and dynamic racket sport, played by two players as a pair (doubles only) on a court (10 × 20 m), comparable to tennis, but bounded by walls, a fence and an opening next to the net. Matches are the best of three sets using tennis scoring. At the elite level, average playing time for male players is just under 1 h with ball in play time approximately 35% of the total time

(Torres-Luque et al., 2015). Castillo-Rodríguez et al. (2014) found that players of different standard averaged between 609 and 1043 m per set, but higher ranked players covered less distance than lower ranked players. However, in closely contested elite level matches, players covered 1470 m during ball in play time (Ramón-Llin et al., 2014).

As with other racket sports, Padel players tend to apply tactics depending on the situation, either advantageous or disadvantageous, which determines shot selection typically based on players' movement or positioning. Tactical analysis has showed that Spanish players at National and Regional levels used more volleys, trays and smashes (National 28.3%, 8.9%, 5%; Regional 26.2%, 11.8%, 4.1%, respectively) than amateur players (16.7%, 7.4%, 2.9%; Ramón-Llin et al., 2017). These results indicated different tactical behaviors, for players of different standard, which also implied different positioning by players, i.e., greater net dominance allowing the increase in these attacking shots. The importance and effectiveness of players' tactical positioning has also been analyzed in squash and tennis. For example, Vučković et al. (2008, 2009) found that the frequency of occupying the T area in squash, at the moment the opponent played their shot, best discriminated playing standard. Winners of a game also spent a greater proportion of total playing time on the T, suggested as indicative of a player's dominance. In tennis, Martinez-Gallego et al. (2013) showed that game winners spent less time in defensive zones than losers suggesting that successful performance was related to offensive tactics. However, gender and court surface have been shown to have an effect on tactical parameters during tennis Grand Slam tournaments (O'Donoghue and Ingram, 2001). Offensive strategy was assessed in elite Padel, finding that 60% of points were either won or lost at the net (Courel-Ibáñez et al., 2015). The authors concluded that being at the net was a key factor for successful performance, where players could win more points but also tended to make less unforced errors.

The serve in tennis has been shown to be advantageous (Kovalchik and Reid, 2018), e.g., players win 67.3% of points with the 1st serve on a slow court surface (Gillet et al., 2009), but that proportion is greater in men's singles compered to women's (O'Donoghue, 2001). This is probably due to the significantly higher ball speed achieved by male players, which was only evident on serve, but not in other groundstrokes (Reid et al., 2016). Furlong (1995) found that the serve was more effective in tennis doubles compared to singles, likely due to the smaller target area for the return of serve (ROS) due to the server partner covering the net. This also allows the server in doubles to serve from a wider position and hence slice the ball further outside the court. The accuracy of the serve has not been widely studied although Vial et al. (2019) suggested that the landing accuracy measures in badminton were inappropriate. Whilst badminton is quite different from most other racket sports, since all shots are volleyed, the point can be made that trajectory, speed and spin, along with where the ball lands, all contribute to the difficulty associated with making a good ROS. Martin et al. (2019) analyzed first and second serves during 50 main draw 5 set matches during the 2014 Grand slam tennis events. They found fairly consistent ball velocities, percentage serves in and percentage points won between each of the five sets suggesting that professional tennis players can maintain serving performance over the course of a match. Whilst the authors suggested that small differences in serve velocity in the fifth set between match winners and losers may have led to the match outcome no other factors, such as trajectory and spin, were considered. Another factor not considered in this study is the ability to anticipate the serve trajectory, clearly if players can improve this ability during a match their ROS performance would potentially improve. Gillet et al. (2009) analyzed 116 matches, all lasted over 100 points, from the 2016 and 2017 French Open tournaments, to determine that flat serves to the T (centre of the court) and ROS to a central zone were the most effective in men's singles tennis. This study recognised that multiple factors contribute to the effectiveness of both the serve and ROS and highlighted the fact that the coupling of these two "most important shots" leads to different strategies employed for both. Gómez et al. (2017) suggested that psychological factors, such as confidence and momentum, are likely to affect performance during a match, accounting for their finding that table tennis serving performance tended to fluctuate throughout the 140 men's and women's matches analyzed from the 2016 Olympic games.

O'Donoghue and Brown (2008) investigated the effectiveness of tennis serves showing that men's first serves still had an impact on rally outcome in rallies that lasted four shots, i.e., servers won statistically more of these rallies. However, for second serves this advantage had diminished by the third shot. In table tennis, Zhang et al. (2013) assessed a player's technique effectiveness using the "three phase evaluation theory." This methodology calculated rally success rates for a player for rallies that lasted four shots or less, i.e., separate calculations for when serving and receiving, and for rallies that lasted over four shots irrespective of serving or not. The authors suggested players accorded high validity to these measures, particularly elite Chinese players. These studies suggest that the influence of the service extends some way into the rally in both tennis and table tennis although the service in both these sports are intuitively strong shots due to the speed in tennis and spin in table tennis. The impact of the serve in tennis was further corroborated by Fitzpatrick et al. (2019) who found that the player who won the most rallies containing 1 to 4 shots won the match almost 9 out of 10 times. This was the best predictor of match outcome from a range of measures which was somewhat surprising in that these matches were from the 2016 and 2017 French Open tournaments, played on the slowest surface, and where rallies were shown to be significantly longer than any of the other Grand Slams (O'Donoghue and Ingram, 2001).

The service in Padel is different to its closest similarity, the tennis service, because the rules dictate that it must be an underhand shot from a bouncing ball hit from below waist level. Thus, the ball cannot be hit as hard as in tennis although spin and the side wall can influence the difficulty in returning the shot. Additionally, similar to tennis doubles, the serving pair initially has an attacking opportunity because of the spatial advantage at shot three, i.e., one player at the net and the other approaching the net. This implies that the receiver is under some pressure to play an accurate ROS to try to prevent the serving pair from attacking by hitting the ball (shot 3) into a tactically advantageous area. This contention is supported by Courel-Ibáñez et al. (2014) who found that World padel tour players (n = 15 matches) won 83.4% of their service games. Ramón-Llin et al. (2013) found that, independent of performance level, the server in Padel, covered a significantly greater distance than his partner during rallies. To some extent this is obvious since the server immediately runs to the net following the service whereas the partner is standing at the net waiting for the ROS. However, lob returns over the serve partner's head would probably negate this effect although Courel-Ibáñez et al. (2017) suggested that lobs tended to be directed to both sides of the court, near the walls but accounted for <16% of total shots played. This paper did not differentiate serve and ROS from other shots but did analyze spatial positioning, shot type and their effectiveness although only four players were analyzed during an unspecified number of matches.

At present little is known about the relationship between the serve and ROS, in all racket sports, other than the fact that the server tends to maintain the tactical advantage until around shot 5 when the advantage has dissipated. This knowledge has been gained from simple analyses of rally outcomes (e.g., O'Donoghue and Brown, 2008) or from experiential knowledge gained through exposure to elite match play (e.g., Zhang et al., 2013). Whilst the importance of a good ROS (technically and tactically) is well understood by coaches and players, there is little research to illustrate this. Zhang and Zhou (2017) differentiated specific serve tactics in table tennis that were associated with higher scoring rates whilst Vernon et al. (2018) qualitatively interviewed eight former or current top 250 professional male tennis players to reveal three types of returner. "Aggressive" returns put pressure on the server, "counter-punchers" got every return into court and the "neutral" played each serve according to its merits. This research also highlighted the difference between first and second serves in term of how aggressive the ROS could be. The objective of this research was to initially assess the effectiveness of the serve, in terms of winning the point, before analyzing quantitative data in relation to the effectiveness of the ROS and assess its impact on rally outcome. Since the ROS only directly impacts the third shot of the rally we decided to undertake an in-depth analysis of the ROS and third shots only. Serve type (first or second serve), service formation (Australian or Conventional), return type (flat or lob), see **Table 1** for operational definitions, and playing standard were selected as parameters that could potentially affect the time, distance and velocity values of interest. Hence, the effectiveness of the ROS was analyzed using physical parameters of the serving pair at the time of the third shot being played to see whether these determined rally length and outcome.

The methodology used in this paper led to a couple of hypotheses. First, we thought that the serve would cease to have an effect on rally outcome after more than the four shots found for tennis singles (O'Donoghue and Brown, 2008), due to the territorial advantage gained by serving in doubles. Secondly, we hypothesised that if the ROS was effective the rally would tend to be longer and the winner of the rally would be unpredictable.

TABLE 1 | Operational definitions for Padel terminology used.

	Variations	Definition
Serve	1st or 2nd serve	The serve is hit from lower than the server's waist after the ball bounces behind the serve line (**Figure 1**). The shot is usually played with back spin most often toward the opposite side wall.
Service formation	Conventional or Australian	At serve, the serve partner stands close to the net either on the other side of the court to the server (conventional) or always stays on the same side of the court (Australian) irrespective of the side where the serve takes place.
Flat return of serve (flat ROS)	Directed toward server, serve partner or between them	Service return is hit low over the net after the ball bounces. The direction is often determined by the serve formation and direction of serve.
Lob return of serve (lob ROS)	Directed toward server or serve partner	Service return is hit high over the net toward the back of the court.

MATERIALS AND METHODS

Participants

Matches took place at two tournaments, sanctioned by the Valencian Federation, in 2012 with 2000€ prize money for each. All matches were processed using Tracker software, a newer version of the SAGIT/Squash software (Perš et al., 2008). The main sample consisted of 26 National (professionals playing on Pro tour) players (mean age 33.5 years, SD = 6.8) who played in 9 matches of the main draws. A further comparison sample of 30 Regional (elite amateur) players (mean age 31.1 years, SD = 6.9) who played in 9 matches during the qualification rounds was also used. The written consent of the tournament organisers was obtained to film and analyze the matches. All the participants signed an informed consent of their participation, which guaranteed the anonymity and exclusive use of the video recordings for scientific purposes. The Ethics Committee of University of Valencia (protocol H1494417717437) approved this study.

Procedure

Two digital Bosch Dinion Model IP 455 video cameras (Bosch, Munich, Germany) were used to film the matches (25 frames per second), sagittally placed over the courts at 6 m from the centre and over the service line (**Figure 1**).

The techniques for transferring video images into Tracker were identical to SAGIT/Squash, i.e., automatic processing with operator supervision, and have been well documented (Vučković et al., 2009). Similarly, the reliability for resultant calculations of distance and speed for each player (Vučković et al., 2010) and positions on court (Vučković et al., 2009) have been published.

Data Processing

The shot type of the ROS (flat and lob) and x and y coordinates of the ball and player locations for each shot were recorded.

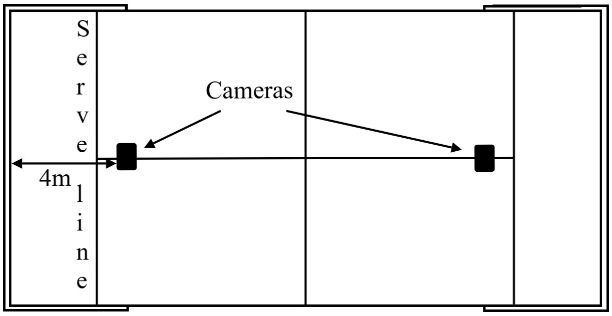

FIGURE 1 | Placement of the cameras at the ceiling above the court.

James et al. (2007) suggested that reliability tests should reflect the way in which notation data is analyzed. Reliability measures for the Tracker software has been shown to be acceptable for analysis purposes (Vučković et al., 2010). Further measures were calculated for distinguishing a random sample of flat and lob ROS (n = 364) using both inter-operator (98.67% agreement, Kappa = 0.98) and intra-operator tests (99.33% agreement, Kappa = 0.99). Additional information regarding time between ROS and third shot, average speed of movement and distance covered for server between ROS and third shot and distance from the net for server and his partner at the third shot were recorded. Independent variables used to assess for ROS differences were (1) variables under the control of the serving pair which determine ROS difficulty, i.e., first or second serve and serve formation (conventional or Australian); (2) playing standard (National or Regional); (3) an outcome variable of serve effectiveness, rally length (short rallies of 7 shots or less or long). Finally, for lob ROS, whether the shot was directed at the server or serve partner was recorded.

To determine whether the service had a significant effect on the outcome of the rally Wilcoxon Signed Ranks tests and associated effect sizes (z score converted into effect size with >0.3 deemed medium and >0.5 large; Rosenthal, 1991) determined whether the serving pair won more rallies than receivers for rallies of different length. Friedman tests assessed whether the rally length had a significant effect on National and Regional players in similar ways.

Cluster analysis is a data mining technique that enables the formation of groups within a data set based on maximising the homogeneity of cases within a group and the heterogeneity between clusters (Hair et al., 1995). Cluster analysis begins with all cases as separate groups and the two "most alike" cases combined in the first step using the most appropriate distance measure. The two cases with the smallest distance measure will then cluster together and a group mean (cluster centroid) calculated and used in the next step. The next two most alike cases (or groups once cases have been clustered) are then combined. This process continues until an optimal cluster solution is obtained, based on the Silhouette coefficient, a measure of cohesion and separation. The number of clusters may also be changed if the optimal number of clusters is deemed practically not the best (Hair et al., 1995). In this study, the optimal number of clusters was deemed acceptable for both flat ROS (coefficient = 0.35, fair) and lob ROS (coefficient = 0.4, fair).

The two-step cluster analysis, using a probability-based log-likelihood distance measure (IBM SPSS Statistics, v.24, Chicago, IL, United States) enabled the continuous (two distance parameters, time, and average speed) and four categorical (serve type, serve formation, return type, and playing level) variables to be used.

RESULTS

As rallies increased in length the advantage for the serving pair diminished significantly for both Nationally (N) and Regionally (R) ranked players to the point where rallies of five or more shots (about two thirds of rallies) were equally likely to be won by either pair (**Table 2**). Thus, the serving pair only won more rallies of length 1 or 2 shots (large effect size) and 3 or 4 shots (medium effect size).

Return of serves were either hit flat (70.6%) or lobbed high toward the back of the court (29.4%). Flat shots were predominately directed at the server (71.9%) whereas lobs could be directed at either server (48.8%) or serve partner (51.2%). Flat shots, aimed at the serve partner, did not require this player to move very much to hit a shot, as already positioned at net for service, these returns were therefore excluded from the analysis.

26.8% of N level player's ROS (cluster 5; **Table 3**) consisted of flat shots played against a first serve in a conventional formation (not Australian) compared to 29.5% of R player's ROS (cluster 2; **Table 3**). The higher playing standard players tended to allow the server less time to play the shot (N mean = 0.86 s SD = 0.19 s; R mean = 0.98 s SD = 0.29 s) which occurred closer to the net (N mean = 3.84 m SD = 0.91 m; R mean = 4.46 m SD = 0.91 m) as the player's average speed of movement was

TABLE 2 | Percentage of rallies won per match by serving pair in rallies of different numbers of shots (proportion of total rallies).

Playing standard	Rallies of 1 or 2 shots	Rallies of 3 or 4 shots	Rallies of 5 or 6 shots	Rallies of 7 or 8 shots	Rallies of 9+ shots	Friedman test χ^2_5
National	97.9 ± 4.2*ES 0.96 (2.6%)	64.5 ± 5.0*ES 0.30 (11.5%)	63.7 ± 12.1*ES 0.27 (14.9%)	56.7 ± 14.7*ES 0.12 (12.8%)	41.6 ± 9.6ES 0.16 (58.2%)	16.2, $p < 0.001$
Regional	94.9 ± 10.2*ES 0.92 (2.3%)	65.8 ± 14.4*ES 0.36 (9.4%)	56.8 ± 11.7*ES 0.11 (10.2%)	51.6 ± 19.2 ES 0.09 (11.5%)	46.8 ± 9.3 ES 0.06 (66.7%)	20.2, $p < 0.001$

*Key: *Wilcoxon Signed Ranks test revealed serving pair won more rallies than receivers. ES, Effect size.*

TABLE 3 | Frequency of different rally characteristics and summary statistics of parameters related to the server hitting the third shot in each cluster for a flat return of serve (ROS).

Cluster	Serve		Playing standard		Service formation		Rally length			Time (between ROS and third shot)		Distance covered by server (between ROS and third shot)		Distance of server from net (at third shot)		Average velocity of server (between ROS and third shot)	
	1st	2nd	National	Regional	Australian	Conventional	Short (lost)	Short (won)	Long	Mean (s)	SD (s)	Mean (m)	SD (m)	Mean (m)	SD (m)	Mean (m/s)	SD (m/s)
1	0	178	95	83	94	84	17	27	134	0.90	0.24	1.64	0.55	4.13	0.87	1.88	0.53
	0.0%	90.8%	18.3%	16.6%	19.3%	15.7%	12.1%	14.5%	19.3%								
2	148	0	0	148	0	148	0	0	148	0.98	0.29	1.62	0.64	4.46	0.91	1.68	0.56
	18.0%	0.0%	0.0%	29.5%	0.0%	27.7%	0.0%	0.0%	21.4%								
3	257	0	135	122	122	135	114	143	0	0.92	0.25	1.67	0.56	4.12	0.88	1.89	0.53
	31.2%	0.0%	26.0%	24.4%	25.1%	25.3%	80.9%	76.9%	0.0%								
4	131	0	0	131	131	0	0	0	131	0.99	0.30	1.78	0.68	4.45	0.84	1.85	0.61
	15.9%	0.0%	0.0%	26.1%	27.0%	0.0%	0.0%	0.0%	18.9%								
5	139	0	139	0	0	139	0	0	139	0.86	0.19	1.65	0.49	3.84	0.91	1.98	0.47
	16.9%	0.0%	26.8%	0.0%	0.0%	26.0%	0.0%	0.0%	20.1%								
6	122	0	122	0	122	0	0	0	122	0.88	0.23	1.73	0.42	3.86	0.82	2.03	0.47
	14.8%	0.0%	23.5%	0.0%	25.1%	0.0%	0.0%	0.0%	17.6%								

Key: Percentages calculated for columns but do not add to 100% because outliers were not included.

higher (*N* mean = 1.98 m/s *SD* = 0.47 m/s; *R* mean = 1.68 m/s *SD* = 0.56 m/s; **Table 3**). All of these rallies lasted more than five shots.

Similarly, when N level players played a flat return of serve against an Australian formation first serve (23.5% of shots, cluster 6; Regional 26.1% of shots, cluster 4; **Table 3**) the N level players tended to allow the server less time to play the shot (*N* mean = 0.88 s *SD* = 0.23 s; *R* mean = 0.99 s *SD* = 0.30 s) which occurred closer to the net (*N* mean = 3.86 m *SD* = 0.82 m; *R* mean = 4.45 m *SD* = 0.84 m) as the player's average speed of movement was higher (*N* mean = 2.03 m/s *SD* = 0.47 m/s; *R* mean = 1.85 m/s *SD* = 0.61 m/s). All of these rallies lasted more than five shots.

The spatial variables associated with the flat ROS off a 2nd serve (Cluster 1; **Table 3**) exhibited similar values to those for a flat ROS off 1st serves, with the exception of 9.2% of shots deemed outliers, and hence were not differentiated for any individual situation. Finally, cluster 3 (ROS off 1st serve) occurred only in rallies that ended within four shots, although either pair could have won the rally (**Table 3**) and none of the four spatial variables were unusual.

When National players played lob ROS they usually achieved similar outcomes, irrespective of which opponent they played the shot to, or whether returning a first [opponent distance to net (mean = 5.43 m *SD* = 1.67 m) for the 66.5% of shots in cluster 1; **Table 4**] or second serve [opponent distance to net (mean = 5.57 m *SD* = 1.07 m) for the 14.4% of shots in cluster 2; **Table 4**]. These returns resulted in long rallies 48.8% [63/(44+22+63), cluster 1, **Table 4**] and 61.8% [63/(22+17+63), cluster 2, **Table 4**], respectively.

The rest of the lob returns (16.5% cluster 5; **Table 4**), and occurred in all situations, resulted in the opponent hitting the ball moving greater distances (mean = 5.82 m *SD* = 0.86 m) to positions further from the net (mean = 8.61 m *SD* = 0.37 m) and over a great time (mean = 3.03 s *SD* = 0.28 s) than the other lob returns and 79.80% [79/(3+17+79)] of the time resulted in long rallies.

Regional player's lob returns also achieved clusters 2 (17.1%) and 5 (15.5%; **Table 4**). Regional player's lob shots achieved slightly different results when played to the server (distance to net: mean = 5.96 m *SD* = 0.92 m and distance opponent moved: mean = 2.42 m *SD* = 0.83 m) compared to the serve partner (distance to net: mean = 5.46 m *SD* = 1.05 m and distance opponent moved: mean = 2.67 m *SD* = 0.90 m) when returning first serves that resulted in long rallies. However, 29.1% of Regional player's lob ROS off first serves (cluster 3) always resulted in short rallies {winning 34.9% [43/(83+43)] of them} where the opponent's distance to the net (mean = 5.03 m *SD* = 1.56 m) and distance covered (mean = 2.34 m *SD* = 1.03 m) tended to be lower than any other cluster.

DISCUSSION

The serving pair for Padel players were found to have a significant advantage in rallies, which lasted until shot 8 for National and shot 6 for Regional level players. However, effect sizes clarified

TABLE 4 | Frequency of different rally characteristics and summary statistics of parameters related to either opponent hitting the third shot in each cluster for lob return of serves (ROS).

Cluster	Serve		Playing standard		Player ROS aimed toward		Rally length			Time (between ROS and third shot)		Distance covered by opponent hitting third shot (between ROS and third shot)		Distance of by opponent hitting third shot from net (at third shot)	
	1st	2nd	National	Regional	Server	Serve partner	Short (lost)	Short (won)	Long	Mean (s)	SD (s)	Mean (m)	SD (m)	Mean (m)	SD (m)
1	129	0	129	0	62	67	44	22	63	1.65	0.48	2.68	1.19	5.43	1.67
	26.0%	0.0%	66.5%	0.0%	21.1%	20.1%	28.8%	21.4%	17.0%						
2	0	102	28	74	43	59	22	17	63	1.65	0.23	2.43	0.79	5.57	1.04
	0.0%	78.5%	14.4%	17.1%	14.6%	17.7%	14.4%	16.5%	17.0%						
3	126	0	0	126	55	71	83	43	0	1.64	0.42	2.34	1.03	5.03	1.56
	25.4%	0.0%	0.0%	29.1%	18.7%	21.3%	54.2%	41.7%	0.0%						
4	80	0	0	80	0	80	0	0	80	1.69	0.23	2.67	0.90	5.46	1.05
	16.1%	0.0%	0.0%	18.5%	0.0%	24.0%	0.0%	0.0%	21.6%						
5	74	25	32	67	47	52	3	17	79	3.03	0.28	5.82	0.86	8.61	0.37
	14.9%	19.2%	16.5%	15.5%	16.0%	15.6%	2.0%	16.5%	21.3%						
6	86	0	0	86	86	0	0	0	86	1.72	0.26	2.42	0.83	5.96	0.92
	17.3%	0.0%	0.0%	19.9%	29.3%	0.0%	0.0%	0.0%	23.2%						

Key: Percentages calculated for columns but do not add to 100% because outliers were not included.

that this advantage diminished once the rallies lasted over four shots although National level players appeared to maintain an advantage closer to a medium effect (0.27) for rallies of five or six shots. This suggests that the serve advantage is greater for better players due to them being more able to play winners, or force errors from their opponents, from an advantage situation. This finding probably reflects the nature of Padel in that it is much harder to play a winner, due to the court dimensions and structure, meaning that when a pair is dominating a rally, as for the start of the rally when serving, it often takes more shots to finish the rally compared to tennis. Hence, the defending pair is more likely to be able to stay in the rally, i.e., the defending team is able to return more shots, shown to be determined by level of skill in this study, and therefore also more likely to return the rally to a more equal situation than evident in tennis. This would suggest that rallies are longer in Padel than tennis, backed up by previous studies which found the average rally to be 15 s for professional Padel players (Almonacid, 2012). The service in tennis has been shown to be advantageous in many studies (e.g., Kovalchik and Reid, 2018). Tennis serves tend to increase the probability of winning the rally, but the extent of this advantage is determined by court surface (O'Donoghue and Ingram, 2001) and length of rally, with the effect of the serve seemingly having dissipated by the third or fourth shot (O'Donoghue and Brown, 2008). In tennis, the advantage is based on speed of serve, direction and court size. Padel, uses different equipment and playing area, is therefore likely to exhibit differences in terms of serve advantage, as well as for other factors.

In the ROS players hit about 70% flat and 30% lob shots potentially reflecting the need for the server to run toward the net and hence leave enough space at the net to make the flat ROS more advantageous. The fact that over 70% of flat ROS was directed at the server supports this view. Courel-Ibáñez et al. (2015) showed how important playing at the net was to winning rallies in Padel. In tennis, Gillet et al. (2009) found a relationship between the effectiveness of the ROS and the direction of the serve. This study did not consider serve direction, which may have impacted on the ROS decision. Torres-Luque et al. (2015) found that about 75% of serves were directed to the backhand and this should therefore be included in future studies.

However, two thirds of flat ROS resulted in long rallies (8 or more shots) with National level players achieving this on 65.9% of their flat ROS against first serves. Comparing National and Regional players on flat ROS, the time, distance and speed parameters showed that National players hit the ball harder than Regional ones. Previously, Courel-Ibáñez et al. (2015) suggested that the best players should be aggressive when returning and adopt a defensive style when serving. Similarly, Vernon et al. (2018) differentiated "aggressive" and "neutral" ROS in tennis. However, in response to the ROS, National players approached the net faster than Regional players and were thus able to hit the ball nearer the net, and hence being in a strategically advantageous position (Courel-Ibáñez et al., 2015). This was accomplished in both conventional and Australian formations even though the task demands for the server were different, player had to move quicker due to further distance, as suggested by Ramón-Llin et al. (2013).

When using a lob ROS, players did not favor hitting to one player over the other, corroborating the findings of Almonacid (2012) who found that professional Padel players hit equally to the deuce and advantage sides. The key objective for the lob was obviously depth, as short lobs present an easy opportunity for a powerful smash or tray. National players' lob ROS tended to either achieve good (around 5.5 m beyond the net) or excellent (around 8.5 m) depth. Decisively, these lob ROS achieved long rallies 48.8% of the time for good depth off first serves, 61.8% of the time for good depth off second serves and 79.8% of the time for excellent depth irrespective of serve. For Regional players, however, if their lob ROS achieved a depth of about 5.5 m or more they always achieved long rallies whereas if they only achieved 5.0 m depth the rallies were always short. It would seem, therefore, that Regional players were still playing fairly weak lob ROS on occasion, something very unusual at National level. Another perspective related to the lob ROS is to consider it as an attacking shot. Indeed, Muñoz et al. (2017) presented how the best way to move from defense to attack was to gain the net using the lob. Taking these into consideration it seems clear that National level players were more able to consistently negate the offensive nature of the serve using accurate lobs whereas Regional players were less successful due to the presence (29.1%) of lobs that lacked sufficient depth.

Whilst this study assessed detailed parameters associated with the outcome of the ROS some parameters associated with the serve were not included in the analyses. The time between serve and ROS and the direction of the serve were not included even though Vial et al. (2019) reported that speed and trajectory impacted on the difficulty of the ROS. However, the serve in Padel has been shown in this paper to exert different pressure on the opponents than in tennis. Whilst it is common to assume a significant difference between first and second serves (consistently shown in tennis, e.g., O'Donoghue and Brown, 2008) cluster analysis did not indicate significant differences for the distance, time and speed parameters associated with a flat ROS in Padel. This may be due to the relative ease of playing a good service in Padel but the difficulty in playing a very good one. Since the rules dictate an underhand service it would seem that hitting unreturnable serves are very unlikely and even forcing very weak ROS unlikely, less than 15% of National rallies ended before five shots had been played. However, future studies should consider other variables in relation to the serve and ROS including the time between the two and some consideration should be given to classifying attacking and defending positions since this distinction appears important for determining shot selections. It would be reasonable to analyze these parameters during and between all shots and hence using more in-depth quantitative analysis to determine serve and ROS impact on rally outcome. Finally, since playing standard has a clear impact on performance, future studies need to sample the best players with respect to the parameters studies here.

PRACTICAL APPLICATIONS

The findings of this study suggest that coaches should consider teaching return of serve shots from a tactical perspective. Given that in short rallies, up to around 6 to 8 shots depending on skill level, the server has a significant advantage, the aim of the ROS is to prevent the serving pair winning the rally quickly. This is best achieved by good depth on lobs, regardless of the direction, and pace on low shots, predominately aimed toward the server.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

ETHICS STATEMENT

This study was approved by the Ethics Committee of University of Valencia (protocol H1494417717437).

AUTHOR CONTRIBUTIONS

JR-L, RM-G, JG, and SL undertook data acquisition and processing. JR-L, NJ, and GV designed the study, conducted the analysis, interpreted the data, and wrote the manuscript. All authors read and approved the final manuscript.

REFERENCES

Almonacid, B. (2012). *Perfil De Juego En El Pádel De Alto Nivel*. Doctoral thesis, University of Jaén, Spain.

Castillo-Rodríguez, A., Alvero-Cruz, J., Hernández-Mendo, A., and Fernández-García, J. (2014). Physical and physiological responses in paddle tennis competition. *Int. J. Perform. Anal. Sport* 14, 524–544.

Courel-Ibáñez, J., Sánchez-Alcaraz, B. J., and Cañas, J. (2014). "Performance differences between winning and losing padel players regarding serve situation," in *Proceedings of the VIII International Congress of Sport Sciences*, Granada.

Courel-Ibáñez, J., Sánchez-Alcaraz, B. J., and Cañas, J. (2015). Effectiveness at the net as a predictor of the final match outcome in professional padel players. *Int. J. Perform. Anal. Sport* 15, 632–640.

Courel-Ibáñez, J., Sánchez-Alcaraz Martínez, B. J., and Muñoz, M. (2017). Exploring game dynamics in pádel. implications for assessment and training. *J. Strength Cond. Res.* doi: 10.1519/JSC.0000000000002126 [Epub ahead of print].

Fitzpatrick, A., Stone, J. A., Choppin, S., and Kelley, J. (2019). A simple new method for identifying performance characteristics associated with success in elite tennis. *Int. J. Sports Sci. Coach.* 14, 43–50.

Furlong, J. D. G. (1995). "The service in lawn tennis: how important is it?," in *Science and Racket Sports I*, eds T. Reilly, M. Hughes, and A. Lees (London: E & FN Spon), 266–271.

Gillet, E., Leroy, D., Thouvarecq, R., and Stein, J. F. (2009). A notational analysis of elite tennis serve and serve-return strategies on slow surface. *J. Strength Cond. Res.* 23, 532–539. doi: 10.1519/JSC.0b013e31818efe29

Gómez, M. A., García-de-Alcaráza, A., and Furley, F. (2017). Analysis of contextual-related variables on serve and receiving performances in elite men's and women's table tennis players. *Int. J. Perform. Anal.* 17, 919–933.

Hair, J. F., Anderson, R. E., Tatham, R. L., and Black, W. C. (1995). *Multivariate Data Analysis With Readings*, 4th Edn. Englewood Cliffs, NJ: Prentice-Hall.

James, N., Taylor, J., and Stanley, S. (2007). Reliability procedures for categorical data in performance analysis. *Int. J. Perform. Anal. Sport* 7, 1–11.

Kovalchik, S., and Reid, M. (2018). A.shot taxonomy in the era of tracking data in professional tennis. *J. Sports Sci.* 36, 2096–2104. doi: 10.1080/02640414.2018.1438094

Martin, C., Bideau, B., Touzard, P., and Kulpa, R. (2019). Identification of serve pacing strategies during five-set tennis matches. *Int. J. Sports Sci. Coach.* 14, 32–42.

Martinez-Gallego, R., Guzman, J. F., James, N., Perš, J., Ramon-Llin, J., and Vučković, G. (2013). Movement characteristics of elite tennis players on hard courts with respect to the direction of ground strokes. *J. Sports Sci. Med.* 12, 275–281.

Muñoz, D., Courel-Ibáñez, J., Sánchez-Alcaraz, B. J., Díaz, J., Julián, A., and Muñoz, J. (2017). Diferencias en las acciones de subida a la red en pádel entre jugadores profesionales y avanzados. *J. Sport Health Res.* 9, 223–232.

O'Donoghue, G. P., and Brown, E. (2008). The importance of service in grand slam singles tennis. *Int. J. Perform. Anal. Sport* 8, 70–78.

O'Donoghue, P., and Ingram, B. (2001). A notational analysis of elite tennis strategy. *J. Sports Sci.* 19, 107–115.

O'Donoghue, P. G. (2001). The most important points in grand slam singles tennis. *Res. Q. Exerc. Sport* 72, 125–131.

Perš, J., Kristan, M., Perše, M., and Kovačič, S. (2008). "Analysis of player motion in sport matches," in *Computer Science in Sport - Mission and Methods*, eds A. Baca, M. Lames, K. Lyons, B. Nebel, and J. Wiemeyer (Wadern: Schloss Dagstuhl - Leibniz-Zentrum fuer Informatik).

Ramón-Llin, J., Guzmán, J., Llana, S., Vučković, G., and James, N. (2013). Comparison of distance covered in paddle in the serve team according to performance level. *J. Hum. Sport Exerc.* 8, 738–742.

Ramón-Llin, J., Guzmán, J., Llana, S., Vučković, G., and James, N. (2017). Analysis of padel rally characteristics for three competitive levels. *Kinesiol. Sloven.* 23, 39–49.

Ramón-Llin, J., Guzmán, J. F., Martínez-Gallego, R., Vučković, G., and James, N. (2014). "Time motion analysis in two matches of the 2011Pro Tour," in *Performance Analysis of Sport IX*, eds D. M. Peters and P. G. O'Donoghue (London: Routledge), 295–300.

Reid, M., Morgan, S., and Whiteside, D. (2016). Matchplay characteristics of grand slam tennis: implications for training and conditioning. *J. Sports Sci.* 34, 1791–1798. doi: 10.1080/02640414.2016.1139161

Rosenthal, R. (1991). *Meta-Analytic Procedures for Social Research*, 2nd Edn. Newbury park, CA: Sage.

Torres-Luque, G., Ramirez, A., Cabello-Manrique, D., Nikolaidis, P. T., and Alvero-Cruz, J. R. (2015). Match analysis of elite players during paddle tennis competition. *Int. J. Perform. Anal. Sport* 15, 1135–1144.

Vernon, G., Farrow, D., and Reid, M. (2018). Returning serve in tennis: a qualitative examination of the interaction of anticipatory information sources used by professional tennis players. *Front. Psychol.* 9:895. doi: 10.3389/fpsyg.2018.00895/full

Vial, S., Cochrane, J., Blazevich, A. J., and Croft, J. L. (2019). Using the trajectory of the shuttlecock as a measure of performance accuracy in the badminton short serve. *Int. J. Sports Sci. Coach.* 14, 91–96.

Vučković, G., Perš, J., James, N., and Hughes, M. (2008). "Automated tracking system assessments of player distances from the T at the moment the ball is hit for winners and losers of games in elite squash," in *Proceedings of the World Congress of Performance Analysis of Sport VIII*, (Magdeburg: Otto-von-Guericke-Universität), 339–344.

Vučković, G., Perš, J., James, N., and Hughes, M. (2009). Tactical use of the T area in Squash by players of differing standard. *J. Sports Sci.* 27, 863–871. doi: 10.1080/02640410902926412

Vučković, G., Perš, J., James, N., and Hughes, M. (2010). Measurement error associated with the Sagit/squash computer tracking software. *Eur. J. Sports Sci.* 10, 129–140.

Zhang, H., Liu, W., Hu, J., and Liu, R. (2013). Evaluation of elite table tennis players' technique effectiveness. *J. Sports Sci.* 31, 1526–1534. doi: 10.1080/02640414.2013.792948

Zhang, H., and Zhou, Z. (2017). An analytical model of the two basic situation strategies in table tennis. *Int. J. Perform. Anal. Sport* 17, 970–985.

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Multifactorial Benchmarking of Longitudinal Player Performance in the Australian Football League

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This study aimed to develop a model to objectively benchmark professional Australian Rules football (AF) player performance based on age, experience, positional role and both draft type and round in the Australian Football League (AFL). The secondary aims were to identify the stage of peak performance and specific breakpoints in AF player performance longitudinally. AFL Player Ratings data were obtained for all players (n = 1052) from the 1034 matches played during the 2013–2017 seasons, along with data pertaining to the abovementioned player characteristics. Two separate linear mixed models revealed that all factors influenced player performance, with age and experience the strongest in each model, respectively. *Post hoc* Tukey tests indicated that performance was affected by age at each level up until the age of 21 (effect ranging from 0.98 to 3.70 rating points), and by experience at the levels 1–20 and 21–40 matches in comparison to all higher levels of experience (effect ranging from 1.01 to 3.77 rating points). Two segmented models indicated that a point of marginal gains exists within longitudinal performance progression between the age levels 22 and 23, and the experience levels 41–60 and 61–80 matches. Professional sporting organisations may apply the methods provided here to support decisions regarding player recruitment and development.

Keywords: decision support, performance analysis, data visualisation, player evaluation, team sport

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INTRODUCTION

Identifying when peak performance typically occurs in athletes is an important consideration within professional team sport organisations. Specifically, at what point in an athletes career are they likely to reach their peak. Such information can be used to inform contracting as well as the make-up of team rosters. The identification of peak performance can be measured longitudinally on various time series including the age of an athlete, amount of years within a professional program and their match's experience (Torgler and Schmidt, 2007). Additionally, various type of peaks have been investigated within the notational team sport literature, including when an athlete is at their physiological peak (Reilly et al., 2000), when they reach their peak market value (Kalén et al., 2019), as well as when their on-field performance is at its peak (Fair, 2008; Bradbury, 2009; Dendir, 2016). Although peak performance has been well documented longitudinally for age in individual sporting events (Schulz and Curnow, 1988; Allen and Hopkins, 2015; Longo et al., 2016), its identification within team sports may be more complex. This complexity primarily arises due to the difficulty objectively outlining individual performances given that there are no quantifiable outcomes which occur directly from player actions in most team sports (Travassos et al., 2013; Robertson et al., 2015). Additionally, there is an increased importance of specific skill demands required in team based sports, including non-physical abilities such as experience and strategic knowledge (Bradbury, 2009), as well as the complexity of accounting for differences individual playing roles.

Despite this, individualised assessment of match performance in professional team sports is commonplace. This includes both subjective assessments of performance, as made by team coaches, management and within the media, as well as objective assessments made through data-driven techniques (Carling et al., 2008; Bonney et al., 2019). Although subjective assessments are often made by those in influential decision making positions (i.e., coaches), there has been a change within professional sport organisations toward supporting decisions with objective assessments (Maymin, 2017). Concurrently, there has been an increasing amount of data-driven techniques proposed in literature regarding assessing individual player performance in team sport on a quantitative scale. Some examples include Radovanović et al. (2013) who developed a player efficiency rating, which objectively measures a player's productivity in basketball based on player actions such as points, assists, rebounds, steals and turnovers, and their outcomes. Similarly, McHale et al. (2012) developed a player performance index to rate the performance of players in the top two leagues of English soccer on a quantitative scale including items such as match contributions, winning performance, match appearances, goals scored, assists, and clean sheets.

Australian Rules football (AF) is a dynamic invasion team sport played between two opposing teams consisting of 22 players each (18 on the field and four interchange). In the elite competition of AF, the Australian Football League (AFL), players can be drafted to a professional club and begin playing as early as the age of 18, with various players managing to continue playing into their middle-to-late thirties. There has been a substantial amount of research developed in AF to identify the physical and technical characteristics of individual players with respect to match performance (Young et al., 2005; Veale et al., 2008; Mooney et al., 2011; Tangalos et al., 2015; Woods et al., 2016). However, to our knowledge there has been no research examining longitudinal player performance in professional AF. However, various studies exist in the wider notational sport literature which investigate longitudinal player performance, predominantly on identifying the age at which peak performance occurs. Examples include Dendir (2016), who used mixed effects models, and identified that the peak age of performance in the top four professional soccer leagues varied between 25 and 27, depending on position. Kalén et al. (2019) similarly looked to identify the peak age of performance in professional soccer. Using a one-way ANOVA and linear regression they found that a significant longitudinal shift in peak age has occurred from 24.9 years in 1992–1993 to 26.5 years in 2007–2018. Using a random effects model Bradbury (2009) investigated peak performance of skills in baseball, finding that overall performance peaks around the age of 29. Specifically, athletic skills such as hitting and running peak earlier, whilst skills based on experience and knowledge such as drawing walks, peak later. Fair (2008) also examined the estimated age effects in baseball. Using a non-linear fixed effects regression, they found that the peak age and begin of decline in performance occurred around the age of 26 years for pitchers, and 28 years for batters.

In the abovementioned studies, both Dendir (2016) and Fair (2008) emphasise that considerations or assumptions must be made about other factors when assessing longitudinal player performance. Notably, a player's position and their level of experience. In addition to these factors, another consideration is the position at which players are selected in their respective draft. Studies such as O'Shaughnessy (2010) have looked to develop a valuation system for the AFL National Draft, indicating that earlier selections are valued more highly on the basis that clubs can select the best available player in the pool.

In addition to identifying peak player performance, longitudinal research has also looked to identify whether specific changes in trends occur within a time series. Within sport performance, this research has consisted of identifying longitudinal changes in trends of physical performance (Fransen et al., 2017; Towlson et al., 2018), game related statistics (Lorenzo et al., 2019), and gameplay (Wolfson et al., 2015; Woods et al., 2017), as well as whether external factors such as a player's contract status effect performance (Gómez et al., 2019). Though this type of model has not been applied to player performance in team sports, the use of this procedure would allow for the construction of a model to identify whether a breakpoint in longitudinal player performance exists.

The ability to benchmark player performance longitudinally is inherently valuable to many sports, and could be used to support organisational decisions regarding player contracting, recruitment and development (Kalén et al., 2019). In the AFL, there is a large emphasis on decisions relating to player contracting and recruitment as clubs are confined in their ability to remunerate players by a salary cap. Decisions relating to player development are also vital, as clubs do not have the opportunity to attain additional players within season. As such, the ability to inform these decisions based on comparisons of player performance against model-expected performance, or the ability to forecast future performance is advantageous. Further, a greater understanding of when performance progression is at its maximum, or conversely when progression is expected to deteriorate, could have important implications for the type of skill development implemented for specific individuals.

There are various player performance measures which are produced commercially within the AFL. The "AFL Player Rankings" is produced by statistics provider Champion Data Pty Ltd., measures player performance by awarding players a fixed value for specific performance actions. The values for these actions were determined relative to their observed relationship to team winning margin (Herald Sun, 2016). Alternatively, the "AFL Player Ratings", which is also produced by statistics provider Champion Data Pty Ltd., measures player performance based on the principle of field equity. In this metric, points are awarded to (or deducted from) a player based on contextual information relating to each possession, relative to how much their actions increase or decrease their team's expected value of scoring next (Jackson, 2009; McIntosh et al., 2018).

The primary aim of this study was to develop a model to objectively benchmark AFL player performance whilst considering their age, experience, positional role and both draft type and round in which they were selected. The secondary aims were to identify the stage of peak performance and specific breakpoints in player performance longitudinally. To achieve these, this study will consider the player characteristics and model types outlined in the abovementioned literature.

MATERIALS AND METHODS

Data

The AFL Player Ratings were utilised as the objective measure of player performance in this study due to its validity and its equity-based nature (Jackson, 2009; McIntosh et al., 2018). In this metric, a player's overall match performance is measured by the overall change in equity that is created by that player's actions during the course of a match (Jackson, 2009). The change in equity is determined by expected value of their team scoring next. These expected values are based on contextual information relating to possessions (i.e., field position, pressure from opponents, possession outcome) collected from all AFL matches preceding back to the 2004 season (Jackson, 2009).

These AFL Player Ratings were obtained from Champion Data Pty Ltd. for all 1034 matches played throughout the 2013–2017 AFL seasons. This included 22 matches played by each team during the regular season rounds, as well as a total of nine matches played throughout the finals series each season. One match was abandoned prior to play during the 2015 season. The AFL Player Ratings data were expressed as a mean season rating for each player across each of the five seasons. The sample included a mean of 3.15 seasons per player (±1.55 SD) among 1052 unique players, giving a total sample size of n = 3317.

Data pertaining to player characteristics were also collected in order to assess their relationship with performance. Age (determined by the players age at 31st December of the previous year), experience (determined by the number of AFL matches played, independent of seasons, and taken at the conclusion of each season), positional role classification (determined by Champion Data's classification at the conclusion of each season; classifications outlined in **Appendix Table A1**) and the characteristics of the draft (draft types outlined in **Appendix Table A2**) in which each player was first selected by an AFL club were all collected as descriptive variables. Prior to data collection, the study was approved by the relevant human research ethics committee.

Data Analysis

For modelling purposes, various aspects of the data required transformation. All characteristics were considered as categorical variables. Categorisation levels for age and experience were determined by evaluating the change in Akaike's Information Criterion for differing amounts of categories (Akaike, 1987). Sixteen categories for both characteristics were chosen by identifying the minimum number of categories at which the point gains in Akaike's Information Criterion became minimal (<10). This allowed for discretisation that balanced model fit and complexity (Bozdogan, 1987). Age was expressed as integer categories (18, 19, 20, . . ., 33+), where due to the limited sample size of players aged 33–40 years, data were combined into one category. Experience was expressed in intervals of 20 matches (1–20, 21–40, 41–60, . . ., 301+), where all players with 301 or more matches experience were similarly combined into one category due to the limited sample size. Categorisation levels for draft selection were arbitrarily expressed over ten levels relative to the type and round in which they were first selected by an AFL club (five levels for National Draft rounds 1 to 5+, four levels for Rookie Draft rounds 1 to 4+, and one category for the Preseason Draft). Due to the limited sample size of players drafted after round five of the national draft, after round four of the rookie draft, and in total from the preseason draft, data were combined into one category for each draft type. Positional role classification was expressed across the seven levels as determined by Champion Data (general defender, key defender, general forward, key forward, midfielder, midfield-forward, and ruck).

Further, as part of the entry concessions given to newly established clubs, the Gold Coast Suns and the Greater Western Sydney Giants, 45 players from the dataset were drafted to AFL clubs prior to the 2011, 2012, and 2013 AFL seasons via non-traditional draft methods. Considering the circumstances of these concessions, all players drafted via methods of zone selection, as an underage recruit, through the AFL mini-draft, as an AFL initiative or were pre-listed by an AFL club (n = 42), were considered as first round selections within the national draft. Further, those drafted after being overlooked in the prior year's national draft (n = 3) were considered as first round selections within the rookie draft.

Statistical Analysis

Descriptive statistics for age and experience, and how they relate to AFL Player Ratings [mean ± 95% confidence intervals (CI)] were obtained. The number of matches played per season and proportion of players were also collected and plotted across age and experience. Prior to undertaking the main analyses, Spearman's correlation analyses were employed to determine the extent of collinearity between each of the four player characteristics. This analysis was undertaken using the *Hmisc* package (Harrell, 2017) in the R statistical computing software version 3.3.2. (R Core Team, 2016). This analysis revealed a strong association between age and experience (r = 0.83), whilst all remaining associations were weak (r < 0.15). As a result, separate models were created throughout the further analyses, utilising age and experience as the independent variables in each.

To determine the extent to which these characteristics affect performance, linear mixed models were applied using the *lme4* package (Bates et al., 2015). Two separate models were created, each incorporating either age or experience, with all other factors included in both. This particular approach was used to control the variability created by the repeated measures data on each player. Specifically, the factors of interest (age, experience, positional

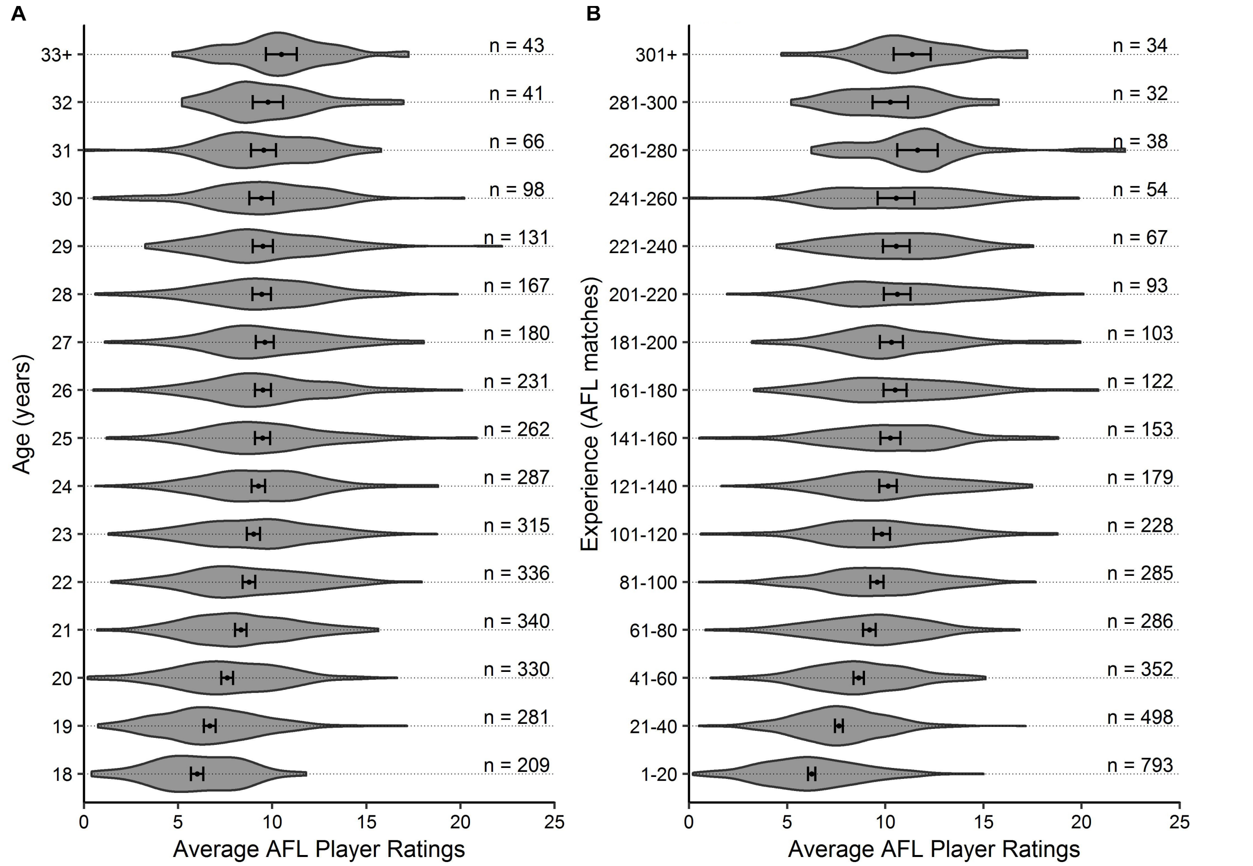

FIGURE 1 | Violin plot outlining the density of the average AFL Player Ratings (±95% CI) for **(A)** age and **(B)** experience, respectively. The number of observations in each group are outlined.

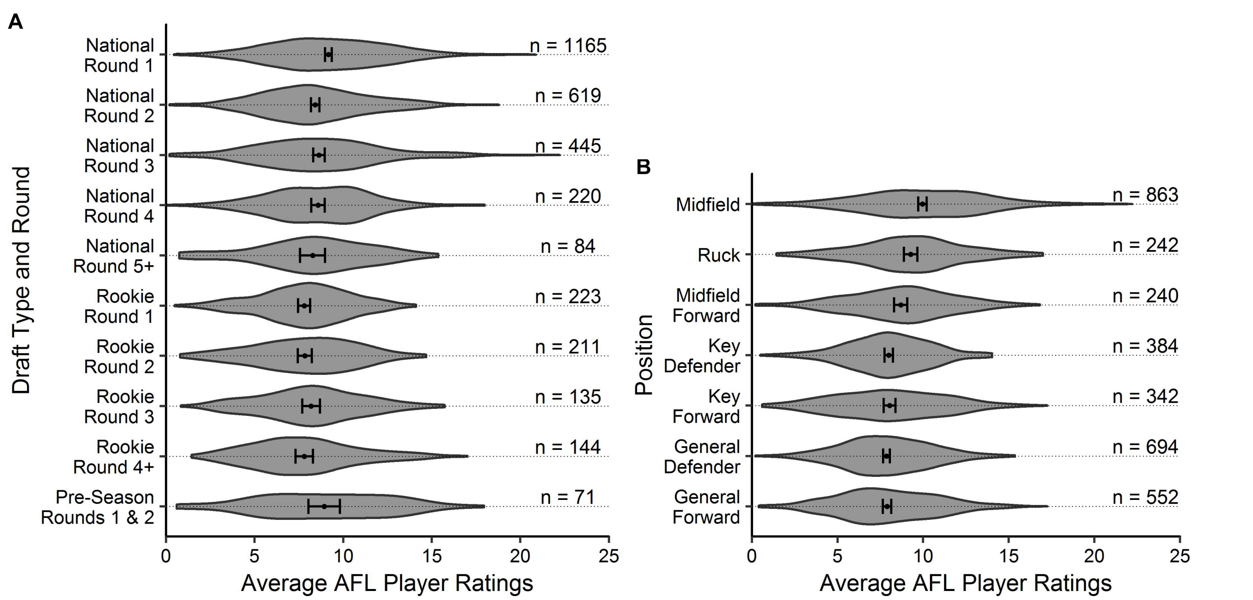

FIGURE 2 | Violin plot outlining the density of the average AFL Player Ratings (±95% CI) for **(A)** draft and **(B)** positional role, respectively. The number of observations in each group are outlined.

role, and draft selection) were treated as fixed effects, and player as a random effect in both models. Each model took the form of:

$$PR_{ps} = \beta_0 + \beta_1 X_{ps} + \beta_2 Y_{ps} + \beta_3 Z_p + \propto_p + \varepsilon_{ps}$$

where PR_{ps} is the AFL Player Rating average of player p in season s (s = 2013–2017). β_0, β_1, β_2, and β_3 are fixed coefficients, and X, Y, and Z are observed covariates. In model (1), X_{ps} and Y_{ps} represent the player's age and positional role for the corresponding season, respectively, whilst Z_p represents the category outlining the player's draft selection, which stays consistent between seasons. The parameter $\propto_p$ is a player random effect, which makes the intercept of the model specific to each player and allows for individualised performance projections. The player random effect is treated as constant across seasons and each effect is a draw from a normal distribution with equal variance for all players. The parameter ε_{ps} denotes the player-season residual error. Model (2) takes the exact same form as model (1), however, X_{ps} instead represents a player's experience for the corresponding season.

Based on the fixed effects estimates, benchmark levels of performance were plotted ($\propto_p$ = 0) for age and experience, respectively, where means and 90% prediction intervals (PI) are averaged over the levels of positional role and draft for both. A *post hoc* Tukey test was performed to adjust for multiple comparisons, and to determine whether performance was different within each level of age and experience, and thus identifying a hypothesised breakpoint in performance. To further assess whether a breakpoint exists in each of the linear mixed models, a segmented model (or "piecewise linear model") was fit to the data to estimate if a change in the trend of the data occurs. This analysis was undertaken using the *segmented* package (Muggeo, 2008). As a result of the *post hoc* Tukey tests, we specified the levels 22 for age, and 41–60 for experience as the hypothesised break points. Within this analysis, these points are used as starting points for which the model uses to estimate

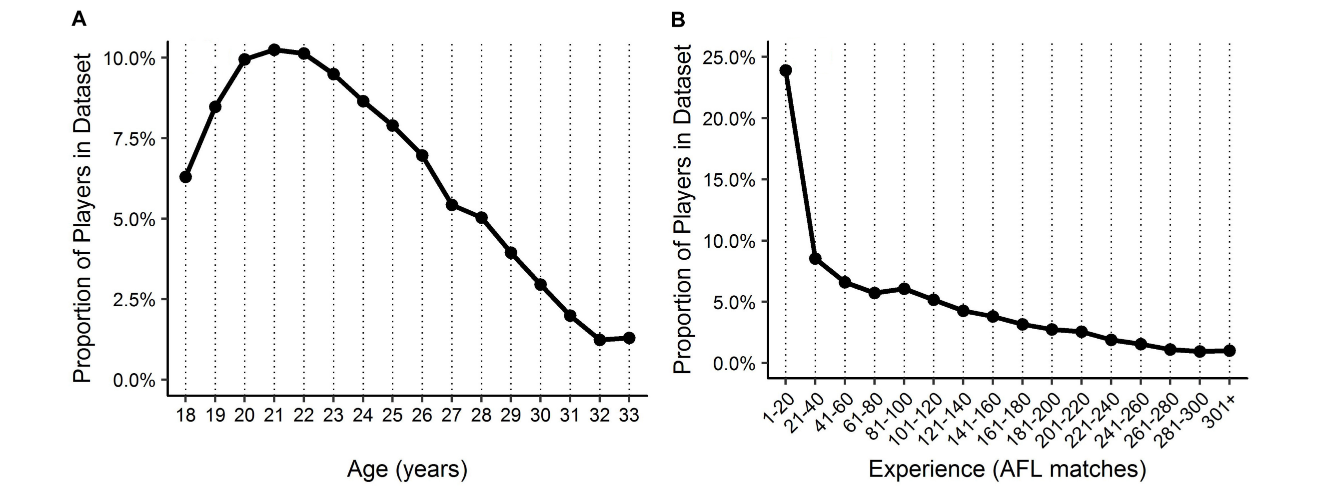

FIGURE 3 | Proportion of players in the dataset by **(A)** age and **(B)** experience.

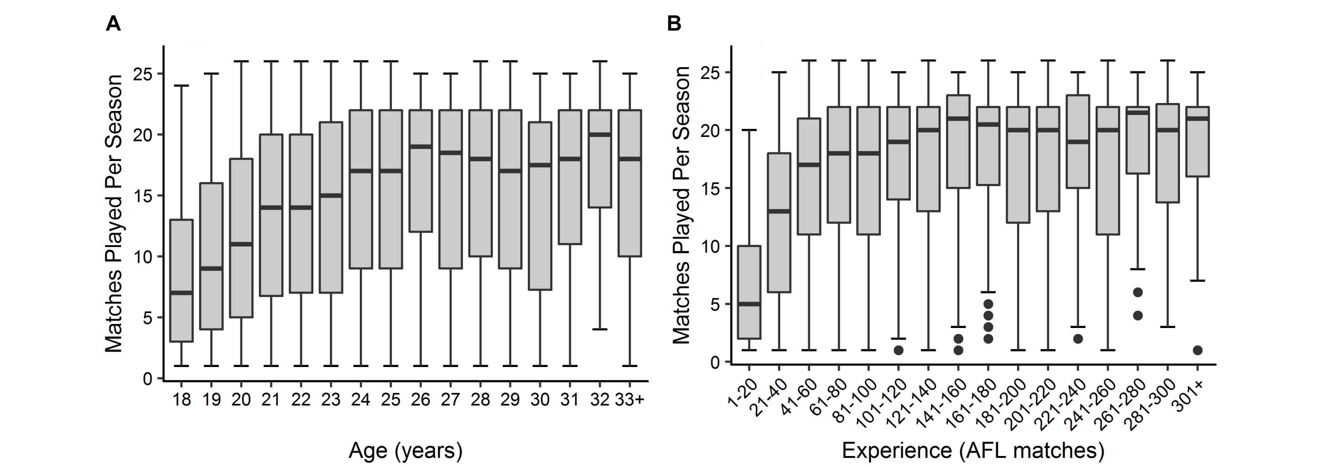

FIGURE 4 | Boxplot outlining the distribution of matches played per season by players in each level of **(A)** age and **(B)** experience.

TABLE 1 | Model (1) fixed effect regression coefficients outlining the estimated difference in rating points from the reference level of each factor.

	Regression coefficients (±SE)
(Intercept)	7.11 (0.23)
Age 19	0.98 (0.20)
Age 20	1.93 (0.21)
Age 21	2.62 (0.21)
Age 22	3.06 (0.22)
Age 23	3.32 (0.22)
Age 24	3.39 (0.23)
Age 25	3.69 (0.24)
Age 26	3.70 (0.25)
Age 27	3.68 (0.26)
Age 28	3.31 (0.27)
Age 29	3.18 (0.29)
Age 30	2.80 (0.32)
Age 31	2.48 (0.37)
Age 32	2.56 (0.44)
Age 33+	2.46 (0.47)
Positional role Gen Def	−1.25 (0.17)
Positional role Gen Fwd	−1.13 (0.17)
Positional role Key Def	−1.128 (0.23)
Positional role Key Fwd	−1.79 (0.23)
Positional role Mid Fwd	−0.79 (0.19)
Positional role Ruck	−0.38 (0.29)
Draft National 2	−0.78 (0.23)
Draft National 3	−0.74 (0.25)
Draft National 4	−0.94 (0.32)
Draft National 5+	−1.21 (0.47)
Draft Rookie 1	−1.47 (0.32)
Draft Rookie 2	−1.62 (0.33)
Draft Rookie 3	−1.56 (0.39)
Draft Rookie 4 +	−1.75 (0.38)
Draft Preseason	−1.03 (0.57)

Reference level for each factor were: age 18, positional role midfield, Draft National 1.

TABLE 2 | Model (2) fixed effect regression coefficients, outlining the estimated difference in rating points from the reference level of each factor.

	Regression coefficients (±SE)
(Intercept)	7.43 (0.18)
Experience 21–40	1.31 (0.14)
Experience 41–60	2.32 (0.16)
Experience 61–80	2.79 (0.18)
Experience 81–100	3.19 (0.18)
Experience 101–120	3.38 (0.20)
Experience 121–140	3.48 (0.22)
Experience 141–160	3.39 (0.23)
Experience 161–180	3.77 (0.25)
Experience 181–200	3.43 (0.27)
Experience 201–220	3.53 (0.29)
Experience 221–240	3.32 (0.33)
Experience 241–260	3.02 (0.36
Experience 261–280	3.74 (0.43)
Experience 281–300	2.46 (0.47)
Experience 301+	3.02 (0.52)
Position Gen Def	−1.17 (0.16)
Position Gen Fwd	−1.24 (0.16)
Position Key Def	−1.07 (0.21)
Position Key Fwd	−1.49 (0.22)
Position Mid Fwd	−0.74 (0.19)
Position Ruck	−0.12 (0.26)
Draft National 2	−0.54 (0.20)
Draft National 3	−0.30 (0.23)
Draft National 4	−0.27 (0.29)
Draft National 5+	−0.75 (0.42)
Draft Rookie 1	−0.89 (0.29)
Draft Rookie 2	−0.85 (0.30)
Draft Rookie 3	−0.46 (0.35)
Draft Rookie 4 +	−0.71 (0.34)
Draft Preseason	−0.49 (0.51)

Reference level for each factor were: experience 1–20, positional role midfield, Draft National 1.

breakpoints. A level of significance was accepted at $p < 0.01$ in all analyses.

RESULTS

Descriptive statistics are outlined in **Figures 1**, **2** for age and experience, and positional role and draft, respectively. **Figure 3A** highlights that the proportion of players competing in the AFL is at its highest at ages 20–22, and then declines with each consecutive age level thereafter. Further, **Figure 3B** highlights that the proportion of players is highest in the least experienced group (20 matches or less), and similarly declines with each consecutive category level of experience thereafter. On the contrary, **Figure 4** indicates that the average number of matches played per season increases with both age and experience.

Results of the linear mixed models revealed that all factors affected levels of performance in both models at $p < 0.01$. Model (1) produced a root mean square error of 1.77 and Chi-square values of 356.9 for age, 98.7 for positional role and 57.1 for draft. Comparatively, model (2) produced a root mean square error of 1.82 rating points and Chi-square values of 523.5 for experience, 100.4 for positional role and 21.7 for draft. The values indicate that age and experience had the largest influence on performance in each of the models, respectively, followed by positional role. **Tables 1**, **2** outline the fixed effect coefficients (β_0, β_1, β_2, and β_3) for each factor level of the characteristics in each of the respective models.

Results of the *post hoc* Tukey test indicated that performance was affected by age at various age levels up until the age of 21 (mean differences ranged from 0.98 to 3.70 player rating points). However, no two levels above the age of 21 were seen to exhibit different levels of performance. For experience, differences were seen at the levels of 1–20 matches and 21–40 matches in comparison to all higher levels of experience (mean differences ranged from 1.01 to 3.77 player rating points), and for various experience levels in comparison to 41–60 matches. No differences were seen between any levels above this for experience.

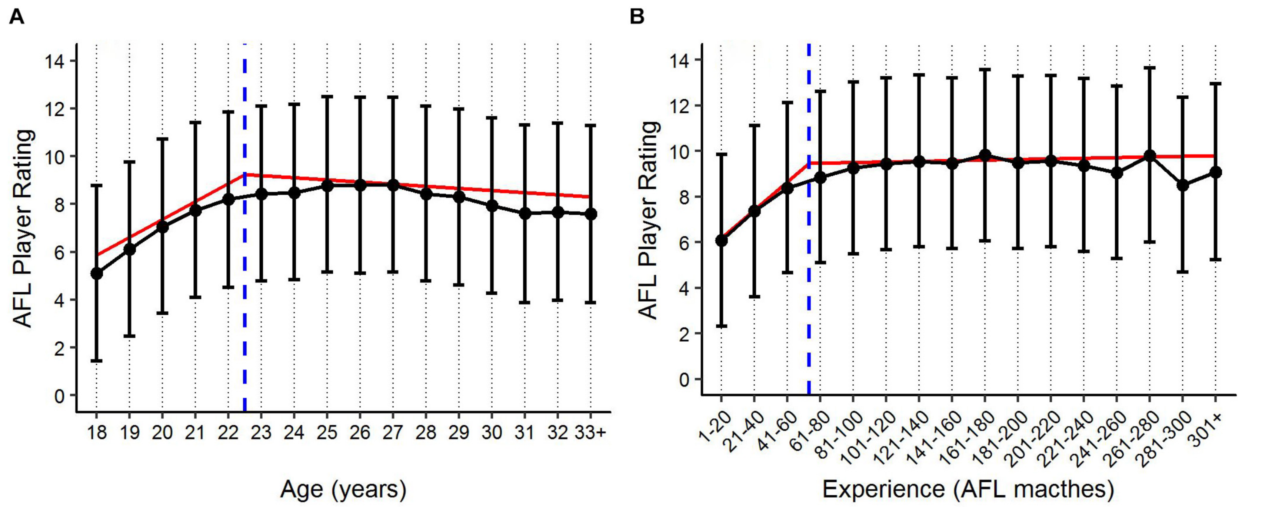

FIGURE 5 | Benchmark levels of AFL Player Ratings (±90% PI) by **(A)** age and **(B)** experience, based on the fixed effects estimates. Blue *x*-axis intercept lines represent the level at which the breakpoint in performance occurs for both age and experience, respectively. Red regression lines represent the multiple linear fits of the segmented models.

The segmented models identified a breakpoint in performance for both age and experience. The results indicate that a breakpoint in age occurs between the age levels 22 and 23, where performance is seen to increase linearly 0.75 rating points per age level prior to this breakpoint, and decline linearly 0.09 rating points per age level thereafter. The breakpoint identified for experience occurs between the levels 41–60 and 61–80, where performance is seen to increase linearly 1.24 rating points per level of experience prior to this breakpoint, and then continue to increase linearly 0.04 rating points per experience level thereafter. **Figure 5** displays the benchmark levels of performance for both age and experience, where player specific random effects (PSRE) are removed. *X*-axis intercept lines and regression lines were added to **Figure 5** to represent the level at which the identified breakpoint in performance occurs, and the change in the trend of player performance, respectively, for both age and experience.

By applying the PSRE and the fixed effect estimates from the linear mixed models, various applications can be created to benchmark player performance. For example, **Figure 6** visualises the actual past performance and future player specific expectation of performance (fit and 90% PI) for a specific player, as compared to their fixed effect estimate of performance using model (1). This application indicates the player's performance has been below the benchmark level of performance since 2014, but within the 90% PI, and is expected to remain fairly consistent in the three forecasted seasons. **Figure 7** outlines how model (1) could be used for player comparison, indicating that the player in blue is likely to perform better in each of the forecasted seasons. Further, **Figure 8** visualises the actual past performance and future player specific expectation of performance (fit only) for a specific player, using both the models based on age (blue) and experience (red).

Additionally, the PSRE provide a measure of player ranking, which adjusts for the individual fixed effects characteristics. **Table 3** outlines the top five players in each positional roles, as determined by the average of the PSRE across the two linear mixed models. Player positional role was determined by the category in which they were categorised the most frequently over the five seasons.

DISCUSSION

The primary aim of this study was to develop a model to objectively benchmark player performance whilst considering

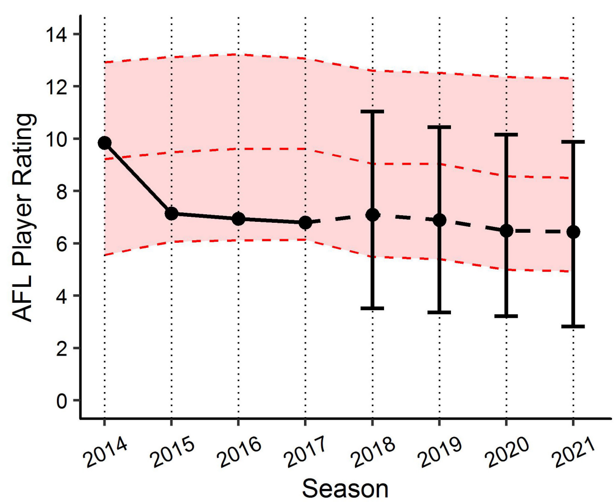

FIGURE 6 | Benchmark levels of AFL Player Ratings for a specific player using the age linear mixed model. Black lines represents actual performance to 2017 and player specific expectation (±90% PI) of performance from 2018. Red ribbon represents fixed effects estimates based on characteristics of same player.

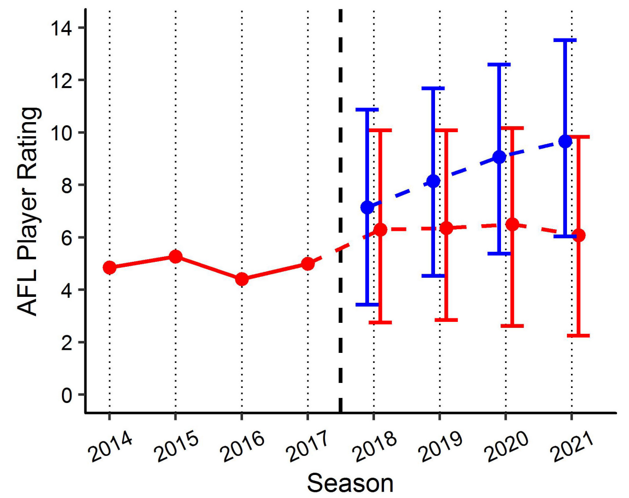

FIGURE 7 | Benchmark levels of AFL Player Ratings for two specific players using the age linear mixed model. Red line represents actual performance prior to 2017. Red and blue lines indicate player specific expectations (±90% PI) of performance from 2018 for each player. Black *x*-axis intercept line indicates point of comparison.

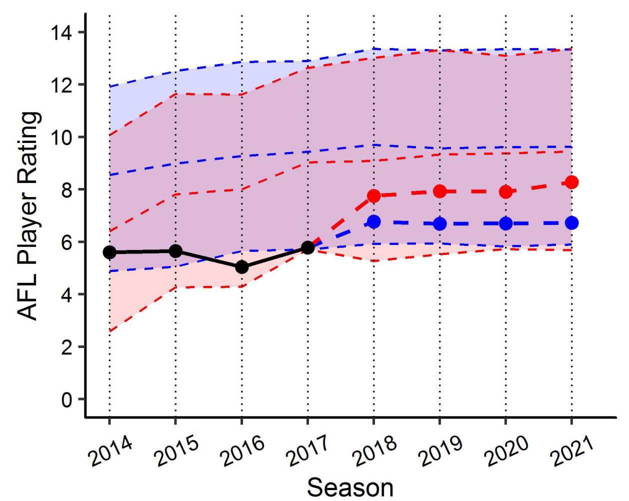

FIGURE 8 | Benchmark levels of AFL Player Ratings for a specific player using the both the age (blue) and experience (red) linear mixed models. Black line represents actual performance to 2017. Blue and red points indicate expectation of performance from 2018 using each the age and experience models, respectively. Similarly, each ribbon represents fixed effects estimates based on characteristics of same player in each model.

their age, experience, positional role, and both draft type and round in which they were selected. It also aimed to identify the stage of peak performance and specific breakpoints in player performance longitudinally. Separate linear mixed model analyses were implemented to benchmark performance based on the multifactorial fixed effects estimates. Segmented models were fit to these fixed effect estimates to determine if and where a change in the linear trend of performance progression occurs.

Visual inspection of the descriptive statistics in **Figures 1A,B** indicate that performance continues to improve throughout an AFL players career (as indicated by the gradual increase in average AFL Player Ratings for both age and experience, respectively). However, it must be noted that this type of analysis is susceptible to selection biases (Brander et al., 2014). Specifically, previous research has identified that these biases can be bought upon as a result of better-performing players typically having longer careers than other players (Bradbury, 2009; Dendir, 2016). **Figures 3**, **4** highlight this bias on the basis that player selection is a subjective identification of each clubs best performers. Specifically, **Figure 3** outlines the proportion of players in the dataset, and indicates that there are less players across the sample in older and more experienced categories, respectively; however, **Figure 4** shows that these older and more experienced players on average play more games per season. The substantially smaller interquartile ranges and presence of outliers in **Figure 4B**, as opposed to **Figure 4A**, indicates that despite showing similar increasing trends between the two distributions, there is less variance in matches played per season with respect to experience. However, this is somewhat expected due to the compounding nature of matches played per season, to total career matches. Visual inspection of the descriptive statistics in **Figures 2A,B** also indicates that performance differences are seen between varying levels of both draft and position, respectively. These findings align with previous literature investigating longitudinal player performance, and supports the use of a mixed model approach to account for fixed and PSRE (Bradbury, 2009; Dendir, 2016).

Each of the two linear mixed models provide context when looking to benchmark player performance longitudinally in AF. In addition to identifying a universal benchmark trend of performance longitudinally, the models produced in this study allow player specific values to be obtained, by adjusting each of the fixed effects relative to the player's characteristics in each model. These player specific benchmarks allow for both retrospective assessment of a players past performance against expected performance, as well as to forecast player performance relative to expected characteristics (assumptions must be made with regards to positional role and experience to forecast). Applications of these models have the potential to be beneficial in supporting the decision making processes within professional AF organisations. Decisions relating to player recruitment and contracting could be objectively informed by gaining an understanding of the past and future potential performance of players, which the club maybe looking to recruit, resign or remove from their current playing squad. Though the examples provided in this study feature 90% PI, clubs/organisations wanting to be more aggressive with their predictions regarding expected performance could adapt the current models to include lower PI. **Figure 6** provides a specific example of how this can be visualised. It outlines an actual player's past performance (2014–2017) and expected future performance (2018–2021), and compares this to the benchmark level of performance based on the characteristics for that player. Alternatively, **Figure 7** outlines an actual player's past performance (2014–2017) and expected future performance (2018–2021), and compares this to

TABLE 3 | Top five players in each positional role, as determined by the average of the player specific random effects (PSRE) in each of the linear mixed models.

Player	Model 1 PSRE	Model 2 PSRE	Player	Model 1 PSRE	Model 2 PSRE
General defender			**General forward**		
Zac Williams	4.09	3.14	Brent Harvey	6.18	4.74
Adam Saad	3.30	3.22	Chad Wingard	4.31	3.26
Shaun Burgoyne	3.68	2.84	Eddie Betts	4.19	3.19
Brandon White	3.04	2.57	Luke Breust	4.32	3.02
Daniel Rich	2.97	2.57	Cyril Rioli	3.43	3.00
Key defender			**Key forward**		
Jeremy McGovern	4.44	4.11	Lance Franklin	5.21	4.51
Alex Rance	3.59	2.99	Jarryd Roughead	4.23	3.66
Tom McDonald	2.87	2.16	Justin Westhoff	4.22	3.10
Harris Andrews	3.04	1.87	Josh J. Kennedy	3.73	3.02
Josh Gibson	2.94	1.51	Jack Gunston	3.68	2.99
Midfielder			**Midfield-forward**		
Gary Ablett	8.29	6.96	Robbie Gray	4.75	3.76
Patrick Dangerfield	6.96	6.30	Dayne Zorko	3.71	3.88
Nat Fyfe	6.61	5.77	Sam Menegola	3.30	4.11
Scott Pendlebury	6.09	5.60	Christian Petracca	3.53	3.42
Marcus Bontempelli	5.44	4.49	Luke Dahlhaus	3.82	2.72
Ruck					
Todd Goldstein	4.70	3.68			
Nic Naitanui	4.29	3.57			
Sam Jacobs	3.60	2.19			
Aaron Sandilands	3.95	1.83			
Shane Mumford	3.52	1.94			

Player positional role determined by the category in which they were categorised the most frequently over the five seasons.

the expected future performance (2018–2021) of a player who is yet to be drafted.

Though the identified breakpoints found in each model differ marginally to the findings of the *post hoc* Tukey test, both analyses indicate that there is a distinct change in the trend of player performance occurring in each model, occurring at around the age 22, and experience level 41–60, respectively. Specifically, they indicate that this change in the trend represents a point of marginal gains within each of the model, such that once these levels are reached the benchmark level of player performance is expected to somewhat plateau. This indication of marginal performance gains beyond these respective levels could have useful implications for both player development and player recruiting/contracting within professional AF. For example, clubs may look to persist with selection of players who are yet to reach these points of marginal gains (as opposed to older/more experienced players of similar ability), knowing that match opportunities are potentially more detrimental to development of the younger/less experienced players. In regards to player recruiting and contracting, clubs could look to use these breakpoints as an indication of whether the performance of current players and/or potential recruits is likely to continue to improve, or whether their performance has reached a point of marginal gains. Though only one breakpoint was identified for each model in this study, clubs/organisations wanting to further explore the longitudinal performance trends could adapt the current methodology to identify whether multiple breakpoints exist.

Despite minor differences, both the models measured longitudinally on each age and experience might be used for different operational purposes based on the preferences of the organisation. For example, due to the reliance of match opportunity for the model based experience, applications of this model may be more suited to benchmark the performance of players who have experienced long-term injuries or are mature aged recruits. Conversely, for those who have had sufficient match opportunities, the models based on age may be more suitable due to the more progressive nature of age as an independent variable. **Figure 8** visualises this difference in the models through benchmarking the expected performance of a specific older age, but lowly experienced individual, using both models.

In addition to providing benchmark levels of performance, the models produced in this study also provide an indication of the point at which peak performance occurs longitudinally.

Specifically, the findings imply that on average players reach their peak around the age of 22, or 60 matches experience. In comparison to previous literature, this point at which the average player reaches their peak age is younger than what has been identified in other dynamic team sports such as soccer (Dendir, 2016). Though this peak is identified earlier, there was no substantial drop-off in performance noted in this study, indicating that that peak performance in AF may be better outlined by a peak range. There is no literature available to make these comparisons in relation to a player's match experience.

The PSRE outlined in each of the mixed models could also be used to rank players across the 2013–2017 seasons. Specifically, this type of ranking would be more generalisable than other ranking measures that do not adjust for fixed effects such as those used in our model. Thus it allows comparisons to be made between players across different ages, levels of experience, positional roles and draft selections. **Table 3** outlined the top five players in each positional role. The table indicated that despite accounting for position, the top three midfielders still exhibited higher PSRE than any other players. As an indication of the face validity for these random effects to be used to rank players, each of these three outlined individuals have won the AFL's award for the fairest and best player for one of the five seasons included in the dataset (Gary Ablett in 2013, Nat Fyfe in 2015 and Patrick Dangerfield in 2016).

Some limitations of this study should also be noted. Though mixed model approaches have been supported in previous literature to account for the fixed and random effects associated with longitudinal player performance; there is also an inherent understanding that the decline in performance after peak is often underestimated as a result of athlete drop out. For example, only the most successful athletes continue to get renewed playing contracts, and are subsequently selected to play at the elite level. Thus meaning that there is likely some level of performance deterioration that goes unnoticed by the model beyond certain ages/levels of experience. Another limitation is that the methodology could include additional metrics, such as time on ground or spatiotemporal data, potentially allowing for further explanation of the results. Future work in dynamic team sports should focus on the continual development of improving objective player performance rating models, as well as decision support applications to assist with operational decision-making in professional sporting organisations. In AF specifically, the development of these objective player performance rating models could look to include further positioning dynamics, similar to that in other team sports (Gonçalves et al., 2017; Memmert et al., 2017).

CONCLUSION

This study produced two types of models benchmarking player performance in the AFL. The first method utilised two separate linear mixed models to identify the effect of individual characteristics on player performance. Each of these models could be used to identify how a player's performance compares to individualised benchmarks, or to forecast future potential performance. The second method utilised segmented models, finding a point of marginal gains within longitudinal performance of both age and experience. The implementation of these methodologies may provide valuable knowledge for professional AFL organisations. Implications of their use could assist with organisational decisions relating to player recruitment, contracting and development. Future work should focus on the refinement of the models produced in this study as additional seasons of data become available.

AUTHOR CONTRIBUTIONS

SM and SR conceived and designed the study. SM compiled the data, conducted the statistical analyses, and wrote the bulk of the manuscript. SR oversaw the data collection and statistical analyses, and contributed substantially to the writing of the manuscript. SK contributed significantly to the methodology, and assisted with writing of the "Materials and Methods" section.

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REFERENCES

Akaike, H. (1987). "Factor analysis and AIC," in *Selected Papers of Hirotugu Akaike*, eds K. Tanabe, G. Kitagawa, and E. Parzen (Berlin: Springer), 371–386. doi: 10.1007/978-1-4612-1694-0_29

Allen, S. V., and Hopkins, W. G. (2015). Age of peak competitive performance of elite athletes: a systematic review. *Sports Med.* 45, 1431–1441. doi: 10.1007/s40279-015-0354-3

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48.

Bonney, N., Berry, J., Ball, K., and Larkin, P. (2019). Australian football skill-based assessments: a proposed model for future research. *Front. Psychol.* 10:429. doi: 10.3389/fpsyg.2019.00429

Bozdogan, H. (1987). Model selection and Akaike's information criterion (AIC): the general theory and its analytical extensions. *Psychometrika* 52, 345–370. doi: 10.1007/BF02294361

Bradbury, J. C. (2009). Peak athletic performance and ageing: evidence from baseball. *J. Sports Sci.* 27, 599–610. doi: 10.1080/02640410802691348

Brander, J. A., Egan, E. J., and Yeung, L. (2014). Estimating the effects of age on NHL player performance. *J. Quant. Anal. Sports* 10, 241–259.

Carling, C., Reilly, T., and Williams, M. A. (2008). *Performance Assessment for Field Sports*. Abingdon: Routledge.

R Core Team (2016). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Dendir, S. (2016). When do soccer players peak? A note. *J. Sports Anal.* 2, 89–105. doi: 10.3233/JSA-160021

Fair, R. C. (2008). Estimated age effects in baseball. *J. Quant. Anal. Sports* 4, 1–39. doi: 10.2202/1559-0410.1074

Fransen, J., Bennett, K. J., Woods, C. T., French-Collier, N., Deprez, D., Vaeyens, R., et al. (2017). Modelling age-related changes in motor competence and physical fitness in high-level youth soccer players: implications for talent identification and development. *Sci. Med. Football* 1, 203–208. doi: 10.1080/24733938.2017.1366039

Gómez, M. Á, Lago, C., Gómez, M. T., and Furley, P. (2019). Analysis of elite soccer players' performance before and after signing a new contract. *PLoS one* 14:e0211058. doi: 10.1371/journal.pone.0211058

Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jiménez, S., and Sampaio, J. (2017). Exploring team passing networks and player movement dynamics in youth association football. *PLoS one* 12:e0171156. doi: 10.1371/journal.pone.0171156

Harrell, F. E. (2017). *Package 'Hmisc'*. Vienna: R Foundation for Statistical Computing.

Herald Sun (2016). *SuperCoach 2016: Champion Data Explains Key Stats in Scoring Formula*. Southbank, VI: Herald Sun.

Jackson, K. (2009). "Football numbers man brings players to account," in *Swinburne Venture Magazine*, ed. M. Marino (Melbourne: Swinburne University of Technology).

Kalén, A., Rey, E., de Rellán-Guerra, A. S., and Lago-Peñas, C. (2019). Are soccer players older now than before? aging trends and market value in the last three decades of the UEFA champions league. *Front. Psychol.* 10:76. doi: 10.3389/fpsyg.2019.00076

Longo, A. F., Siffredi, C. R., Cardey, M. L., Aquilino, G. D., and Lentini, N. A. (2016). Age of peak performance in Olympic sports: a comparative research among disciplines. *J. Hum. Sport Exerc.* 11, 31–41. doi: 10.14198/jhse.2016.111.03

Lorenzo, J., Lorenzo, A., Conte, D., and Giménez, M. (2019). Long-term analysis of elite basketball players' game-related statistics throughout their careers. *Front. Psychol.* 10:421. doi: 10.3389/fpsyg.2019.00421

Maymin, P. Z. (2017). The automated general manager: can an algorithmic system for drafts, trades, and free agency outperform human front offices? *J. Glob. Sport Manag.* 2, 234–249. doi: 10.1080/24704067.2017.1389248

McHale, I. G., Scarf, P. A., and Folker, D. E. (2012). On the development of a soccer player performance rating system for the English Premier League. *Interfaces* 42, 339–351. doi: 10.1287/inte.1110.0589

McIntosh, S., Kovalchik, S., and Robertson, S. (2018). Validation of the Australian football league player ratings. *Int. J. Sports Sci. Coach.* 13, 1064–1071. doi: 10.1177/1747954118758000

Memmert, D., Lemmink, K., and Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports Med.* 47, 1–10. doi: 10.1007/s40279-016-0562-5

Mooney, M., O'Brien, B., Cormack, S., Coutts, A., Berry, J., and Young, W. (2011). The relationship between physical capacity and match performance in elite Australian football: a mediation approach. *J. Sci. Med. Sport* 14, 447–452. doi: 10.1016/j.jsams.2011.03.010

Muggeo, V. M. (2008). Segmented: an R package to fit regression models with broken-line relationships. *R News* 8, 20–25.

O'Shaughnessy, D. M. (2010). "On the value of AFL player draft picks," in *Proceedings of the 10th MathSport Conference*, (Darwin).

Radovanović, S., Radojičić, M., Jeremiæ, V., and Saviæ, G. (2013). A novel approach in evaluating efficiency of basketball players. *Management* 67, 37–45. doi: 10.7595/management.fon.2013.0012

Reilly, T., Bangsbo, J., and Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *J. Sports Sci.* 18, 669–683. doi: 10.1080/02640410050120050

Robertson, S., Back, N., and Bartlett, J. D. (2015). Explaining match outcome in elite Australian rules football using team performance indicators. *J. Sports Sci.* 34, 637–644. doi: 10.1080/02640414.2015.1066026

Schulz, R., and Curnow, C. (1988). Peak performance and age among superathletes: track and field, swimming, baseball, tennis, and golf. *J. Gerontol.* 43, 113–120.

Tangalos, C., Robertson, S., Spittle, M., and Gastin, P. B. (2015). Predictors of individual player match performance in junior Australian football. *Int. J. Sports Physiol. Perform.* 10, 853–859. doi: 10.1123/ijspp.2014-0428

Torgler, B., and Schmidt, S. L. (2007). What shapes player performance in soccer? Empirical findings from a panel analysis. *Appl. Econ.* 39, 2355–2369. doi: 10.1080/00036840600660739

Towlson, C., Cobley, S., Parkin, G., and Lovell, R. (2018). When does the influence of maturation on anthropometric and physical fitness characteristics increase and subside? *Scand. J. Med. Sci. Sports* 28, 1946–1955. doi: 10.1111/sms.13198

Travassos, B., Davids, K., Araújo, D., and Esteves, P. T. (2013). Performance analysis in team sports: advances from an ecological dynamics approach. *Int. J. Perform. Anal. Sport* 13, 83–95. doi: 10.1080/24748668.2013.11868633

Veale, J. P., Pearce, A. J., Koehn, S., and Carlson, J. S. (2008). Performance and anthropometric characteristics of prospective elite junior Australian footballers: a case study in one junior team. *J. Sci. Med. Sport* 11, 227–230. doi: 10.1016/j.jsams.2006.12.119

Wolfson, J., Koopmeiners, J. S., and DiLernia, A. (2015). Who's good this year? Comparing the information content of games in the four major US sports. *J. Sports Anal.* 4, 153–163. doi: 10.3233/JSA-170199

Woods, C. T., Joyce, C., and Robertson, S. (2016). What are talent scouts actually identifying? Investigating the physical and technical skill match activity profiles of drafted and non-drafted U18 Australian footballers. *J. Sci. Med. Sport* 19, 419–423. doi: 10.1016/j.jsams.2015.04.013

Woods, C. T., Robertson, S., and Collier, N. F. (2017). Evolution of game-play in the Australian Football League from 2001 to 2015. *J. Sports Sci.* 35, 1879–1887. doi: 10.1080/02640414.2016.1240879

Young, W. B., Newton, R. U., Doyle, T. L., Chapman, D., Cormack, S., Stewart, C., et al. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian rules football: a case study. *J. Sci. Med. Sport* 8, 333–345. doi: 10.1016/s1440-2440(05)80044-1

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDICES

TABLE A1 | Descriptions of the seven positional roles used in this study.

Positional roles	Description
General defender	Plays a role on opposition small-medium forwards and usually helps create play from the backline
Key defender	Plays on opposition key forwards with the primary role of nullifying his opponent
General forward	Plays predominantly in the forward half of the ground but with more freedom than a key forward
Key forward	Plays predominantly as a tall marking target in the forward line
Midfielder	Spends the majority of time playing on the ball or on the wing
Midfielder-forward	Splits time equally between the forward line and the midfield. Often lines up on the half-forward flank but plays a significant amount of time in the midfield
Ruck	Has the primary role of competing for hit-outs at a stoppage

TABLE A2 | Descriptions of the three annual draft methods to enter an AFL list.

Draft type	Club participation	Trading of picks	Further description
National draft	Compulsory draft. Each club must exercise a minimum of three selections	Picks can be traded between clubs	Players selected by a club become ineligible to be included on the primary list of any other club for a period of two seasons. For the most part this draft consists of players finishing secondary school, who have been competing in elite junior feeder competitions
Preseason draft	Non-compulsory draft	Picks cannot be traded between clubs	Players selected by a club become ineligible to be included on the primary list of any other club for a period of two seasons. For the most part this draft consists of players who missed out on selection in the National Draft
Rookie draft	Non-compulsory draft	Picks cannot be traded between clubs	Players selected become part of the clubs rookie list, and cannot compete within the AFL until being promoted to the clubs primary list. For the most part this draft consists of players who missed out on selection in the National Draft or older players from second tier competitions

In all three drafts, clubs select players in the reverse order to which they finished on the final premiership ladder in the previous AFL season. To be eligible for selection, a player must be 18 years of age before the 31st of December following the national draft selection meeting.

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Post-activation Potentiation: Effects of Different Conditioning Intensities on Measures of Physical Fitness in Male Young Professional Soccer Players

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The aim of this study was to compare the effects of different warm-up conditioning intensities on the physical fitness (i.e., post-activation potentiation -PAP), of professional male field soccer players. Athletes (n = 10; age: 21.6 ± 3.2 years) completed a control warm-up and warm-ups aimed to induce PAP, in random and counterbalanced order. After control and experimental warm-up sessions participants completed a triple hop test with the dominant (H3Jd) and a non-dominant (H3Jnd) leg, a squat jump (SJ), a countermovement jump (CMJ), a change of direction ability (COD) test, a repeated sprint with a COD (RSCOD) test and a linear 30-m sprint test (S-30). The control warm-up (WU) protocol was designed according to athlete's regular warm-up practice. The experimental warm-ups included the same exercises as the WU, with addition of one set of half-back squats for 10 repetitions at 60%, 5 repetitions at 80%, and 1 repetition at 100% of 1RM (60%-1RM, 80%-1RM and 100%-1RM, respectively.) Threshold values for Cohen's effect sizes (ES) were calculated and used for group's comparison. Likely to most likely improvements were shown in H3Jd (ES = 0.52), H3Jnd (ES = 0.51), COD (ES = 0.38), fasted sprint (RSCODb) (ES = 0.58) and the total time of all sprints (RSCODt) (ES = 0.99) only after the 80%-1RM protocol in comparison to the WU. Conversely, 100%-1RM and 60%-1RM protocols, compared to WU, induced possibly to most likely poorer performance in all jumps, COD and RSCODb (ES = −0.07 to −1.03 and ES = −0.48 to −0.91, respectively). Possibly to most likely improvements were shown in all jumps, COD, RSCODb and RSCODt after the 80%-1RM warm-up protocol in comparison to the 100%-1RM and 60%-1RM warm-up protocols (ES = 0.35 to 2.15 and ES = 0.61 to 1.46, respectively). A moderate warm-up intensity (i.e., 80%-1RM back squat) may induce greater PAP, including improvements in jumping, repeated and non-repeated change of direction speed in male soccer players.

Keywords: plyometric, speed, fatigue, warm-up, soccer

INTRODUCTION

Aside from the total distance covered, performing high-intensity actions repeatedly during a match is a key feature of soccer (Stølen et al., 2005). During a competitive match, soccer players may perform ∼1400 short-duration maximal or near maximal intensity activities, including sprints, change of directions (COD), tackling, accelerations, decelerations, jumps, among others (Iaia et al., 2009). Although training programs may improve such performance actions at long-term, short-term (or acute) improvements may also be induced by warm-up activities, a method routinely used by athletes, coaches and strength and conditioning specialists to improve muscle force and power involved in athletic performance during competition (Evetovich et al., 2015).

A large amount of research regarding the effects of a warm-up on human performance have been conducted (Rahimi, 2014; Barnes et al., 2015; González-Mohíno et al., 2018). There is a general consensus pointing the benefits of a warm-up on subsequent performance (Lockie et al., 2017). However, the optimal warm-up strategy for soccer players before a match is not well established (Hammami et al., 2018). Most soccer-related warm-up strategies involved static and dynamic stretching, neuromuscular activities, and short-duration high-intensity activities (Zois et al., 2011). Regarding the latter, they may induce post-activation potentiation (PAP) (Evetovich et al., 2015).

The PAP is a phenomenon in which neuromuscular performance characteristics are enhanced after intense contractile stimulation (Hodgson et al., 2005). The PAP in humans may be induced by isometric maximum voluntary contraction (Hamada et al., 2000), high-intensity resistance stimulus (McBride et al., 2005), and plyometric exercise (Turner et al., 2015). Although the existing research tends to reveal inconsistent findings (Moir et al., 2009), some studies has shown that performing muscular contractions under near-maximal load conditions improves subsequent performance during movements requiring large muscular power outputs of the stimulated muscle groups (Hodgson et al., 2005). However, there is little research regarding the effects of heavy resistance exercise on subsequent performance in soccer (Hammami et al., 2018). Some authors indicated that heavy resistance exercise may improve subsequent jump and COD (Zois et al., 2011), repeated sprints (Low et al., 2015; Sanchez-Sanchez et al., 2018) and single linear sprint (McBride et al., 2005; Tillin and Cooke, 2009).

The exact mechanism responsible for this PAP response remains uncertain (Lockie et al., 2017). Chemical, neuromuscular and mechanical changes may occur that temporarily aid the contractile properties of muscle tissue (Sale, 2004). One common PAP mechanism theory indicates the phosphorylation of myosin light chains resulting from the initial muscle activity, which would turn the actin and myosin molecules more sensitive to calcium ($Ca2+$) availability (Tillin and Bishop, 2009). Also it is speculated that PAP can increase the excitability of motoneurons (Hodgson et al., 2005) and enhancement of neural output by recruitment of faster motor units (Hamada et al., 2000; Sale, 2004). Moreover, it was also reported that pre-loading may increase muscle stiffness (Moir et al., 2009). Previous studies have suggested that PAP responses might be dependent on individual characteristics (Sanchez-Sanchez et al., 2018). For instance, stronger subjects exhibited a greater PAP response when compared with weaker counterparts (Seitz and Haff, 2016). In contrast, other studies concluded that performance after a PAP inducing activity was not related to training status (McBride et al., 2005). Furthermore, it has been proposed that the PAP may be related to the type of muscle fiber being activated (Wilson et al., 2013), with a higher proportion of fast fibers being related to greater PAP effect (Sole et al., 2013).

Therefore, in order to maximize PAP, these factors (e.g., training status) should be taken into account together with the load used during the warm-up (Lockie et al., 2017). McBride et al. (2005), for example, demonstrated that 1 set of 3 repetitions at 90% of one repetition maximum (1RM) significantly improve sprint time performance, whilst 1 set of 3 repetitions at 30%-1RM did not. In the same context, a previous study conducted with male soccer players showed that in order to induce optimal running speed enhancements, it is necessary to set the intensity of the warm-up protocol with loads ≥80%-1RM (Rahimi, 2014).

The competition rules require the physical trainers to finish the warm-up 15–20 min before the start to the matches. The PAP could be used between the end of the warm up and the start of the game, to maintain the level of activation in the players (Russell et al., 2014). Although greater loads have been recommended to induce PAP in strength and power tasks (McBride et al., 2005; Rahimi, 2014), its practical application in soccer is difficult. This is because of the limited time-frame separating the end of the warm-up and the start of a soccer match which is not sufficient to include multiple sets (Russell et al., 2014). Therefore, the aim of this study was to compare the effects of different warm-up conditioning intensities on physical fitness (i.e., PAP), of professional male field soccer players.

MATERIALS AND METHODS

Participants

Professional male soccer players (n = 10; age: 21.6 ± 3.2 years, body height: 177.9 ± 4.3 cm, and body mass: 69.5 ± 3.1 kg) with ≥6-years of training and competition experience were recruited for the study. Their regular training schedule involved four training sessions plus a competitive match per week in the Spanish second division "B." All participants: (1) were field players (four defenders, four midfielders and two forward), (2) were free of injuries in the last 3-months, (3) had regularly trained and competed in the past 6-months and (4) haven't got any lower extremity surgery in the past 2-years. Soccer players signed an informed consent before starting the data collection. The protocol was approved by the Ethics Committee of the Pontifical University of Salamanca (Annex III, Act 13/2/2019) and conformed to the latest version of the Declaration of Helsinki.

Procedures

The experiments were conducted during the competitive period of the season 2018. The control and experimental warm-up sessions were completed in a random, counterbalanced order, completed in a period of 3-weeks. The tests during control and experimental sessions were completed in the same order, between 15:00 and 20:00 h, at an indoor venue, with the same sports clothes and by the same investigator, who was blinded to the group allocation of the participants. To avoid the effects of fatigue on testing results, participants completed the control and the experimental warm-up sessions no less than 48 h after the last training/competition session. Each intervention was applied twice, making the tests in the following order. After control and experimental warm-up sessions participants completed measure in day 1: triple hop test with dominant (H3Jd) and non-dominant (H3Jnd) leg, squat jump (SJ) and repeated sprint with COD (RSCOD); measure in day 2: linear 30-m sprint test (S-30), countermovement jump (CMJ), COD test. The recovery between tests was 1 min. Participants were asked to attend each session under an adequate feeding and hydration state. The testing protocols were performed in the facilities where athletes usually train and compete.

Familiarization and Maximal Dynamic Strength Test

During a 120 min familiarization session, athletes simulated the warm-up protocols and completed a maximal dynamic strength test (1RM) in order to assess the specific loads to be used during PAP warm-up sessions. The maximal dynamic strength was assessed through the half back squat exercise using the Smith machine (MultipowerPeroga®, Murcia, Spain), with the barbell constrained to move along the vertical axis. The 1RM test was preceded by a 5-minutes low-intensity run in which the heart rate not exceed at 140 b·min^{-1} (Polar RS800CX, Electro Oy, Kempele, Finland), and by 5 and 3 half back squat repetitions at an estimated 50% and 70% 1RM, respectively. In the initial position the barbell was at shoulder-level, feet at shoulder-width distance, and knee and hips in full extension. Adhesive marks were added to the floor and the barbell to assure consistency in the hands and feet position during testing. In addition, a wooden seat with adjustable heights was placed behind the subjects to keep bar displacement and knee angle (∼90° knee angle) constant on each half back squat attempt. The 1RM load was defined as the maximum weight that could be lifted once using the proper exercise technique through a full range of motion (Okuno et al., 2013). A 3-minutes rest interval was adopted between attempts, and the subjects had up to five attempts to obtain their 1RM.

Jumping Test

Athletes completed the H3Jd and H3Jnd (Noyes et al., 1991). Participants take maximal jumps forward as far as possible on the testing leg and land on two legs during the final jump. At the end of each horizontal jump attempt, athletes maintained the landing position for a brief moment. Soccer players also completed the CMJ and SJ tests following previous suggestions (Maulder et al., 2015), with minimal flexion of the trunk during take-off. Jumping was measured with a contact mat (Globus Ergo System®, Codogné, Italy). In all jumps, the hands were used freely, except during the SJ and CMJ, where athletes positioned arms akimbo. Athletes performed two maximal trials for each test with 1-minute of rest in between. The best value achieved was selected for analysis.

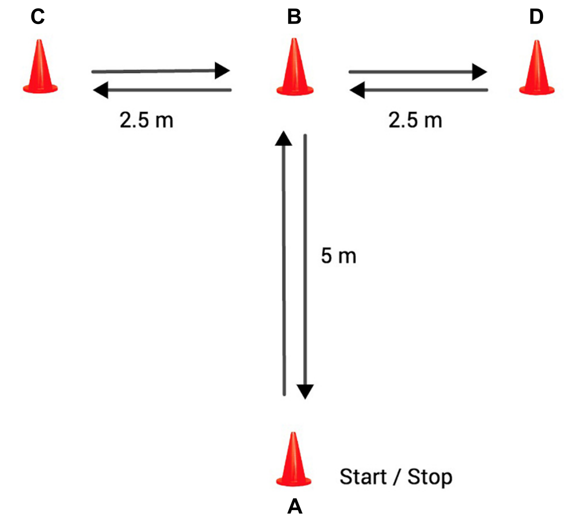

FIGURE 1 | Change of direction ability test.

Change of Direction Ability Test

Athletes also completed a modified *t*-test (Sassi et al., 2009) to evaluate COD. A photocell gate system (Witty, Microgate®, Italy) was used to record the time. The players performed the test using the same directives as the traditional test, although they were not required to move laterally or face forward (**Figure 1**). The players had to touch the top of the cones instead of its base. The displacement followed this route: AB displacement, at his own discretion, each subject sprinted forward to cone B and touched the top of the cone with the right hand; BC displacement, facing forward the participant shuffled to the left to cone C and touched the top of the cone with the left hand; CD displacement, the soccer player then shuffled to the right to cone D and touched its top; DB displacement, the players shuffled back to the left to cone B and touched its top; BA displacement, the players moved backward as quickly as possible and returned to line A. Players performed two maximal trials, with 1-minute of rest in between. The best value achieved was selected for analysis.

Linear 30-m Sprint Test

For maximal sprinting physical fitness assessment, athletes completed a S-30 sprint. The S-30 involved single maximal-effort sprints from a stationary start. Players initiated the sprint at their own discretion, positioning the foot 0.5-m behind the start line. Thirty-meter linear sprint performance was assessed using a double-beam photocell system (Witty, Microgate®, Italy). Athletes performed two maximal trials, with 1-minute of rest in between. The best value achieved was selected for analysis.

Repeated Sprint With COD Test

In addition to the linear sprint, athletes completed a RSCOD test. The RSCOD test included 6 sprints, with a passive recovery period of 20-seconds in between (Okuno et al., 2013). Each sprint involved 15-m of linear sprint, a COD of 180°, and another 15-m linear sprint [15-m + 15-m (COD−180°)]. Times were recorded

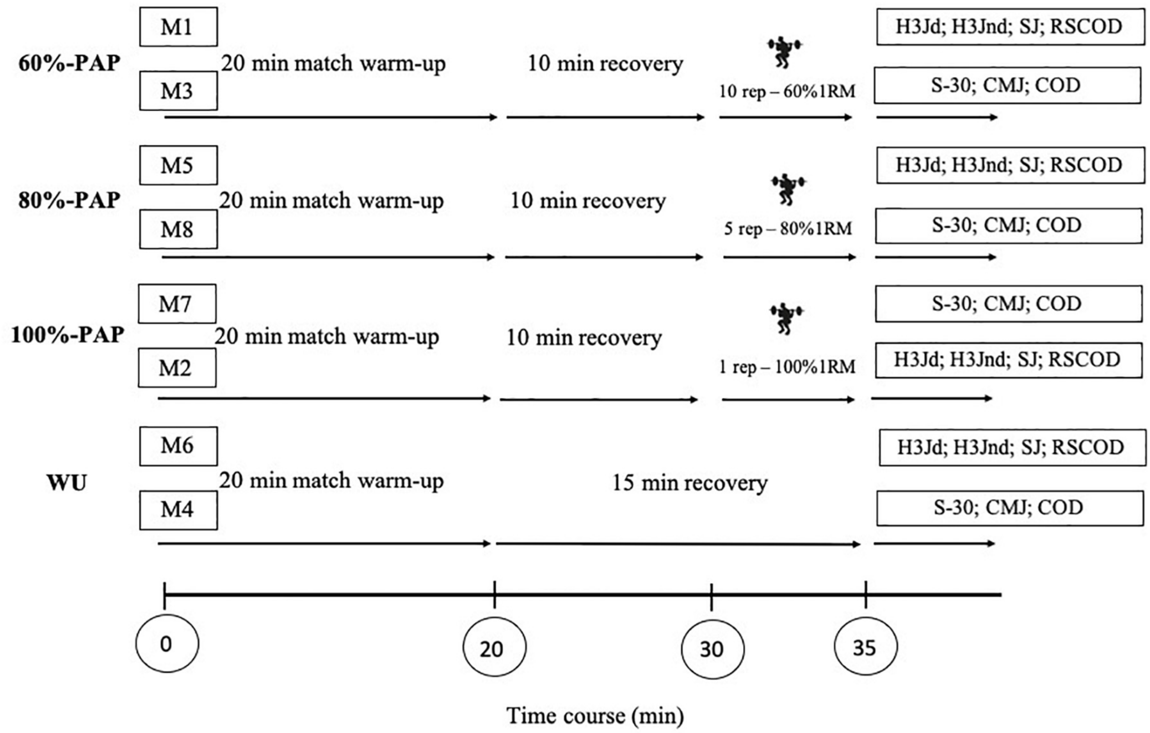

FIGURE 2 | Overview of the cross-over experimental design, indicating the control and three different warm-up conditions. The 15-minutes recovery period was included during control condition. The 10-minutes plus 5-minutes recovery period were included during PAP protocols, to simulate match conditions. The tests were divided at two measurement (M) day corresponding to each protocols. 60%-1RM, 80%-1RM, and 100%-1RM refer to match warm-up post-activation potentiation (PAP) protocols at 60, 80 and 100% of 1RM, respectively; WU, match warm-up protocol; M, measurement; H3Jd, triple hop test with dominant leg; H3Jnd, triple hop test with non-dominant leg; SJ, squat jump test; RSCOD, repeated sprint with change of direction test; S-30, linear 30-m sprint test; CMJ, countermovement jump test; COD, change of direction ability test.

with a double-beam photocell system (Witty, Microgate®, Italy). Athletes received verbal encouragement during the test. The players were verbally and visually informed to assume the starting position 0.5-m behind the starting line 6-seconds before each sprint. Also a 3-seconds countdown was visually provided with a light panel (Microgate®, Italy) that informed of the start of the next sprint. The fastest sprint (RSCODb) and the total time of all sprints (RSCODt) were retained for further analyses.

Warm-Up Protocols

The overview of warm-up protocols is presented in **Figure 2**. A control warm-up protocol (WU) was designed according to athlete's regular warm-up practices. The WU included 7-minutes of general warm-up [i.e., continuous moderate-intensity ($\leq$10 km/h^{-1}) running; general main-joint movements (mobility of upper and lower extremities; proprioceptive drills [landings with dominant and non-dominant leg after low-intensity frontal and lateral jumps)], 3-minutes of specific warm-up [i.e., elastic-bands resisted drills and ballistic drills (lateral and frontal movements on 5-m and simulations of ball shots wearing an elastic on the ankles or knees)], 5-minutes of ball drills (i.e., basic technical drills with a partner), and 5-minutes of small-sided games (i.e., 5vs5 in a 30 $\times$ 20-m size pitch). After the WU athletes rested passively for 15-minutes before testing, as it happens in a competition match. The experimental PAP warm-ups included the same exercises as the WU, with the addition (10-minutes after the end of WU) of one set of half back squats at 60, 80, or 100% of 1RM for a total of 10 repetitions (60%-1RM), 5 repetitions (80%-1RM), or 1 repetition (100%-1RM), respectively. All repetitions were performed at maximal voluntary concentric velocity. After each PAP load, athletes rested passively for 5-minutes before the H3JD, H3Jnd (measure in day 1) and S-30 tests (measure in day 2), 6-minutes before the SJ (measure in day 1) and CMJ tests (measure in day 2), and 8-minutes before the RSCOD (measure in day 1) and COD (measure in day 2), respectively.

Statistical Analyses

Data is presented as mean $\pm$ standard deviation (SD). All data were first log-transformed to reduce biases arising from non-uniformity error. The standardized difference or effect size [ES, 90% confidence limits (CL)] in the selected variables was calculated. Threshold values for Cohen's *ES* statistics were $>$0.2 (small), $>$0.6 (moderate), and $>$1.2 (large) (Hopkins et al., 2009). For within-group comparisons, the chances that the differences in performance were better/greater [i.e., greater than the smallest worthwhile change (0.2 multiplied by the between-subject standard deviation, based on Cohen's *d* principle)], similar, or worse/smaller were calculated. Quantitative chances (QC) of beneficial/better, similar/trivial, or detrimental/poorer effect were assessed qualitatively as follows: <1%, almost certainly not; >1–5%, very unlikely; >5–25%, unlikely; >25–75%, possible; >75–95%, likely; >95–99%, very likely; and >99%, most likely (Hopkins et al., 2009). If the chance that the true value is >25% beneficial and >0.5% chance that it is harmful, the clinically effect was considered as unclear. However, the clinical inference was declared as beneficial when odds ratio of benefit/harm was >66% (Hopkins et al., 2009). A specific Excel spreadsheet from sportsci.org was used to examine the within-group (between PAP protocols) (xPostOnlyCrossover.xls) comparisons.

RESULTS

The mean 1RM half-squat for this study was 114.3 ± 15.0 kg. **Table 1** shows the results for each test after each warm-up protocol.

Comparisons between the control warm-up and the PAP warm-ups are indicated in **Table 2**. Likely to most likely improvements were shown in H3Jd, H3Jnd, COD, RSCODb, and RSCODt only after the 80%-1RM protocol in comparison to WU. Furthermore, a possibly greater enhancement was found in RSCODt after the 60%-1RM protocol compared to WU. Conversely, 100%-1RM and 60%-1RM protocols induced possible to most likely poorer performance in the H3Jd, H3Jnd, SJ, CMJ, COD, and RSCODb in comparison to WU. Similarly, a likely poorer S-30 performance was observed after 100%-1RM compared to WU.

Comparisons between the PAP warm-up protocols are indicated in **Table 3**. Possibly to most likely improvements were shown in H3Jd, H3Jnd, SJ, CMJ, COD, RSCODb, and RSCODt after the 80%-1RM warm-up protocol in comparison to the 100%-1RM and 60%-1RM warm-up protocols. In addition, a possible better performance was achieved in the S-30 after the 80%-1RM warm-up compared to the 100%-1RM warm-up, while the 60%-1RM warm-up induced possible and very likely better S-30 performance in comparison to the 80%-1RM and 100%-1RM warm-up protocols, respectively. Finally, better performance in H3Jd (possible), H3Jnd (likely) and SJ (likely) were observed after 100%-1RM warm-up compared to 60%-1RM warm-up, whereas better performance in RSCODb (possible), RSCODt (likely), and S-30 (very likely) were observed after the 60%-1RM warm-up compared to the 100%-1RM warm-up.

TABLE 1 | Physical performance of soccer players after different warm-up protocols.

	WU	100%-1RM	80%-1RM	60%-1RM
H3Jd (m)	6.53 ± 0.34	6.40 ± 0.36	6.73 ± 0.41	6.26 ± 0.49
H3Jnd (m)	6.57 ± 0.26	6.56 ± 0.43	6.71 ± 0.36	6.32 ± 0.39
SJ (cm)	37.4 ± 4.9	36.7 ± 4.9	38.8 ± 4.7	34.5 ± 5.4
CMJ (cm)	39.8 ± 3.2	38.6 ± 5.3	40.7 ± 4.7	38.4 ± 3.2
COD (s)	7.23 ± 0.27	7.39 ± 0.38	7.12 ± 0.26	7.38 ± 0.33
RSCODb (s)	5.77 ± 0.15	5.94 ± 0.11	5.67 ± 0.13	5.89 ± 0.21
RSCODt (s)	35.7 ± 0.65	35.8 ± 0.62	35.0 ± 0.67	35.5 ± 0.70
S-30 (s)	4.05 ± 0.23	4.13 ± 0.23	4.09 ± 0.28	4.04 ± 0.23

H3Jd and H3Jnd, triple hop test with dominant and non-dominant leg, respectively, SJ, squat jump; CMJ, countermovement jump; COD, change of direction ability test; RSCODb and RSCODt, repeated sprint with change of direction best and total times, respectively, S-30, linear 30-m sprint test. WU, control warm-up protocol; 100%-1RM, 80%-1RM, and 60%-1RM, PAP warm-up protocols at 60, 80, and 100% of one repetition maximum in half-squat.

DISCUSSION

The aim of this study was to compare the effects of different conditioning intensities on the physical fitness (i.e., PAP) of professional male field soccer players. Main results indicate improvements in jumping, single and repeated COD speed after the 80%-1RM protocol in comparison to WU. Moreover, better jumping, as well as single and repeated COD speed improvements were observed after the 80%-1RM compared to the 60%-1RM and 100%-1RM protocols. Therefore, a moderate intensity (i.e., 80%-1RM) appears to be more effective than low (i.e., 60%-1RM) and maximal (i.e., 100%-1RM) warm-up strategies to induce greater PAP, including greater jumping, single and repeated COD speed in male soccer players.

Regarding jumping performance, likely to most likely improvements were shown in H3Jd and H3Jnd only after the 80%-1RM protocol in comparison to WU. Moreover, possibly to most likely improvements were shown in H3Jd, H3Jnd, SJ, and CMJ test after the 80%-1RM warm-up protocol in comparison to the 100%-1RM and 60%-1RM warm-up protocols. Improvements in jumping performance after loaded squat PAP protocols have been previously observed in male athletes from team-sports such as rugby, volleyball and soccer (Gouvêa et al., 2013), and may be explained by several neuro-mechanical short-term adaptations (e.g., increased muscle-tendon stiffness) (Tillin and Cooke, 2009). Moreover, the PAP effects depend on the balance between fatigue and neuromuscular potentiation (Tillin and Bishop, 2009), which in turn depends on the load-related intensity used (Sale, 2004). In the current study, a load of moderate-intensity (i.e., 80%-1RM) induced greater jumping performance improvements compared with loads of lower (i.e., 60%-1RM) or greater (i.e., 100%-1RM) intensity, agreeing with previous studies that found greater PAP effects after loads of intermediate intensity (Gouvêa et al., 2013). Of note, the greater PAP effect after intermediate-intensity loads may be particularly important when PAP actions are performed with the intention of maximizing movement velocity, leading to the recruitment of fast-twitch muscle fibers, which is considered a key factor to induce PAP (Turner et al., 2015). This improvement in jumping performance after loaded squats have been observed even after 6 h from the PAP warm-up (Saez-Saez de Villarreal et al., 2007). In addition, is important to note that soccer players' characteristics may affect the PAP magnitude (Sanchez-Sanchez et al., 2018), thus current results should be interpreted considering the high training level of the soccer players.

The results indicate likely improvements in the COD after the 80%-1RM protocol in comparison to WU, and likely poorer performance after the 100%-1RM and 60%-1RM protocols. Current outcomes are difficult to compare with previous findings,

TABLE 2 | Comparisons of soccer player's physical performance after a traditional (control) warm-up versus three different warm-up conditions.

	% (CL90%)	ES (CL90%)	Chances	Outcome
WU vs. 100%-1RM				
H3Jd	−2.0 (−4.4; 0.5)	−0.35 (−0.79; 0.08)	2/24/73%	Possibly
H3Jnd	−0.3 (−2.7; 2.2)	−0.07 (−0.65; 0.52)	21/44/34%	Possibly
SJ	−2.0 (−8.1; 4.5)	−0.15 (−0.61; 0.32)	10/48/42%	Possibly
CMJ	−3.5 (−8.7; 1.9)	−0.41 (−1.04; 0.21)	5/22/73%	Possibly
COD	−2.1 (−4.4; 0.2)	−0.50 (−1.04; 0.04)	2/14/83%	Likely
RSCODb	−3.0 (−3.9; −2.1)	−1.03 (−1.32; −0.73)	0/0/100%	Most Likely
RSCODt	−0.3 (−0.5; −0.1)	−0.14 (−0.25; −0.03)	0/83/17%	Likely trivial
S-30	−1.7 (−2.2; −1.2)	−0.28 (−0.36; −0.20)	0/5/95%	Likely
WU vs. 80%-1RM				
H3Jd	3.0 (0.7; 5.3)	0.52 (0.13; 0.91)	92/8/0%	Likely
H3Jnd	2.2 (0.2; 4.2)	0.51 (0.05; 0.97)	88/11/1%	Likely
SJ	3.8 (−3.0; 11.1)	0.27 (−0.22; 0.76)	60/34/6%	Unclear
CMJ	2.0 (−2.6; 6.7)	0.22 (−0.30; 0.75)	53/38/9%	Unclear
COD	1.6 (−0.4; 3.5)	0.38 (−0.09; 0.86)	75/22/2%	Likely
RSCODb	1.6 (0.5; 2.8)	0.58 (0.16; 1.00)	93/6/0%	Likely
RSCODt	2.0 (1.2; 2.7)	0.99 (0.60; 1.38)	100/0/0%	Most Likely
S-30	−0.9 (−3.7; 1.7)	−0.15 (−0.60; 0.29)	9/49/42%	Unclear
WU vs. 60%-1RM				
H3Jd	−4.3 (−5.8; −2.7)	−0.77 (−1.06; −0.48)	0/0/100%	Most Likely
H3Jnd	−3.8 (−6.0; −1.6)	−0.91 (−1.46; −0.37)	0/2/98%	Very Likely
SJ	−8.0 (−11.8; −4.0)	−0.60 (−0.91; −0.30)	0/2/98%	Very Likely
CMJ	−3.5 (−5.0; −1.9)	−0.40 (−0.59; −0.22)	0/3/97%	Very Likely
COD	−2.0 (−3.3; −0.7)	−0.48 (−0.80; −0.17)	0/6/93%	Likely
RSCODb	−2.1 (−3.7; −0.4)	−0.72 (−1.28; −0.15)	1/6/94%	Likely
RSCODt	0.5 (−0.1; 1.1)	0.26 (−0.03; 0.56)	65/34/1%	Possibly
S-30	0.2 (0.1; 0.4)	0.04 (0.01; 0.07)	0/100/0%	Most Likely trivial

To avoid a misinterpretation of the results, positive results indicate a better performance in favor of the PAP warm-up protocol, while negative results show a better performance in favor of the control warm-up protocol. CL, confidence limits; ES, effect size; PAP, post-activation potentiation; H3Jd and H3Jnd, triple hop test with dominant and non-dominant leg, respectively; SJ, squat jump; CMJ, countermovement jump; COD, change of direction ability test; RSCODb and RSCODt, repeated sprint with change of direction best and total times, respectively; S-30, linear 30-m sprint test. WU, Control warm-up protocol; 100%-1RM, 80%-1RM, and 60%-1RM, post-activation potentiation warm-up protocols at 60, 80, and 100% of one repetition maximum in half-squat.

given the limited literature related to COD performance and PAP (Lockie et al., 2017). However, two previous studies observed improvements in COD performance after warm-up actions that included loaded exercises (Zois et al., 2011; Sole et al., 2013), and the improvement may be related to acute increase of reactive strength (Sole et al., 2013). Reactive strength is the ability to quickly change from the eccentric to the concentric phase during a stretch-shortening cycle muscle action (Young et al., 1998). In this sense, a greater reactive strength may help to improve the ability to perform sudden stops and to accelerate from there (Spiteri et al., 2013), hence improving COD speed (Sheppard and Young, 2006). Of note, a greater PAP effect (i.e., greater COD performance) was observed after the 80%-1RM versus the 60%-1RM, since the load used in the 80%-1RM may help to maximize the acceleration phase of the COD action (McBride et al., 2005), implicating a better use of the stretch-shortening cycle in the deceleration-acceleration transition of the COD movement. However, the 100%-1RM did not maximize COD performance. In this sense, the PAP effect may not proportionally depend on the load used (i.e., the higher the better), but other factors also may modulate the effect, such as the muscle fiber type, athletes' performance level, exercise type, time interval between the conditioning stimulus and the performance testing, among others (Sanchez-Sanchez et al., 2018). In fact, it has been suggested that there are PAP responders that may benefit from exercises designed to induce PAP, whereas others may not respond (Evetovich et al., 2015).

Regarding the RSCOD test, likely and most likely improvements were found in RSCODb and RSCODt with 80%-1RM in comparison to WU, respectively. Improvements in RSCOD performance after loaded back half-squat PAP protocols have been previously observed in elite male handball (Okuno et al., 2013) and soccer players (Sanchez-Sanchez et al., 2018). The 80%-1RM may improve neuromuscular capacity (Hodgson et al., 2005), allowing an increase in athlete's power (Tillin and Bishop, 2009), thus better ability to repeat sprints (Glaister, 2005). Although warm-ups delivered to induce PAP may increase RSCOD performance, the load used must be applied with caution. Heavy loads (>90% 1RM), with recovery times of 8-minutes, may allow improvements in the total time and sprint time in a repeated sprint test (Low et al., 2015). However, the use of a heavier load (i.e., 100%-1RM protocol)

TABLE 3 | Comparisons of soccer player's physical performance after three different warm-up conditions.

	% (CL90%)	ES (CL90%)	Chances	Outcome
100%-1RM vs. 80%-1RM				
H3Jd	5.1 (3.7; 6.5)	0.79 (0.58; 1.00)	100/0/0%	Most Likely
H3Jnd	2.5 (1.1; 3.9)	0.35 (0.15; 0.55)	90/10/0%	Likely
SJ	5.9 (3.3; 8.7)	0.40 (0.22; 0.57)	96/4/0%	Very Likely
CMJ	5.7 (2.5; 9.1)	0.38 (0.16; 0.59)	92/8/0%	Likely
COD	3.6 (1.4; 5.7)	0.65 (0.25; 1.04)	97/3/0%	Very Likely
RSCODb	4.5 (3.6; 5.4)	2.15 (1.70; 2.59)	100/0/0%	Most Likely
RSCODt	2.3 (1.6; 2.9)	1.21 (0.84; 1.57)	100/0/0%	Most Likely
S-30	0.8 (−2.1; 3.5)	0.13 (−0.36; 0.63)	41/47/12%	Possibly
100%-1RM vs. 60%-1RM				
H3Jd	−2.3 (−5.6; 1.1)	−0.37 (−0.92; 0.17)	4/24/71%	Possibly
H3Jnd	−3.5 (−6.8; −0.1)	−0.51 (−1.01; −0.01)	1/13/86%	Likely
SJ	−6.1 (−11.8; 0.0)	−0.43 (−0.86; 0.00)	1/16/83%	Likely
CMJ	0.1 (−5.7; 6.2)	0.01 (−0.39; 0.40)	20/62/18%	Possibly trivial
COD	0.1 (−2.4; 2.5)	0.01 (−0.43; 0.46)	23/57/20%	Possibly trivial
RSCODb	0.9 (−0.9; 2.7)	0.41 (−0.44; 1.26)	67/22/11%	Possibly
RSCODt	0.8 (0.2; 1.5)	0.43 (0.08; 0.78)	87/12/0%	Likely
S-30	1.9 (1.4; 2.4)	0.34 (0.25; 0.43)	99/1/0%	Very Likely
60%-1RM vs. 80%-1RM				
H3Jd	7.6 (4.3; 10.9)	0.88 (0.51; 1.24)	100/0/0%	Most Likely
H3Jnd	6.2 (3.1; 9.4)	0.90 (0.45; 1.34)	99/1/0%	Very Likely
SJ	12.9 (5.8; 20.3)	0.72 (0.34; 1.11)	98/2/0%	Very Likely
CMJ	5.6 (0.3; 11.2)	0.61 (0.04; 1.18)	89/10/1%	Likely
COD	3.6 (1.5; 5.9)	0.87 (0.36; 1.39)	98/2/0%	Very Likely
RSCODb	3.8 (1.6; 6.0)	1.46 (0.64; 2.29)	99/1/0%	Very Likely
RSCODt	1.5 (0.6; 2.4)	0.69 (0.27; 1.10)	97/3/0%	Very Likely
S-30	−1.2 (−3.8; 1.6)	−0.16 (−0.53; 0.21)	5/52/42%	Possibly

To avoid a misinterpretation of the results, positive results denote a better performance in favor of the PAP warm-up protocol indicated at the right, while negative results denote a better performance in favor of the PAP warm-up protocol indicated at the left. CL, confidence limits; ES, effect size; PAP, post-activation potentiation; H3Jd and H3Jnd, triple hop test with dominant and non-dominant leg, respectively; SJ, squat jump; CMJ, countermovement jump; COD, change of direction ability test; RSCODb and RSCODt, repeated sprint with change of direction best and total times, respectively; S-30, linear 30-m sprint test. WU, control warm-up protocol; 100%-1RM, 80%-1RM, and 60%-1RM, PAP warm-up protocols at 60, 80, and 100% of one repetition maximum in half-squat.

may induce most likely poorer performance in the RSCODb in comparison to a WU, even when 8-minutes of rest are allowed. Although potentiation and fatigue coexist, the 100%-1RM protocol may have induced fatigue to a greater extent than its PAP effect, potentially due to decreased release of calcium from the sarcoplasmic reticulum, leading to reduced calcium concentration in the myoplasm (Rassier and MacIntosh, 2000). In this sense, to optimally induce PAP, the load used must be selected accurately in male soccer players (Hammami et al., 2018). Although previous studies analyzed the effect of PAP warm-ups on RSCOD (Sanchez-Sanchez et al., 2018), this is the first study that compared the effects of three different loaded protocols on RSCOD performance, a key fitness specific-trait for soccer (Schimpchen et al., 2015), which determines match physical performance (Rampinini et al., 2007) and differentiates between competitive levels (Rampinini et al., 2009). Therefore, current findings may help practitioners to optimally prepare players before a match.

No changes in S-30 performance was observed after the 60%-1RM and the 80%-1RM compared to WU. No effects in sprint time after heavy loaded squat PAP protocols have been previously observed in soccer players (Tillin and Cooke, 2009). In contrast, the positive effects of heavy-load squats was obtained at distances of 10 to 40-m (McBride et al., 2005; Chatzopoulos et al., 2007; Rahimi, 2014). The mechanisms that underlie the effects of PAP warm-ups using loaded exercises on sprint performance have not been clarified (McBride et al., 2005). Maximal sprint velocity (i.e., distances >30 m) may depend on the force of the extensor muscles of the hip in order to re-incorporate the leg in the swing phase and thus maintain an adequate stride length (Weyand et al., 2000). Although the muscle force may be increased through a PAP warm-up, inducing an increased muscle stiffness (Moir et al., 2009), based on previous research, it was speculated that the PAP should be related to the volume of the pre-load (Evetovich et al., 2015). The PAP has traditionally been induced through the use of multiple sets of heavy isotonic resistance exercise (Wilson et al., 2013), but in this study only one set of 60%-1RM and 80%-1RM was applied. From a practical perspective, given the timeframe separating the end of the warm-up and the start of a soccer match, there is no time to include multiple sets (Russell et al., 2014). On the other hand, a likely poorer performance after 100%-1RM compared to WU was observed. It is possible that the recovery time used in the present study (i.e., 5-minutes) was not enough to elicit a significant PAP effect after the 100%-1RM in some players. Considering that fatigue and potentiation co-exist (Rassier and MacIntosh, 2000), shorter rest intervals may increase fatigue (Tillin and Cooke, 2009). In this sense, <4 min of rest after a PAP warm-up of 5-RM did not induce an increase in sprint performance (Tillin and Cooke, 2009). However, 5 min of rest after a PAP warm-up, as used in the current study, seems to be adequate in order to reload phosphocreatine stores (Chatzopoulos et al., 2007). Still, this did not explain the lack of improvements or even poorer sprinting capability after the 100%-1RM strategy used in the current study. It has been suggested that in order to improve sprinting performance, the potential effect of heavier PAP protocols, including load scheme and rest time, should be prescribed on an individual basis (Mola et al., 2014).

Using an 80%-1RM protocol could be an effective strategy to enhance the physical performance of elite male soccer player, with potential implications for a better performance, especially at the beginning of games. Coaches should carefully consider the recovery time between the PAP application and the start of a match in order to reduce the risk of fatigue. Moreover, although in the current study an 80%-1RM protocol induced greater mean improvements in the physical performance of soccer players, PAP protocols should be elaborated considering athlete's individual characteristics.

Potential limitations of the current study are related to the lack of physiological and biochemical measurements, in order to further understand the underlying factors related with the observed PAP phenomenon. The limited number of subjects involved in the current study could be recognized as an additional limitation, in line with the use of magnitude-based inferences (MBI). Such statistical approach has been criticized as may induce a greater risk of type I error (Sainani, 2018). On the other side, its use have been strongly supported in sport science studies (Batterham and Hopkins, 2019). Future studies should strive to elucidate if current results may be transferred to competition scenarios, analyzing performance indices during a match, such as covered distance at high-intensity, accelerations, among others short-term high-intensity actions. In addition, future studies may analyse the potential interfering effect (if any) of repeated physical fitness test (i.e., H3JD, SJ) performed on the same testing session and its role on PAP after warm-ups using different 1RM back-squat intensities.

CONCLUSION

In conclusion, a moderate intensity (i.e., 80%-1RM back squat) may induce greater improvements (i.e., PAP effect) in jumping, repeated COD speed and non-repeated COD speed in elite level male soccer players when compared to low (60%-1RM) and high (100%-1RM) intensity warm-up protocols.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of "Ethics Committee, Pontifical University of Salamanca" with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the "Ethics Committee, Pontifical University of Salamanca (Annex III, Act 13/2/2019)."

AUTHOR CONTRIBUTIONS

CP, RR-C, and JS-S designed the work. CP, DH, and JS-S acquired the data. CP, FN, RR-C, JS-S, and OG-S analyzed and interpreted of data. All authors drafted the manuscript, critically revised the manuscript and approved the final version of the manuscript to be published. CP, RR-C, FN, and JS-S agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved.

REFERENCES

Barnes, K. R., Hopkins, W. G., McGuigan, M. R., and Kilding, A. E. (2015). Warm-up with a weighted vest improves running performance via leg stiffness and running economy. *J. Sci. Med. Sport* 18, 103–108. doi: 10.1016/j.jsams.2013.12.005

Batterham, A., and Hopkins, W. (2019). The problems with "The Problem with 'Magnitude-Based Inference'". *Med. Sci. Sports Exerc.* 51:599.

Chatzopoulos, D. E., Michailidis, C. J., Giannakos, A. K., Alexiou, K. C., Patikas, D. A., Antonopoulos, C. B., et al. (2007). Postactivation potentiation effects after heavy resistance exercise on running speed. *J. Strength Cond. Res.* 21, 1278–1281. doi: 10.1519%2F00124278-200711000-00051

Evetovich, T. K., Conley, D. S., and McCawley, P. F. (2015). Postactivation potentiation enhances upper- and lower-body athletic performance in collegiate male and remale athletes. *J. Strength Cond. Res.* 29, 336–342. doi: 10.1519/JSC.0000000000000728

Glaister, M. (2005). Multiple sprint work: physiological responses, mechanisms of fatigue and the influence of aerobic fitness. *Sport Med.* 35, 757–777. doi: 10.2165%2F00007256-200535090-00003

González-Mohíno, F., Martín, R., Juárez Santos-García, D., Fidel, P. A., de Asís-Fernández, F., Yustres, I., et al. (2018). Effects of high-intensity warm-ups on running performance. *Int. J. Sports Med.* 39, 426–432. doi: 10.1055/s-0044-102132

Gouvêa, A. L., Fernandes, I. A., César, E. P., Silva, W. A. B., and Gomes, P. S. C. (2013). The effects of rest intervals on jumping performance: a meta-analysis on post-activation potentiation studies. *J. Sports Sci.* 31, 459–467. doi: 10.1080/02640414.2012.738924

Hamada, T., Sale, D. G., MacDougall, J. D., and Tarnopolsky, M. A. (2000). Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *J. Appl. Physiol.* 88, 2131–2137. doi: 10.1152%2Fjappl.2000.88.6.2131

Hammami, A., Zois, J., Slimani, M., Russel, M., and Bouhlel, E. (2018). The efficacy, and characteristics, of warm-up and re-warm-up practices in soccer players: a systematic review. *J. Sports Med. Phys. Fitness* 58, 135–149. doi: 10.23736/S0022-4707.16.06806-7

Hodgson, M., Docherty, D., and Robbins, D. (2005). Post-activation potentiation: underlying physiology and implications for motor performance. *Sport Med.* 35, 585–595. doi: 10.2165%2F00007256-200535070-00004

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–13.

Iaia, F. M., Rampinini, E., and Bangsbo, J. (2009). High-intensity training in football. *Int. J. Sports Physiol. Perform.* 4, 291–306.

Lockie, R. G., Lazar, A., Davis, D. L., and Moreno, M. R. (2017). Effects of postactivation potentiation on linear and change-of-direction speed: analysis of the current literature and applications for the strength and conditioning coach. *Strength Cond. J.* 40, 75–91.

Low, D., Harsley, P., Shaw, M., and Peart, D. (2015). The effect of heavy resistance exercise on repeated sprint performance in youth athletes. *J. Sports Sci.* 33, 1028–1034. doi: 10.1080/02640414.2014.979857

Maulder, P., Cronin, J., Maulder, P., and Cronin, J. (2015). Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability discriminative and predictive ability. *Phys. Ther. Sport* 6, 74–82. doi: 10.1016%2Fj.ptsp.2005.01.001

McBride, J. M., Nimphius, S., and Erickson, T. M. (2005). The acute effects of heavy-load squats and loaded countermovement jumps on sprint performance. *J. Strength Cond. Res.* 19, 893–897. doi: 10.1519%2F00124278-200511000-00029

Moir, G. L., Dale, J. R., and Dietrich, W. W. (2009). The acute effects of heavy back squats on machanical variables during a series of bilateral hops. *J. Strength Cond. Res.* 23, 1118–1124. doi: 10.1519/JSC.0b013e31819166c2

Mola, J. N., Bruce-Low, S. S., and Burnet, S. J. (2014). Optimal recovery time for postactivation potentiation in professional soccer players. *J. Strength Cond. Res.* 28, 1529–1537. doi: 10.1519/JSC.0000000000000313

Noyes, F. R., Barber, S. D., and Mangine, R. E. (1991). Abnormal lower limb symmetry determined by functional hop tests after anterior cruciate ligament rupture. *Am. J. Sports Med.* 19, 513–518. doi: 10.1177%2F036354659101900518

Okuno, N. M., Tricoli, V., Silva, S. B., Bertuzzi, R., Moreira, A., and Kiss, M. (2013). Postactivation potentiation on repeated-sprint ability in elite handball players. *J. Strength Cond. Res.* 27, 662–668. doi: 10.1519/JSC.0b013e31825bb582

Rahimi, R. (2014). The acute effects of heavy versus light-load squats on sprint performance. *Phys. Educ. Sport* 5, 163–169.

Rampinini, E., Couts, A. J., Castagna, C., Sassi, R., and Impellizzeri, F. M. (2007). Variation in top level soccer match performance. *Int. J. Sports Med.* 28, 1018–1024. doi: 10.1055%2Fs-2007-965158

Rampinini, E., Sassi, A., Morelli, A., Mazzoni, S., Fanchini, M., and Coutts, A. J. (2009). Repeated-sprint ability in professional and amateur soccer players. *Appl. Physiol. Nutr. Metab.* 34, 1048–1054. doi: 10.1139/H09-111

Rassier, D. E., and MacIntosh, B. R. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Braz. J. Med. Biol. Res.* 33, 499–508. doi: 10.1590%2Fs0100-879x2000000500003

Russell, M., Cook, C. J., and Kilduff, L. P. (2014). "Match day strategies to enhance the physical and technical performance of rugby players," in *The Science of Rugby*, eds C. Twist and P. Worsfold (London: Routledge), 97–114.

Saez-Saez de Villarreal, E., Gonzalez-Badillo, J. J., and Izquierdo, M. (2007). Optimal warm-up stimuli of muscle activation to enhance short and long-term acute jumping performance. *Eur. J. Appl. Physiol.* 100, 393–401. doi: 10.1007%2Fs00421-007-0440-9

Sainani, K. L. (2018). The problem with "Magnitude-based Inference". *Med. Sci. Sports Exerc.* 50, 2166–2176. doi: 10.1249%2Fmss.0000000000001645

Sale, D. (2004). Postactivation potentiation: role in performance. *Br. J. Sports Med.* 38, 386–387. doi: 10.1136%2Fbjsm.2002.003392

Sanchez-Sanchez, J., Rodríguez-Fernández, A., Petisco, C., Ramirez-Campillo, R., and Nakamura, F. Y. (2018). Effects of different post-activation potentiation warm-ups on repeated sprint ability in soccer players from different competitive levels. *J. Hum. Kinet.* 61, 189–197. doi: 10.1515/hukin-2017-0131

Sassi, R. H., Dardouri, W., Yahmed, M. H., Gmada, N., Mahfoudhi, M. E., and Gharbi, Z. (2009). Relative and absolute reliability of a modified agility T-test and its relationship with vertical jump and straight sprint. *J. Strength Cond. Res.* 23, 1644–1651. doi: 10.1519/JSC.0b013e3181b425d2

Schimpchen, J., Skorski, S., Nopp, S., and Meyer, T. (2015). Are "classical" tests of repeated-sprint ability in football externally valid? A new approach to determine in-game sprinting behaviour in elite football players. *J. Sports Sci.* 34, 519–526. doi: 10.1080/02640414.2015.1112023

Seitz, L. B., and Haff, G. G. (2016). Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: a systematic review with meta-analysis. *Sport Med.* 46, 231–240. doi: 10.1007/s40279-015-0415-7

Sheppard, J. M., and Young, W. B. (2006). Agility literature review: classifications, training and testing. *J. Sports Sci.* 24, 919–932. doi: 10.1080%2F02640410500457109

Sole, C. J., Moir, G. L., Davis, S. E., and Witmer, C. A. (2013). Mechanical analysis of the acute effects of a heavy resistance exercise warm-up on agility performance in court-sport athletes. *J. Hum. Kinet.* 39, 147–156. doi: 10.2478/hukin-2013-0077

Spiteri, T., Cochrane, J. L., Hart, N. H., Haff, G. G., and Nimphius, S. (2013). Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur. J. Sport Sci.* 13, 646–652. doi: 10.1080/17461391.2013.774053

Stølen, T., Chamari, K., Castagna, C., and Wisløff, U. (2005). Physiology of soccer. *Sport Med.* 35, 501–536.

Tillin, K. A., and Cooke, C. (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *J. Strength Cond. Res.* 23, 1960–1967. doi: 10.1519/JSC.0b013e3181b8666e

Tillin, N. A., and Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sport Med.* 39, 147–166. doi: 10.2165/00007256-200939020-00004

Turner, A. P., Bellhouse, S., Kilduff, L. P., and Russell, M. (2015). Post-activation potentiation of sprint acceleration performance using plyometric exercise. *J. Strength Cond. Res.* 29, 343–350. doi: 10.1519%2Fjsc.0000000000000647

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., and Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J. Appl. Physiol.* 89, 1991–1999. doi: 10.1152%2Fjappl.2000.89.5.1991

Wilson, J. M., Duncan, N. M., Marin, P. J., Brown, L. E., Loenneke, J. P., Wilson, S., et al. (2013). Meta-Analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *J. Strength Cond. Res.* 27, 854–859. doi: 10.1519/JSC.0b013e31825c2bdb

Young, W. B., Jenner, A., and Griffiths, K. (1998). Acute enhancement of power performance from heavy load squats. *J. Strength Cond. Res.* 12, 82–84. doi: 10.1519%2F00124278-199805000-00004

Zois, J., Bishop, D. J., Ball, K., and Aughey, R. J. (2011). High-intensity warm-ups elicit superior performance to a current soccer warm-up routine. *J. Sci. Med. Sport* 14, 522–528. doi: 10.1016/j.jsams.2011.03.012

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Coach Turnover in Top Professional Brazilian Football Championship: A Multilevel Survival Analysis

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In this study, we examined the probability of coaches' survival in the top Brazilian professional football championship considering variation across the competitive seasons between 2012 and 2017, considering a multilevel framework. We also considered whether previous coaching experience in the top Brazilian professional football championship would change the probability of coaches' survival across the season. The data considered 4,560 games from the top professional Brazilian football league (Campeonato Brasileiro Série A) between the 2012 and 2017 seasons. At the start of each season, the coach from each team was followed, being recorded at the time the event occurred, i.e., the coach being sacked. A total survival of 120 coaches was considered between the seasons of 2012 and 2017, i.e., 20 coaches at the beginning of each season. Coaches were assigned as novice (no previous experience as head coach in the top Brazilian championship) or experienced (with at least some previous experience as head coach in the top Brazilian championship). Data were available and extracted from the official website of the Brazilian Football Confederation[1]. On average and considering un-pooled observations, the median life of a coach was about 16.5 rounds. Considering variation between 2012 and 2017 seasons, only about 26.3% (95% CI: 18.2–36.1) of the coaches ended a season without being sacked. By mid-season, at round 19, the probability of coaches' survival was 0.42 (95% CI: 0.32–0.53). Variation between season on survival estimates per round was substantial (between-season standard deviation = 0.48, 95% credible intervals: 0.25–0.95; corresponding to an inverse logit = 0.62, 95% CI: 0.56–0.72). There was no substantial variation between novice and experienced coaches' survival probability. The present results expose the vulnerability of the coaching context in Brazilian football, potentially highlighting an excessive emphasis on short-term results to mediate club management decisions.

Keywords: employment, work performance, soccer, proportional hazards models, bayesian methods

[1]https://cbf.com.br/

INTRODUCTION

Sports coaching is a relatively new professional field in comparison to other professions, such as medicine, law, or teaching (Mallett and Lara-Bercial, 2016). Particularly in football, in the past few decades, the vocation of sports coaching has continued to develop toward professionalization across the world.

High performance football coaches play a central role in the coach-athlete-performance relationship (Lyle, 2002; Mallett and Lara-Bercial, 2016). Coaches often face challenges and constraints that influence their daily practice and the competitive outcome. These challenges often include increased number of international competitions, the increased importance of the stakes relative to the club investment in the football team, discrepancy between available resources and competitive expectations (Mallett and Lara-Bercial, 2016). Nevertheless, high performance football coaches are evaluated for wins or losses, potentially leading to a high coach turnover (Duffy et al., 2011; Mallett and Lara-Bercial, 2016). Hence, the development of the high-performance football coach professional activity is developed within a dynamic, complex, and demanding context.

Observations in European top football leagues have shown a consistent trend of high coach turnover rate (Barros et al., 2009; Lago-Peñas, 2011; Paola and Scoppa, 2012; Bell et al., 2013; van Ours and van Tuijl, 2016), despite the negative impacts of coaches' changes (Balduck et al., 2010; Lago-Peñas, 2011; Paola and Scoppa, 2012; van Ours and van Tuijl, 2016). It appears that coaches not meeting expectations in the first games or when results are worse than the results from the predecessor coach, have a higher likelihood of being sacked (Mallett and Lara-Bercial, 2016; van Ours and van Tuijl, 2016). Also, coaches turnover is noted to have a negative impact for the development of players and team performance after coaches' turnover (Barros et al., 2009; Mallett and Rynne, 2015; Mallett and Lara-Bercial, 2016). On the other hand, coaches' turnover also has potential negative impacts on the financial safety of sports clubs (Bell et al., 2013; Mallett and Lara-Bercial, 2016). For example, it has been reported that coaches' dismissal in Australian football had a net cost of about $11 million in payouts within a 5-year period (Mallett and Lara-Bercial, 2016).

Brazil is the country with the most wins in the FIFA World Cup (Hoffmann et al., 2002) and is consistently among the highest ranking countries by the Fédération Internationale de Football Association (Hoffmann et al., 2002; FIFA.com, 2019). Football is a highly relevant socioeconomic activity in Brazil, and the activity of football coaching, in particular, is recognized specifically as a profession by law (Brazil, 1993). However, in the Brazilian context, there are limited available data addressing the conflict of interest between the high performance football coach's survival, the team's long-term preparation, and the need for short-term club results, influenced by industry specificities such as media and sports fans pressure.

To the best of our knowledge, research questions and designs dealing with occurrence and timing of critical events in sports and exercise research are scarce. Event history analysis (also known as survival analysis) is used to study the timing of events where the response variable is the length of time between becoming exposed to the risk of an event and event occurrence (Steele, 2011). Changes in coaches' job status is an example of observations of each coach's time of survival to the risk of being sacked. These data can be viewed as a type of two-level hierarchical structure with episodes of being at risk of an event nested within individuals, and individuals may themselves be nested by competitive season. When considering events such as a coach being sacked, coaches' survival probabilities may vary substantially by competitive seasons due to potential influences on their daily practice and the competitive outcome. Multilevel modeling framework provides a flexible approach for the analysis of hierarchical (and nonhierarchical) structures, in particular in the case of clustered event history data (Goldstein, 2011). Therefore, in the present study, we examined the probability of coaches' survival in the top Brazilian professional football championship considering variation across the competitive seasons between 2012 and 2017, considering a multilevel framework. We also considered whether variation between head coaching experience in the top Brazilian professional football championship would influence the survival probability across the seasons.

MATERIALS AND METHODS

Data

The data in the present study are based on observations of 4,560 games from the top professional Brazilian football league (Campeonato Brasileiro Série A) between the 2012 and 2017 seasons. Hence, the period of observation comprised six seasons. The Serie A Brazilian football league is composed by 20 teams. Each plays 38 matches per season (i.e., 38 rounds), and at the end of the competition, the four teams with the lowest score are relegated and replaced by the four best teams of the second division. Considering variation between seasons in the teams entering the league, we considered 38 rounds of the season as the time unit of observation. At the start of each season, the coach from each team was followed, being recorded at the time event occurred, i.e., the coach being sacked. A total survival of 120 coaches was considered between the seasons of 2012 and 2017.

Data were extracted from the 4,560 match reports for the seasons between 2012 and 2017, available on the official website of the Brazilian Football Confederation (see text footnote 1). Considering the available information, we assigned coaches by experience as novice, i.e., with no previous experience as head coach in the top Brazilian championship, or experienced, i.e., with at least a previous experience as head coach in the top Brazilian championship. From the 120 coaches observed, 17 were assigned as novice, and the remaining 103 were assigned as experienced.

Data Analysis

Given that the unit of time comprises the 38 rounds in each season, we assumed the possibility for right censoring. Right censoring occurs in survival analysis when some individuals never experience the target event during the period of observation (Singer and Willett, 2003). In the present study, the follow-up of the coaches that did not experience the event at the end of the season was not considered in the present analysis, whether the coaches remained in the same team competing in the Serie A, remained in the same team if the team was relegated to the lower division, or changed to another team after the end of the season.

The survival function gives the probability that a randomly selected coach survives longer than some specified time period (in the present study, each league round). Hence, the survivor function is generally given by the number of individuals who have not experienced the event by the end of each time period divided by the number of individuals in the data set (Singer and Willett, 2003). Initially, the survival function was estimated for each coach without accounting for coach turnover variation by season using an un-pooled logistic regression. Hence, each round across the Brazilian top professional football league between 2012 and 2017, without accounting for variation between seasons, had its own intercept with a simple aggregated binomial model, described following a Bayesian notation:

$surv_i \sim$ Binomial($n_{[i]}$, $p_{[i]}$)	[likelihood]
logit(p_i) = $\alpha_{[i]}$	[unique log-odds for each round *i*]
$\alpha \sim$ Normal(0,1)	[weakly regularizing prior]

Considering the hierarchical data, where each coach observation occurs within a higher order entity (between season), we then described the survival probability across the 38 rounds within the seasons using Bayesian multilevel modeling to estimate a partial pooling model. The multilevel model was produced as follows:

$Surv_i \sim$ Binomial($n_{[i]}$, $p_{[i]}$)	[likelihood]
logit($p_{[i]}$) = $\alpha_{SEASON[i]}$	[unique log-odds for each round *i* by season]
$\alpha_{SEASON} \sim$ Normal(α,σ)	[varying intercepts prior]
$\alpha \sim$ Normal(0,1)	[prior for average season]
$\sigma \sim$ Cauchy(0,1)	[prior for standard deviation of season]

Survival probabilities were extracted from both binomial models using the inverse logit function (Gelman and Hill, 2007; McElreath, 2015).

In the final step of the analysis, we examined the influence of previous experience as head coach on the top Brazilian professional championship. We considered the main effects for the proportion of novice coaches by experienced coaches at each round per season as population-level effect, plus the interaction with each round. We allowed for the proportion between novice and experienced coaches at each round to vary randomly by season at level 2.

We used weakly informative prior distributions for population-level, normal priors (0,1), and for group-level, Cauchy priors (0,1), effects. Posterior predictive checks were used to confirm that we did not omit relevant interactions (Gelman et al., 2013). Comparisons between un-pooled (single-level model) and partial pooled (multilevel model) models were made with the widely applicable information criteria (WAIC) (McElreath, 2015; Vehtari et al., 2016). For each model, we ran two chains for 4,000 iterations with a warm-up length of 1,000 iterations. The models were implemented with Markov Chain Monte Carlo (MCMC) simulation, *via* Hamiltonian Monte Carlo using Stan (Stan Development Team, 2015), obtained using "brms" package (Bürkner, 2017), available as a package in the R statistical language.

RESULTS

From the 120 coaches in the competitive top Brazilian football league between 2012 and 2017, 87 coaches were sacked during a season. On average and considering un-pooled observations, the median life of a coach was about 16.5 rounds.

Models' codes and respective summaries, trace plots to ascertain chains' convergence, and posterior predictive checks are presented as **Supplementary Material**. WAIC was substantially lower for the partial pooled model (WAIC = 847.99, standard error = 9.76) in contrast to un-pooled model (WAIC = 990.66, standard error = 21.60). Partial pooled model performed substantially better fitting the data when compared to un-pooled model.

Results from the partial pooled models, i.e., a multilevel logistic model to estimate the football coaches' survival across the 38 rounds in the Brazilian top professional league, are presented in **Table 1** and **Figure 1**. Considering variation between 2012 and 2017 seasons, only about 26.3% (95% CI: 18.2–36.1%) of the coaches ended a season without being sacked. By mid-season, at round 19, the probability of coaches' survival was 0.42 (95% CI: 0.32–0.53). Variation between season on survival estimates per round was substantial (between-season standard deviation = 0.48, 95% credible intervals: 0.25–0.95; corresponding to an inverse logit = 0.62, 95% CI: 0.56–0.72). Posterior estimates considering the influence of previous experience as head coach on the top Brazilian professional championship are presented as **Supplementary Material** (model m3). Conditional on the data, the observation of posterior draws posterior estimates for each coefficient of the interaction between each round and the proportion of novice. Experienced coaches showed that novice coaches had a similar survival probability to coaches with previous experience as head coach in the Brazilian top professional championship. As expected, there was substantial uncertainty in the proportion of experienced coaches across the 2012–2016 seasons. Codes, model summaries, and posterior predictive checks are available as **Supplementary Material**.

DISCUSSION

To the best of our knowledge, this is the first study to consider data surrounding turnover of top South-American, in particular Brazilian, professional football coaches across several seasons. Hence, the probability of coaches' survival in the top Brazilian professional football championship, considering variation across the competitive seasons between 2012 and 2017, was considered adopting a Bayesian multilevel framework. The survival probability of coaches in the top Brazilian professional football championship at the end of the seasons was about 26%. Hence, only about 7 coaches from 20 coaches at the beginning of each season were not dismissed during the season, indicating

TABLE 1 | Results from the Bayesian multilevel binomial model allowing for between-season variation at level 2.

Round	Estimate (95% credible interval)	Survival probability (95% credible interval), inverse logit estimate
1	3.62 (2.71–4.69)	0.97 (0.94–0.99)
2	2.64 (1.95–3.38)	0.93 (0.88–0.97)
3	1.93 (1.39–2.51)	0.87 (0.80–0.92)
4	1.61 (1.11–2.14)	0.83 (0.75–0.89)
5	1.25 (0.78–1.75)	0.78 (0.69–0.85)
6	0.95 (0.48–1.42)	0.72 (0.62–0.81)
7	0.68 (0.23–1.13)	0.66 (0.56–0.76)
8	0.64 (0.20–1.10)	0.65 (0.55–0.75)
9	0.57 (0.13–1.02)	0.64 (0.53–0.53)
10	0.50 (0.06–0.94)	0.62 (0.51–0.72)
11	0.35 (–0.08 to 0.79)	0.59 (0.48–0.69)
12	0.22 (–0.20 to 0.64)	0.55 (0.45–0.65)
13	0.15 (–0.30 to 0.60)	0.54 (0.43–0.65)
14	0.15 (–0.29 to 0.58)	0.54 (0.43–0.64)
15	0.08 (–0.34 to 0.51)	0.52 (0.42–0.62)
16	–0.05 (–0.47 to 0.36)	0.49 (0.38–0.59)
17	–0.12 (–0.55 to 0.31)	0.47 (0.37–0.58)
19	–0.32 (–0.75 to 0.11)	0.42 (0.32–0.53)
20	–0.36 (–0.79 to 0.06)	0.41 (0.31–0.51)
21	–0.39 (–0.82 to 0.03)	0.40 (0.31–0.51)
22	–0.39 (–0.82 to 0.05)	0.40 (0.31–0.51)
23	–0.43 (–0.88 to 0.01)	0.39 (0.20–0.50)
24	–0.49 (–0.93 to –0.04)	0.38 (0.28–0.49)
25	–0.60 (–1.04 to –0.16)	0.35 (0.26–0.46)
26	–0.71 (–1.15 to –0.27)	0.33 (0.24–0.43)
27	–0.79(–1.24 to –0.36)	0.31 (0.22–0.41)
28	–0.83 (–1.28 to –0.38)	0.30 (0.22–0.41)
29	–0.86 (–1.33 to –0.42)	0.30 (0.21–0.40)
30	–0.87 (–1.33 to –0.42)	0.30 (0.21–0.40)
31	–0.86 (–1.33 to –0.42)	0.30 (0.21–0.40)
32	–0.87 (–1.32 to –0.42)	0.30 (0.21–0.40)
33	–0.86 (–1.32 to –0.41)	0.30 (0.21–0.40)
34	–0.90 (–1.36 to –0.46)	0.29 (0.20–0.39)
35	–0.95 (–1.41 to –0.50)	0.28 (0.20–0.38)
36	–0.94 (–1.40 to –0.49)	0.28 (0.20–0.38)
37	–0.98 (–1.45 to –0.54)	0.27 (0.19–0.37)
38	–1.03 (–1.50 to –0.57)	0.26 (0.18–0.36)

a high coaching turnover among the top Brazilian professional football championship. We also considered here the possibility that novice coaches (i.e., with no previous experience as a head coach in the Brazilian top professional championship) might differ from coaches with previous experience as head coach in the Brazilian top professional championship. Conditional on the data, the survival rates were consistent between coaches according to previous experience as a head coach experience in the Brazilian top professional championship.

Considering the coaches at the start of the season, the coach turnover in the Brazilian professional football championship between 2012 and 2017 was higher at the beginning of the seasons, and in particular, it was apparent that by the first quarter of the competitive season, about 40% of the coaches were already dismissed. The present results contrast with observations in European professional football leagues such as the Jupiler League in Belgium (Balduck et al., 2010), the Premier League in England (Bachan et al., 2008), the Bundesliga in Germany (Barros et al., 2009), the Serie A in Italy (Paola and Scoppa, 2012), the Eredivise in the Netherlands (van Ours and van Tuijl, 2016), or the La Liga in Spain (Lago-Peñas, 2011). These observations highlight the vulnerability of the professional football coach in the Brazilian top professional championship.

It has been shown in the first three divisions of the main football leagues in Belgium that after a coaching change, teams tended to have positive results in the first games with a new coach (Balduck et al., 2010). On the other hand, observations based on 14 season data in the Netherlands showed that coaches were retained even when results were less positive in the earlier games but showed an improvement in performance in the subsequent games (van Ours and van Tuijl, 2016). Furthermore, clubs that maintain the coaches during the whole season tend to present better results and tend to be ranked higher at the end of the season (Balduck et al., 2010; Lago-Peñas, 2011; Paola and Scoppa, 2012; van Ours and van Tuijl, 2016). On the other hand, there has been consistent observation in different contexts showing that coaching changes have either no effect on team performance, or a slight negative impact. Particularly in football data, a null effect of coaching changes on team performance has been demonstrated in the Italian league (Paola and Scoppa, 2012) and the Dutch Premier League (Koning, 2003). Moreover, there are available observations that coaching changes resulted in worse team performance in English professional football (Audas et al., 1997). Similar null or negative trends between coaching changes and null or negative team performance have been noted in NBA teams (Giambatista, 2004), NFL (Rowe et al., 2005) and college basketball (Fizel and D'Itri, 1999). Hence, Brazilian club boards appear to overvalue the short-term impact of a coaching change, likely disregarding and/or compromising the potential for coaches to fully undertake their task. However, the coaches' professional context is complex and dynamic, hence other factors other than winning may contribute to maintain or dismiss the coach in the top Brazilian teams. Often, the power of the individuals involved in the club management, ownership and coach tenure, as well as expectations and the coach's reputation, all together contributes to alter the likelihood of dismissal (Wangrow et al., 2018). For example, considering other professional sports, observations in the NBA showed that first-year coaches had an important rate of dismissal, about 16% of the coaches (Wangrow et al., 2018).

Particularly in the present results, coaches were more likely to be dismissed during the first seven games, where about 35% of the coaches had been dismissed, on average, across the seasons. These results contrast with the observation in European leagues, where coaches' turnover tends to occur later in the season (Bachan et al., 2008; van Ours and van Tuijl, 2016). Overall, the present results showed a high probability (74%) of coaches being dismissed across the 38-round season, accounting for season variation in the top professional Brazilian football championship. Again, the present results markedly contrast with observations in European top football leagues. For example, in the Netherlands, it has been observed that after 34 games, 15–20% of coaches' changes were caused by dismissal, while 10% of coaches apparently left the club voluntarily (van Ours and van Tuijl, 2016).

The comparison between the un-pooled binary model, based on aggregated binomial model without accounting for variation between season, and the partial pooled model based on multilevel binomial model highlighted the importance of clustering effects

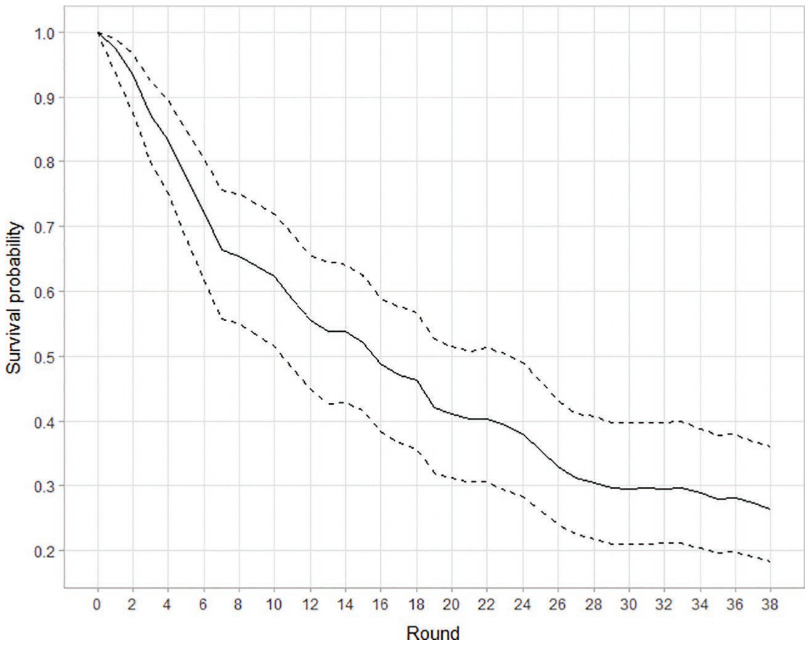

FIGURE 1 | Sample survival function for round at coach dismissal among 120 coaches between 2012 and 2017.

on the data. The need to consider the influence of group- or macro-level variables has been noted in other areas (Diez-Roux, 2000; Goldstein, 2011; McElreath, 2015), particularly in longitudinal observations such as event history analysis (Singer and Willett, 2003). Although there are studies considering multilevel approaches, particularly modeling coaches' turnover (Barros et al., 2009), its use in sports and exercise research is still limited. The present study adds by illustrating the application of a simple binomial modeling to describe the probability of coaches' survival across the season, allowing for variation between higher units of observation, in the present case' the multiple seasons observed. We also illustrated the possibility to consider covariates to explore between the coaches' variation in each round and across the period of observation. Furthermore, we used Bayesian methods to fit the models as an alternative to the limitations of frequentist methods (Gelman and Shalizi, 2013), as well as other approaches used in sports and exercise science (Welsh and Knight, 2015; Sainani, 2018). In particular, Bayesian methods consider parameters as random variables combining both sample data and prior distribution information to estimate posterior information (Gelman et al., 2013; McElreath, 2015). Bayesian estimations allow a probabilistic interpretation of how different parameters are used to simulate predictions and assess the quality and fit of the model (McElreath and Koster, 2014). Although we were not able to retain reliable information about coaches' characteristics that would allow a deeper understanding of the overall coaching turnover in the top Brazilian Football Championship within and between seasons, we illustrate an analytical framework to describe an applied example of time-event data in exercise and sport sciences.

In the **Supplementary Material**, we provide additional information about how we modeled the data, specifically the codes and assessment of the quality and fit of the derived models.

In the present study, we considered the available data of the Brazilian Football Confederation, which did not enable us to explore reasons for coaches' job termination during the period of observation (e.g., dismissal, voluntary exit, transfer to another team, retirement, among others). Also, we only considered coaches who started the season, which likely underestimates the overall coaching turnover in the top Brazilian Football Championship within and between seasons.

In summary, there was a substantial turnover of coaches in the Brazilian Football Championship between 2012 and 2017, with a large amount of variation between seasons. The present results expose the vulnerability of the coaching context in Brazilian football, apparently independent of the coaches' previous experience as head coach in the Brazilian Football Championship, potentially highlighting an excessive emphasis on short-term results to mediate club management decisions.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

AT, FM, RR, and WS contributed conception and design of the study. AT, FM, HC, RR, and WS organized the database. HC performed the statistical analysis. AT, FM, RR, and WS wrote the first drafts of the manuscript. AT, FM, HC, JN, and MM wrote sections of the manuscript. All authors contributed to manuscript review, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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REFERENCES

Audas, R., Dobson, S., and Goddard, J. (1997). Team performance and managerial change in the English Football League. *Econ. Aff.* 17, 30–36. doi: 10.1111/1468-0270.00039

Bachan, R., Reilly, B., and Witt, R. (2008). The hazard of being an English football league manager: empirical estimates for three recent league seasons. *J. Oper. Res. Soc.* 59, 884–891. doi: 10.1057/palgrave.jors.2602408

Balduck, A.-L., Buelens, M., and Philippaerts, R. (2010). Short-term effects of midseason coach turnover on team performance in soccer. *Res. Q. Exerc. Sport* 81, 379–383. doi: 10.1080/02701367.2010.10599686

Barros, C. P., Frick, B., and Passos, J. (2009). Coaching for survival: the hazards of head coach careers in the German "Bundesliga". *Appl. Econ.* 41, 3303–3311. doi: 10.1080/00036840701721455

Bell, A., Brooks, C., and Markham, T. (2013). The performance of football club managers: skill or luck? *Econ. Financ. Res.* 1, 19–30. doi: 10.1080/21649480.2013.768829

Brazil (1993). *Law no 8650. It deals with the work relations of the professional football coach and gives other measures.* (Brasília, DF: Diário oficial da União). (Official journal of State).

Bürkner, P. C. (2017). brms: An R package for bayesian generalized linear mixed models using Stan. *J. Stat. Softw.* 80, 1–28. doi: 10.18637/jss.v080.i01

Diez-Roux, A. V. (2000). Multilevel analysis in public health research. *Annu. Rev. Public Health* 21, 171–192. doi: 10.1146/annurev.publhealth.21.1.171

Duffy, P., Hartley, H., Bales, J., Crespo, M., Dick, F., Vardhan, D., et al. (2011). Sport coaching as a "profession": challenges and future directions. *Intern. J. Coach. Sci.* 5, 93–123.

Fifa.Com (2019). *FIFA/Coca-Cola World Ranking*. Available at: https://www.fifa.com/fifa-world-ranking/associations/association=bra/men/index.html (Accessed February 07, 2019).

Fizel, J. L., and D'itri, M. P. (1999). Firing and hiring of managers: does efficiency matter? *J. Manag.* 25, 567–585.

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., and Rubin, D. B. (2013). *Bayesian data analysis,* 3rd edn. (Boca Raton, FL: Chapman & Hall/CRC Press).

Gelman, A., and Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models.* (Cambridge: Cambridge University Press).

Gelman, A., and Shalizi, C. R. (2013). Philosophy and the practice of Bayesian statistics. *Br. J. Math. Stat. Psychol.* 66, 8–38. doi: 10.1111/j.2044-8317.2011.02037.x

Giambatista, R. C. (2004). Jumping through hoops: a longitudinal study of leader life cycles in the NBA. *Leadersh. Q.* 15, 607–624. doi: 10.1016/j.leaqua.2004.07.002

Goldstein, H. (2011). *Multilevel statistical models.* (Chichester, West Sussex: Wiley).

Hoffmann, R., Ging, L. C., and Ramasamy, B. (2002). The socio-economic determinants of international soccer performance. *J. Appl. Econ.* 5, 253–272. doi: 10.1080/15140326.2002.12040579

Koning, R. H. (2003). An econometric evaluation of the effect of firing a coach on team performance. *Appl. Econ.* 35, 555–564. doi: 10.1080/0003684022000015946

Lago-Peñas, C. (2011). Coach mid-season replacement and team performance in professional soccer. *J. Hum. Kinet.* 28, 115–122. doi: 10.2478/v10078-011-0028-7

Lyle, J. (2002). *Sports coaching concepts: A framework for coaches' behaviour.* (London: Routledge).

Mallett, C. J., and Lara-Bercial, S. (2016). "Serial winning coaches: people, vision, and environment" in *Sport and exercise psychology research*: From theory to practice. eds. M. Raab, P. Wylleman, R. Seiler, A. Elbe, and A. Hatzigeorgiadis (Amsterdam, The Netherlands: Elsevier), 289–322. doi: 10.1016/B978-0-12-803634-1.00014-5

Mallett, C., and Rynne, S. (2015). "Changing role of coaches across development" in *Routledge handbook of sport expertise.* ed. J. F. B. Damian (Abingdon: Routledge).

McElreath, R. (2015). *Statistical rethinking: A Bayesian course with examples in R and Stan.* (Boca Raton, FL: Chapman & Hall/CRC Press).

McElreath, R., and Koster, J. (2014). Using multilevel models to estimate variation in foraging returns. Effects of failure rate, harvest size, age, and individual heterogeneity. *Hum. Nat.* 25, 100–120. doi: 10.1007/s12110-014-9193-4

Paola, M. D., and Scoppa, V. (2012). The effects of managerial turnover: evidence from coach dismissals in Italian soccer teams. *J. Sports Econ.* 13, 152–168. doi: 10.1177/1527002511402155

Rowe, W. G., Cannella, A. A., Rankin, D., and Gorman, D. (2005). Leader succession and organizational performance: integrating the common-sense, ritual scapegoating, and vicious-circle succession theories. *Leadersh. Q.* 16, 197–219. doi: 10.1016/j.leaqua.2005.01.001

Sainani, K. L. (2018). The problem with "magnitude-based inference". *Med. Sci. Sports Exerc.* 50, 2166–2176. doi: 10.1249/MSS.0000000000001645

Singer, J. D., and Willett, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence.* (Oxford; New York: Oxford University Press).

Stan Development Team (2015). Stan: A C++ Library for Probability and Sampling, Version 2.7.0. http://mc-stan.org/

Steele, F. (2011). Multilevel discrete-time event history models with applications to the analysis of recurrent employment transitions. *Aust. N. Z. J. Stat.* 53, 1–20. doi: 10.1111/j.1467-842X.2011.00604.x

van Ours, J. C., and Van Tuijl, M. A. (2016). In-season head-coach dismissals and the performance of professional football teams. *Econ. Inq.* 54, 591–604. doi: 10.1111/ecin.12280

Vehtari, A., Gelman, A., and Gabry, J. (2016). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. ArXiv e-prints [Online]. 27, 1413–1432. Available at: http://arxiv.org/abs/1507.04544

Wangrow, D. B., Schepker, D. J., and Barker Iii, V. L. (2018). Power, performance, and expectations in the dismissal of NBA coaches: a survival analysis study. *Sport Manag. Rev.* 21, 333–346. doi: 10.1016/j.smr.2017.08.002

Welsh, A. H., and Knight, E. J. (2015). "Magnitude-based inference": a statistical review. *Med. Sci. Sports Exerc.* 47, 874–884. doi: 10.1249/MSS.0000000000000451

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METHODS
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Assessment of Basic Motions and Technique Identification in Classical Cross-Country Skiing

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Cross-country skiing is a popular Olympic winter sport, which is also used extensively as a recreational activity. While cross-country skiing primarily is regarded as a demanding endurance activity it is also technically challenging, as it contains two main styles (classical and skating) and many sub-techniques within these styles. To further understand the physiological demands and technical challenges of cross-country skiing it is imperative to identify sub-techniques and basic motion features during training and competitions. Therefore, this paper presents features for identification and assessment of the basic motion patterns used during classical-style cross-country skiing. The main motivation for this work is to contribute to the development of a more detailed platform for comparing and communicating results from technique analysis methods, to prevent unambiguous definitions and to allow more precise discussions and quality assessments of an athlete's technical ability. To achieve this, our paper proposes formal motion components and classical style technique definitions as well as sub-technique classifiers. This structure is general and can be used directly for other cyclic activities with clearly defined and distinguishable sub-techniques, such as the skating style in cross country skiing. The motion component features suggested in our approach are arm synchronization, leg kick, leg kick direction, leg kick rotation, foot/ski orientation and energy like measures of the arm, and leg motion. By direct measurement, estimation, and the combination of these components, the traditional sub-techniques of diagonal stride, double poling, double poling kick, herringbone, as well as turning techniques can be identified. By assuming that the proposed definitions of the classical XC skiing sub-techniques are accepted, the presented classifier is proven to map measures from the motion component definitions to a unique representation of the sub-techniques. This formalization and structure may be used on new motion components, measurement principles, and classifiers, and therefore provides a framework for comparing different methodologies. Pilot data from a group of high-level cross-country skiers employing inertial measurement sensors placed on the athlete's arms and skis are used to demonstrate the approach. The results show how detailed sub-technique information can be coupled with physical, track, and environmental data to analyze the effects of specific motion patterns, to develop useful debriefing tools for coaches and athletes in training and competition settings, and to explore new research hypotheses.

Keywords: cross-country skiing, inertial measurement unit (IMU), motion estimators, technique definition, technique classification

1. INTRODUCTION

Cross-country (XC) skiing is a popular Olympic winter sport but is also used extensively as a recreational activity. XC skiing is regarded as one of the most demanding of endurance sports and involves competitions on varying terrain where skiers employ different sub-techniques of the classical and skating styles. These sub-techniques include different technical features that require upper- and/or lower-body work to different extents. Specifically, XC skiers are continuously changing between and adapting the sub-techniques of the classical style—diagonal stride (DIA), double poling (DP), double poling with a kick (DK), and herringbone (HRB)—and skating style—paddle dance (G2), double dance (G3), single dance (G4), and skating without poles (G5)—to the varying terrain. In addition, the downhill tuck position (TCK) and a variety of turn techniques (TRN) are employed with both styles. Accordingly, XC skiers design their training to improve not only their physiological capacities, but also their technical and tactical expertise (Smith, 1992; Nilsson et al., 2004; Andersson et al., 2010; Bolger et al., 2015; Sandbakk and Holmberg, 2017).

The skiers' continuous choice of sub-technique is influenced by speed and external conditions (e.g., the profile of the track, snow conditions, waxing of skis, etc.), as well as individual performance level and physical characteristics. Thus, skiers must choose the terrain they train in and thereby the extent to which they train the different sub-techniques and technical features purposefully. In the classical style, DIA is primarily used in moderately steep to steep terrain, with the arms and legs moving in a manner similar to that of walking (Pellegrini et al., 2013; Dahl et al., 2017). During DP, propulsive forces are generated solely with the poles by the symmetrical and synchronous movement of both arms supported by considerable trunk flexion while crossing relatively flat terrain (Holmberg et al., 2005; Danielsen et al., 2015). In DK the upper-body movement is quite similar to the movement in DP but with additional propulsion from a left or right DIA-like leg kick. DK is normally used while traversing slightly uphill and flat terrain, depending on resistance imposed by the snow conditions (Lindinger et al., 2009a). The HRB is used during very steep uphill runs (Andersson et al., 2014b), whereas the TCK is used during downhill runs, and various TRN are employed during turns and track changes (Bucher Sandbakk et al., 2014).

In addition to mastering the different sub-techniques, a skier needs to adapt and efficiently shift between these, at speeds ranging from 5 to 70 km/h on inclines ranging from –20 to +20 percent gradients (Sandbakk and Holmberg, 2014). In the classical techniques, attaining higher speed requires both the production of sufficient propulsive force to increase cycle length, as well as more rapid cycles. Longer cycles are particularly important at high speeds on flat terrain, whereas rapid shorter cycles are mandatory for accelerating on steep hills, and during the start and sprinting at the finish of races (Lindinger et al., 2009b; Stöggl and Müller, 2009; Zory et al., 2009; Mikkola et al., 2013; Andersson et al., 2014b; Haugnes et al., 2018). To accomplish this, more explosive techniques, such as "running diagonal" and "kangaroo" double poling, have been developed (Holmberg et al., 2005; Andersson et al., 2014a). In addition, there is increasing focus on the downhill sections of a race, especially the challenging downhill turns, where faster skiers utilize the accelerating step-turn technique more extensively (Sandbakk et al., 2014). In order to properly communicate and study the effects of such motion patterns, more formal, detailed, and nuanced descriptions of the sub-techniques are needed. Such understanding contributes by providing a communication platform of high relevance for researchers in this field, as well as for developing preparation and debriefing tools for coaches and athletes in the new age of digital coaching.

Describing the motion patterns during training and competitions is now possible due to micro-sensor technology, which has revolutionized the possibilities of performing advanced field analyses of XC skiing. Since further understanding of both the physiological demands and technical challenges depends on detecting the sub-techniques, it is imperative to identify the features needed to classify sub-techniques and to describe the motion quality. The field of automatic identification of sub-techniques within XC skiing styles is getting more mature, and various models utilizing different methodologies are being published with increasing precision and accuracy of the classification results (Myklebust et al., 2011, 2015; Marsland et al., 2012, 2015, 2017, 2018; Holst and Jonasson, 2013; Sakurai et al., 2014, 2016; Stöggl et al., 2014; Rindal et al., 2017; Seeberg et al., 2017; Jang et al., 2018; Solli et al., 2018). However, comparing precision and specific results across different studies is challenging due to the lack of detailed quantitative sub-technique definitions. In addition, the results from different studies depend on the sensor system and placement of sensors, the experimental setup and protocol, the methodology for classification, the athlete's capability and instructions on how to ski, as well as the expert labeling and interpretation of the sub-techniques using video analysis or other data sources.

The literature on sub-technique classification methodology based on inertial measurement unit (IMU) sensors can mainly be divided into two groups. The first group is mechanism-driven, where the classification is based on general understanding of the dynamics, kinematics and other descriptions of the sub-techniques. See for example the following studies where this approach is employed: (Myklebust et al., 2011, 2015; Sakurai et al., 2014, 2016; Marsland et al., 2015, 2017, 2018; Seeberg et al., 2017). The second group consists of models based on expert-driven learning, where classification is based on supervised machine learning models trained by data sets labeled by experts (Holst and Jonasson, 2013; Stöggl et al., 2014; Rindal et al., 2017; Jang et al., 2018). These approaches can also be combined by considering labeled data and machine learning for calibration of the parameters in the mechanism-based methods or by using selected features instead of raw data in the training process of the supervised machine learning models. Independent of the approach, common definitions of the sub-techniques should be established and used in order to gain a proper comparison of the results from different approaches. Examples where ambiguity occur with today's sub-technique definitions are in: The transition phase between, or cycles containing, two different sub-techniques; new motion patterns that are significantly different from the established sub-techniques; and direction-changing motion patterns that occur in turns, track changes or during evasive actions. In the mechanism-based approaches, the common definitions need to be incorporated directly in the model definition, while the machine learning methods need data labeled according to the same detailed definitions. In the post-analysis of the results proposed by any of the classification methods, detailed insight into the sub-technique mechanisms may be gained. Incorporating these insights as they are discovered in different implementations (sensors and methodology) may gain a more unified and precise definition basis for discussing and classifying the sub-techniques.

Previously, in Seeberg et al. (2017), we demonstrated the possibility of using a multi-sensor system with time-synchronized multiple tri-axial IMU sensors placed on the arms (wrist) and lower legs (ankle) combined with heart rate (HR) and global positioning data to detect sub-technique distribution during classical XC skiing on snow. In a follow-up study (Rindal et al., 2017), we used the same sensor system framework with data from IMU sensors placed on the sternum and one arm (wrist) to develop an automatic classification of the sub-techniques based on machine-learning techniques. Finally, we have utilized a similar sensor system setup, with IMU sensors placed on the skis (in front of binding) and arms (wrist), to investigate sex-based differences in speed, sub-technique selection, and kinematic patterns during training for classical XC skiing across varying terrain (Solli et al., 2018). In the current paper we aim to bridge some of the gaps in these previous studies and to improve the comparability between the different classification methods in the literature in general.

This paper proposes a framework where basic motion components are used to specify the XC classical style sub-techniques in more detail. This framework formalizes the essential motion components, constructs non-intersecting sets of sub-techniques based on these components, and also proposes a selection of estimators for each of the components. Under the assumption that the proposed detailed specification of sub-techniques are accepted as definitions and that each of the components are perfectly measured, a theoretical proof declaring unique sub-technique classes is in principle sufficient validation of the approach. However, since the motion components are only estimated through models and real sensor data, our approach is also validated by a pilot data set utilizing labels independent of the proposed definitions. Furthermore, a classification method using sensors on arms and legs/skis was employed to describe the TRN and HRB sub-techniques in more detail than in previous approaches.

2. METHODOLOGY

The foundation of the proposed approach is to define a set of measurable motion components that can fully describe the distinguishable sub-techniques in a given sport. This concept is general and may be applied in any sport with cyclic motion patterns. The approach consists of:

- Motion and technique definitions, describing the basic observable motion components and the sport's techniques/sub-techniques
- Technique classification: The composition of the motion components that lead to unique technique/sub-technique decision functions and associated tolerance parameters
- Motion estimation: The implementation and realization of the motion components

The two first bullet points require fundamental knowledge of motion patterns typical for the considered sport and should be verifiable by researchers within the field. The collection of defined motion components may vary with respect to sensor types and placement. It will also vary with respect to the expert's qualitative evaluation of the sub-techniques, focusing on different aspects of the motion patterns in order to most efficiently separate the sub-techniques, i.e., identifying and formulating the motion components that provide the best balance between sensitivity and robustness with respect to each individual sub-technique. The core of the approach is to build on these motion components and show that resulting technique/sub-technique decision functions and tolerance parameters exist that produce unique technique/sub-technique classifications.

The terms sensitivity and robustness also reflect on the tolerance parameters, which need to be set such that the effects from the imperfections of the sensor systems and estimator are minimized. The sensor systems themselves introduce measurement errors in terms of bias and scaling factors, drift, noise, and precision limitations. In addition, the estimator may bring in modeling errors as the motion components are not necessarily measured directly. Thus, the selection and setting of the tolerance parameters are important for the performance and handling of uncertainty. As the parameters are integrated in the technique definitions, the tuning can be handled by the definition process and specified by a domain expert. Another approach to handle this is to formulate an optimization/calibration program, solved with machine learning or adaptive methods, relying on labeling of training/validation data sets. In the reminder of this

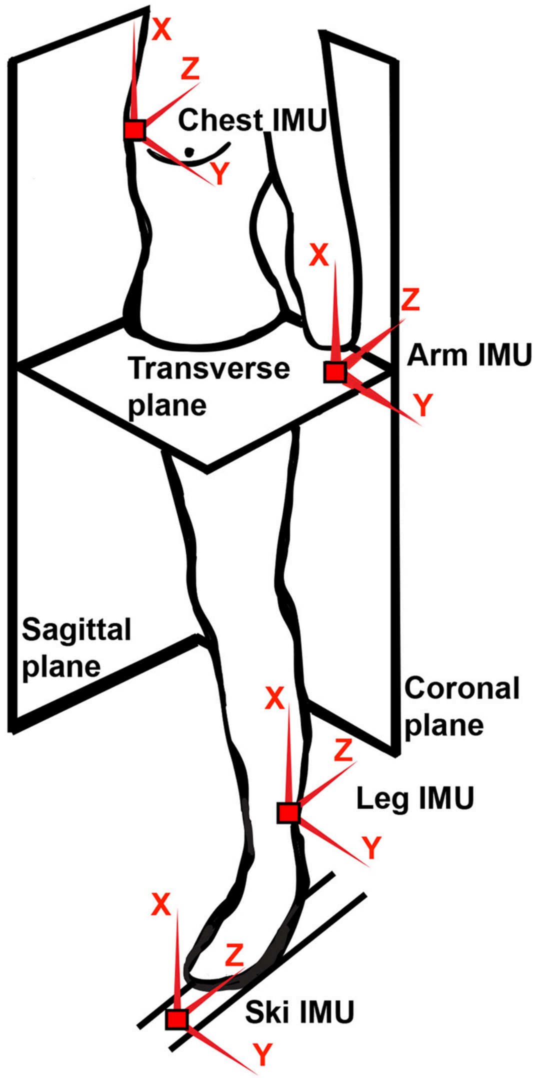


FIGURE 1 | Illustration of body coordinates and placement of the IMU sensors. Note that the IMU sensors are depicted for the purpose of relating the case-study in section 3 to the diagram. However, other information sources such as camera-based systems may also be considered.

section the methodology is applied to the case of classifying classical XC skiing sub-techniques.

2.1. Motion and Sub-technique Definitions

Definition 1. *Motion components and measures for classical XC skiing. For a time window* $\Delta > techCycle$*, where techCycle is the time the athlete uses to perform a technique cycle, the following motion component definitions can be evaluated:*

1. *Arm synchronization: Level of synchronous arm motion around a common axis* $a_{lateral}$ *defined in body coordinate frame, y in* ***Figure 1****, measured by for example correlation: armCorr [−1 , 1].*
2. *Independent leg motion: Level of independent leg sagittal motion measured by the function* $legMoS(leg_{workS}):[0,a] \rightarrow [0,\infty]$ *of class K. That is, legMoS is continuous, strictly increasing and* $legMoS(0) = 0$*. Here* leg_{workS} *represents the independent energy or displacement of the leg motions in the body sagittal plane. There is also a function* $legMoST(leg_{workST})$ *that exhibits the same properties as the independent leg sagittal motion measure, but here the* leg_{workST} *represents the energy or displacement of the independent leg motion in the sagittal and transversal planes.*
3. *Arm motion: Level of arm motion measured by the function* $armMo(arm_{work})$ *that exhibits the same properties as the leg motion measures.*
4. *Kick direction: The foot kick motion direction around the axis* $a_{vertical}$ *defined in body coordinate frame, x in* ***Figure 1****. Measured by the cycle average rotation around* $a_{vertical}$*: kickDir.*
5. *Kick rotation: The foot kick rotation around the axis* $a_{vertical}$ *defined in body coordinate frame, x in* ***Figure 1****. Measured by a function of* K_∞*,* $kickRot(leg_{rotwork})$ *where* $leg_{rotwork}$ *represents the energy or relative angular displacement of the leg motion rotation around* $a_{vertical}$*.*
6. *Foot/ski orientation: The foot/ski orientation* Θ *relative to the body coordinate frame measured by the angles* ϕ_{xx}*,* θ_{xx} *and* ψ_{xx} *where* $xx \in [foot, ski]$ *around the axes z, y, x in* ***Figure 1****.*

The motion component measures are lumped in a vector $x_{motionComp}$ *defined by the following:*

$$x_{motionComp} := [legMoS, legMoST, armMo, armCorr, kickDir, kickRot, \psi_{ski}] \in \mathbb{R}_{>} \times \mathbb{R}_{>} \times \mathbb{R}_{>} \times [-1,1] \times [-\pi,\pi] \times \mathbb{R}_{>} \times [-\pi,\pi] \quad (1)$$

Definition 2. *Classical XC skiing sub-techniques*

1. *DIA: Arms and legs are active, and opposite leg and arms are in-phase synchronous while the arms are anti-phase synchronous. Ski orientation is kept in the longitudinal direction. Arm or leg motion defines the start and stop of the cycles.*
2. *DP: Poling with in-phase synchronous arm motion and insignificant independent leg motion. Arm motion defines the start and stop of the cycles.*
3. *Rotational kick (rK): A significant kick with a significant rotation around the vertical axis. The active leg motion defines the start and stop of the cycles.*
4. *DK: Poling with in-phase synchronous arm motion with a significant kick that is not defined as a rK. Arm motion defines the start and stop of the cycles.*
5. *HRB: Same as DIA but skis are rotated outwards in the opposite direction around the vertical axis. Arm or leg motion defines the start and stop of the cycles.*
6. *Double poling with a rotational kick (DPrK): Poling with in-phase synchronous arm motion and a rK. Arm motion defines the start and the stop of the cycles.*
7. *noTech: Any skiing activity not defined by the bullets above.*

Definition 2 represents the authors' qualitative description of the classical XC sub-techniques. It relates to the FIS International

Competition Rules (ICR) 310.2.2[1] from the FIS website[2], but describes the movement patterns more explicitly.

Remark 1. *Excluded activities*

- *Activities where an athlete is performing skating style sub-techniques, skiing without poles, running with poles, bare running or performing any other activity that could produce motion patterns similar to the definitions are not considered valid in this context.*
- *Additional motion components may be included to provide a more specific description of the sub-techniques. Specific examples are components related to ski gliding and the diagonal synchronicity between arms and legs to also classify running and amble gait.*
- *Non-cyclic activities like downhill tucking, standing still and non-repetitive motion are not standard classical XC skiing sub-techniques and will be covered by the noTech class. However, these activities are included here in order to fully span the classification sample space.*

2.2. Sub-technique Identification

Assumption 1. *The athlete performs classical XC skiing, and the variables $x_{motionComp}$, representing the chosen measures from Definition 1, are independent.*

Proposition 1. *Under Assumption 1, the motion components from Definition 1 are sufficient measures for a unique decision function description of the classical XC sub-techniques in Definition 2.*

Proof: In the following, $x = x_{motionComp}$ is used to allow a more compact notation. The outline proof is given by proposing the following logical compositions, derived from the definition 2, as decision functions:

$$l_{DParm}(x) := (armMo > tol_{armMo}) \wedge (armCorr > tol_{armPole}), \in [0, 1] \quad (2)$$

$$l_{HRBDIA}(x) := (armMo > tol_{armMo}) \wedge (armCorr < tol_{armDiag}), \in [0, 1] \quad (3)$$

$$l_{HRB}(x) := l_{HRBDIA}(x) \wedge (kickDir > tol_{kickDir} \vee \psi_{ski} > tol_{\psi}), \in [0, 1] \quad (4)$$

$$l_{DIA}(x) := l_{HRBDIA}(x) \wedge \neg l_{HRB}(x) \wedge (legMoS > tol_{legMoS}), \in [0, 1] \quad (5)$$

$$l_{DPrK}(x) := l_{DParm}(x) \wedge (kickRot > tol_{kickRot}) \wedge (legMoST > tol_{legMoST}), \in [0, 1] \quad (6)$$

$$l_{DK}(x) := l_{DParm}(x) \wedge (legMoS > tol_{legMoS}) \wedge \neg l_{DPrK}(x) \wedge (legMoS > tol_{legMoS}), \in [0, 1] \quad (7)$$

$$l_{DP}(x) := l_{DParm}(x) \wedge (legMoST < tol_{legMoST}) \wedge (legMoS < tol_{legMoS}), \in [0, 1] \quad (8)$$

$$l_{rK}(x) := (kickRot > tol_{kickRot}) \wedge (armMo < tol_{armMo}) \wedge (legMoST > tol_{legMoST}), \in [0, 1] \quad (9)$$

[1] https://res.cloudinary.com/fis-production/image/upload/v1540201631/fis-prod/ICR_Cross-Country_2018_clean.pdf
[2] www.fis-ski.com

Let all tolerance variables: $tol_{armDiag}$, $tol_{armPole}$, tol_{legMoS}, $tol_{legMoST}$, tol_{armMo}, $tol_{kickRot}$, tol_{ψ}, $tol_{kickDir}$, be within the domain of the comparable motion measures. Then since x are independent measures, the sets $\{x \mid l_i(x) = 1\}, \forall i \in A := \{HRB, DIA, DP, DPK, DPrK, rK\}$ are pair-wise disjoint by construction, see **Figure 2** for an overview of the decision flow—i.e., $\{x \mid l_j(x) = 1\} \cap \{x \mid l_i(x) = 1\} = \emptyset \forall i \neq j \in A$. The non-technique set is defined by:

$$l_{noTech} := \neg(\vee_{j \in A} l_j(x)), \in [0, 1] \quad (10)$$

Thus, the sets $\{x \mid l_i(x) = 1\}, \forall i \in A^* := A \cup \{noTech\}$ are also pair-wise disjoint, and Equations (3)–(10) are unique decision function descriptions that represent the classical XC skiing sub-techniques in Definition 2.

Remark 2. *Note that Proposition 1 only has a "sufficient" claim, and that this claim is two-fold. First, this means that there may exist different motion component measures that can be used in the sub-technique decision functions. Second, since Definition 2 only holds qualitative information, other decision function definitions may be proposed, i.e., the realization of Definition 2, represented by the decision functions from the proof may be changed with other measures and function definitions.*

Remark 3. *The structure of the proposed decision function relies on three "super" classes derived from the arm motion component: Correlated, anti correlated and no-arm motion. All sub-techniques belong to either of these classes and are further refined by the leg motion components.*

Remark 4. *The decision functions l_j and the specific set of tolerance parameters in proof of Proposition 1 may be used as a detailed measurable definition of the classical XC sub-techniques. A drawback of such an approach is that this would require models and sensor systems that specifically estimate the proposed motion components. This can however be handled by standards, specifying motion components and decision functions dependent on the sensor setup.*

Remark 5. *Note that the requirement in Definition 1 $\Delta t > techCycle$, may be conservative when considering a fixed window for all sub-techniques, all sessions and all athletes. If a sub-technique cycle consists of two anti- or in-phase motion patterns, and the motion components do not discriminate between the two, then the time window can be relaxed to $\Delta t > \frac{techCycle}{2}$ for that particular sub-technique. This is the case for DIA and HRB. In Definition 2, DK is defined independent of which leg generates the kick, such that the DK cycle is constrained by the arm cycle time.*

2.3. Motion Estimators

The quantification of the motion components in Definition 1 relies on measurements from sensor systems either in the environment or being attached to the athlete or the equipment. In this work, IMU sensors were attached to the arms and skis of the athlete to provide acceleration and angular rate information that were used to estimate the motion components. The term "estimators" is used here since the components were indirectly

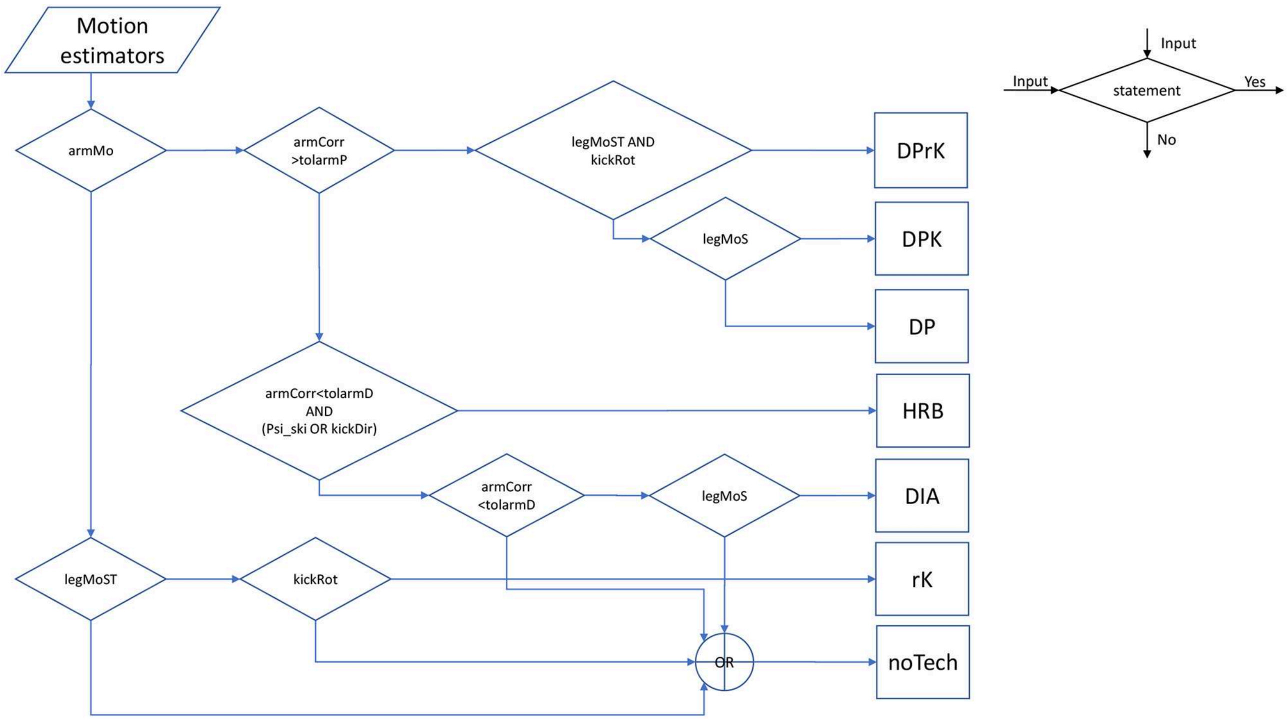


FIGURE 2 | An example flowchart of the decision functions from Equation (3) to (9). With the exception for *armCorr* the tolerances are omitted in the diagram in order to reduce the notation.

estimated through a model relying on certain assumptions, or since signal processing on the sensor raw data (like filtering) were necessary due to sensor measurement errors and noise.

Assumption 2. *Sensor calibration. All sensor information is time synchronous and aligned to a common athlete body coordinate frame, defined in* ***Figure 1***.

2.3.1. Arm Synchronization

To obtain a measure of the arm synchronization level, the correlation coefficient for each time-stamp t over the window Δt related to *techCycle* is used here and calculated as follows:

$$ss_{xy}(t, \Delta_t) := \sum_{i \in [t-\frac{\Delta t}{2}, t+\frac{\Delta t}{2}]} (x_i - \bar{x_t})(y_i - \bar{y_t}) \tag{11}$$

$$armCorr(t, \Delta_t) := \frac{ss_{A_{left}A_{right}}(t, \Delta_t)}{ss_{A_{left}A_{left}}(t, \Delta_t) ss_{A_{right}A_{right}}(t, \Delta_t)} \tag{12}$$

To simplify calibration and maximize the signal to noise ratio, gyroscope sensors were used as comparison signals A. Here A_{left} and A_{right} are the angular rates around the **lateral axis** from the left and right arms respectively. Note that more elaborated approaches utilizing all the channels of the accelerometers and gyroscopes may be considered.

2.3.2. Leg and Arm Motion

As for arm synchronization, the angular rate around the arm's lateral axis was used as a basis for estimating arm motion. From the sum of squared values in Equation (11), the variance of the arm motion components can be calculated:

$$\sigma_x^2(t, \Delta_t) = \frac{ss_{xx}(t, \Delta_t)}{fr\Delta_t} \tag{13}$$

$$armMo(t, \Delta_t) := \sigma^2_{A_{right}}(t, \Delta_t) + \sigma^2_{A_{left}}(t, \Delta_t) \tag{14}$$

where $\sigma(t, \Delta_t)$ denotes the standard deviation at time t over a window of Δ_t and fr is the sampling rate of the signal.

For the independent leg motion estimation, the difference in relative angles of the legs is used as a basis. These signals are derived from the angular rate around the lateral and vertical body axes. The angular rate raw data are band-pass filtered, integrated with bias removal and finally differentiated accordingly:

$$r_{FLH}(t) = bandpass(lowB, highB, r_F(t)) \tag{15}$$

$$\Theta(t) = \int r_{FLH}(t)dt \tag{16}$$

$$\Theta_M(t) = \Theta(t) - mean(\Theta(t)) \tag{17}$$

$$angDiff_{\Theta_R}(t) := \Theta_{Mleft}(t) - \Theta_{Mright}(t) \tag{18}$$

where r_F and r_{FBH} represent the measured and filtered rotational rates, and Θ and Θ_M are the estimated and bias removed orientation of the legs. Here $angDiff_{\Theta}(t)$ represents the angular difference between the left and the right leg. The independent leg motion is then estimated similar to Equation (13) given by:

$$legMoS(t, \Delta_t) := \sigma^2_{angDiff_{\theta_R}}(t, \Delta_t) \quad (19)$$

$$legMoST(t, \Delta_t) := \sigma^2_{angDiff_{\theta_R}}(t, \Delta_t) + \sigma^2_{angDiff_{\psi_R}}(t, \Delta_t) \quad (20)$$

Where θ_R and ψ_R denote the angle differences around the lateral and vertical axes respectively.

2.3.3. Kick Rotation

Several methods may be applied to quantify the athlete's kick rotation. For example, any norm of the angle around the vertical axis over the time period Δt could be used. In this presentation, the signal strength of the rotation around the vertical axis is compared with the rotation around the lateral axis. This was chosen such that the tolerance parameter was less influenced by the individual differences in athlete capabilities.

$$kickRot(t, \Delta t) := \frac{\sigma_{angDiff_{\psi H}}(t, \Delta_t)}{\sigma_{angDiff_{\theta H}}(t, \Delta_t)} \quad (21)$$

Note that $kickRot(t, \Delta t) \xrightarrow{\sigma_{angDiff_{\theta H}}(t,\Delta_t)\rightarrow 0} \infty$. This is handled by the leg motion restrictions, preventing rotational kick classification in cases of insignificant motion.

2.3.4. Foot/Ski Orientation

Typically angular rate measurements provide a good signal to noise estimation of orientation, but at the cost of estimator drift due to bias and numerical issues during the integration step, i.e., the absolute orientation is not available. Due to the gravitational field, the accelerometer data may be used to generate absolute estimates of angles around the longitudinal and lateral axis, under the assumption of relative low dynamic environment. Combining the two measurement sources is common in navigational and robotic applications, see for example Fossen (2002) or Grøtli et al. (2016), producing high resolution and precision attitude estimates. However, the main requirement in the following section HRB estimator is the availability of absolute estimates, i.e., the angular rate measures are in this context less relevant. Absolute yaw/heading estimates may be provided by magnetometers or a dual antenna global navigation satellite system (GNSS) setup, using the ski as a baseline. However, neither of these sensor systems were available in this work, thus only absolute roll and pitch estimates are provided. These can be estimated through knowledge of the gravity components, see for example the textbook by Farrell and Barth (1999), and calculated according to the following relationship:

$$f = \begin{bmatrix} \sin\theta \\ -\cos\theta\sin\phi \\ -\cos\theta\cos\phi \end{bmatrix} g \quad (22)$$

$$f_f(t, \Delta t_{skiOri}) := \frac{1}{\Delta t_{skiOri}} \sum_{i \in [t - \frac{\Delta t_{skiOri}}{2}, t + \frac{\Delta t_{skiOri}}{2}]} f(i) \quad (23)$$

$$\phi(t, \Delta t_{skiOri}) = atan2(-f_{fy}, -f_{fz}) \quad (24)$$

$$\theta(t, \Delta t_{skiOri}) = atan2(f_{fx}, \sqrt{f_{fz}^2 + f_{fy}^2}) \quad (25)$$

where g is the gravity component and f represents the acceleration measurements. The use of the absolute angular estimates of the skis in this work is limited to the low pass components (f_f). Therefore, a moving average filter with a window Δt_{skiOri} was used to remove the high frequency components of $f(t)$.

2.3.5. ψ_{ski} Estimator and Kick Direction

HRB can be identified by using the ski orientation or the kick direction as estimators. The kick direction may be identified by acceleration measurements from the skies but this has not yet been explored and is left for further work. The preferred estimator of HRB is the difference in ski yaw/heading. For example in Andersson et al. (2014b) the HRB technique was video analyzed and characterized at an incline of 15 degrees. The athletes employed in this study a lateral angle/yaw between the skis at mean values of 25–30 degrees and standard deviation between 4 and 11 degrees, both values increasing with lower velocity. In our presentation reliable estimates of the absolute yaw were not available as there was no magnetometer in the applied IMU sensors. Absolute ski roll and pitch are however estimated by using the gravitational acceleration component as a reference. Note that these estimates differ from the relative angular estimates presented in Equation (15), which were based on the angular rate measurements from the IMU. It is common to combine the two estimates in an attitude observer, as discussed in section 2.3.4. For simplicity this is not considered as it will not gain any principal advantages for the presented low frequency estimator. However, in cases with absolute yaw measurements available and estimators utilizing high frequency components, such observers should be considered. The HRB estimator used in this study was defined by:

$$e\psi_{ski} := (\phi_{left} - \phi_{right})(\theta_{left} + \theta_{right}) \quad (26)$$

$$l_{HRBDIA}(x) = (armMo > tol_{armMo}) \wedge (legMo > tol_{legMo}) \wedge (armCorr < tol_{armDiagHrb}) \quad (27)$$

$$l_{HRB}(x, \phi, \theta) = l_{HRBDIA}(x) \wedge (e\psi_{ski} > tol_{e\psi}) \quad (28)$$

$$l_{DIA}(x) = l_{HRBDIA}(x) \wedge \neg l_{HRB}(x) \wedge (armCorr < tol_{armDiagD}) \quad (29)$$

where $e\psi_{ski}$ is the ski orientation estimate that replaces $kickDir$ and ψ_{ski} in Equation (4). ϕ and θ are the ski pitch and roll angles in radians. Furthermore, notice that the negative arm correlation constraint is made more strict for the DIA sub-technique with $tol_{armDiagD} < tol_{armDiagHrb}$, in order to have a more robust separation between the two sub-techniques (DIA and HRB). The main component in the $e\psi_{ski}$ estimate is the ski roll angle. Under the assumptions that the roll angles are relatively small and that the athlete keeps the skis in parallel and legs straight with stiff ankle and knee, then the roll angle will measure the distance between the skis:

$$legLatDist = hipWidth + (\phi_{left} - \phi_{right})legHight \quad (30)$$

This estimate may be used for setting a reasonable $tol_{e\psi}$ coefficient. Including the pitch (θ) angles in the estimator and a positive tolerance parameter ensures that HRB will only be classified in uphill terrain. Turning and skating downhill will produce negative estimates.

3. CASE STUDY

In order to demonstrate the framework, data from an outdoor field trial at Meråker in 2017 was used (Solli et al., 2018). All results and plots were generated by MATLAB analysis tools, among them *skiViewer*, developed in the two projects AutoActive and emPower, both supported by the Norwegian Research Council. The study was pre-approved by the Norwegian Centre for Research Data, conducted in accordance with the Declaration of Helsinki and assured by the responsible institution, the Norwegian University of Science and Technology. All participants were fully informed of all test protocols and procedures before they provided their written consent to participate. The main objective of the Meråker study was to combine HR monitoring, GNSS, and micro-sensor technology to investigate sex-based differences in speed, sub-technique selection, and kinematic patterns during low-intensity training (LIT) and high-intensity training (HIT), where LIT: HR $<$ 82% of maximal HR (HR_{max}) and HIT: HR $>$ 87% of HR_{max}, for classical XC skiing across varying terrain. The skiers were instructed to initially ski at a low intensity using their preferred sub-technique, then at competition speed (i.e., HIT), with approximately 2 min of rest in between. The same course was used for both the LIT and HIT tests, consisting of three rounds of a 1.7 km-long track with varying elevation and turn topology. The track represents a typical racing track, and it was chosen to stimulate the athlete to use their full repertoire of sub-techniques. In **Figures 3**, **4**, an overview of the course elevation and map positions is shown and decomposed by comparable segments, starting, and stopping at the same positions for each round. To compare the algorithm results with reference data, two men and two women were randomly selected. These skiers are referred to as subjects 1 to 4 throughout the text. All test subjects had competed at national and international levels, and the use of sub-technique in the LIT session was labeled and manually synced to the motion data based on a video, captured by a skier following the test subject. The labeling was done independent of the definitions in this paper. The sub-technique cycles were defined to start and stop when the subject's left arm was extended all the way behind the body (Rindal et al., 2017). Each cycle was then labeled either DIA, DK, DP, HRB, TRN, TCK, transition to DIA (tDIA), and transition from DIA (fDIA)

To establish a proper comparison between the expert qualitative evaluation (labeling of the sub-techniques) and the definitions in paper, a set of rules/mappings of the labels to a common reference set were made.

Definition 3. *Comparison rules*

- *Converting from data samples to cycles: Within each cycle, the sub-technique with the highest sum of algorithm classification samples was chosen to represent the algorithm classification result. Note that this will have some low pass filtering properties, letting the majority of samples represent the cycle*
- *Turn sub-techniques: The two sub-techniques DPrK and rK were merged and labeled to the TRN class.*
- *Tucking: The TCK class appears between cycles and is not considered a sub-technique cycle in this paper. It is therefore labeled as noTech.*
- *Transition techniques: Two mappings were considered.*
  - *a) The first maps tDIA and fDIA to DIA*
  - *b) While the second maps tDIA as DIA but fDIA as DK*

  See section 4.3 for a detailed discussion on the implications.

These mapping rules were based on discussions between XC skiing experts and algorithm developers. Discussions like these are practical examples of why it is necessary to work toward a common framework for motion components and the unique sub-technique definitions. Further discussion of the rules is provided in section 4.3.

3.1. Instrumentation

This work builds upon data presented in Solli et al. (2018), where motion data were collected by six IMU sensors (Physiolog 5, GaitUp, Switzerland), consisting of a triaxial accelerometer and gyroscope and a barometric pressure sensor. The sensor system sampling frequency, 256 Hz, was down sampled to 20 Hz and all data channels were synchronized in time, before the classification. The IMU sensors were mounted using straps with velcro on the body—the sternum, lower back, and wrists—and with velcro straps in front of the binding on the left and right skis (**Figure 1**). The reason for placing the sensors on the skis was to collect data of the ski-motion directly. Garmin Forerunner 920XT (Garmin Ltd., Olathe, KS, USA), with multi constellation GNSS active (GPS and GLONASS) and barometric altitude monitor, validated in Gløersen et al. (2018), was included in the system and used to measure the position, HR and altitude with a sampling frequency of 1 Hz. The positioning system was mainly used for comparing the identified techniques throughout the track. Hence, a frequency of 1 Hz was sufficient for segment definitions under the assumptions that the segments were sufficiently long. Video was captured during the LIT laps using a Garmin VIRB (Garmin Ltd., Olathe, KS, USA) placed on the forehead of a skier following the test subjects. All data were logged on the individual sensor systems during the tests and analyzed offline in MATLAB (MathWorks, Natick, MA, USA). The GNSS and IMU data were synchronized by high-pass filtering and cross-correlating data were recorded by the barometer in both sensor systems. In order to normalize differences in sensor positioning, the arm sensors were calibrated by following Seeberg et al. (2017), and the ski-mounted sensors were aligned by assuming zero average horizontal acceleration throughout the activity.

3.2. Algorithm Parameters

The sampling and tolerance parameters used in the classification algorithm implementation are given in **Table 1**, related to sections 2.3.1 and 2.3.4, and **Table 2**, related to proof of Proposition 1 and section 2.3.5. The parameters were mainly set by assuming a typical sub-technique cycle length and manual

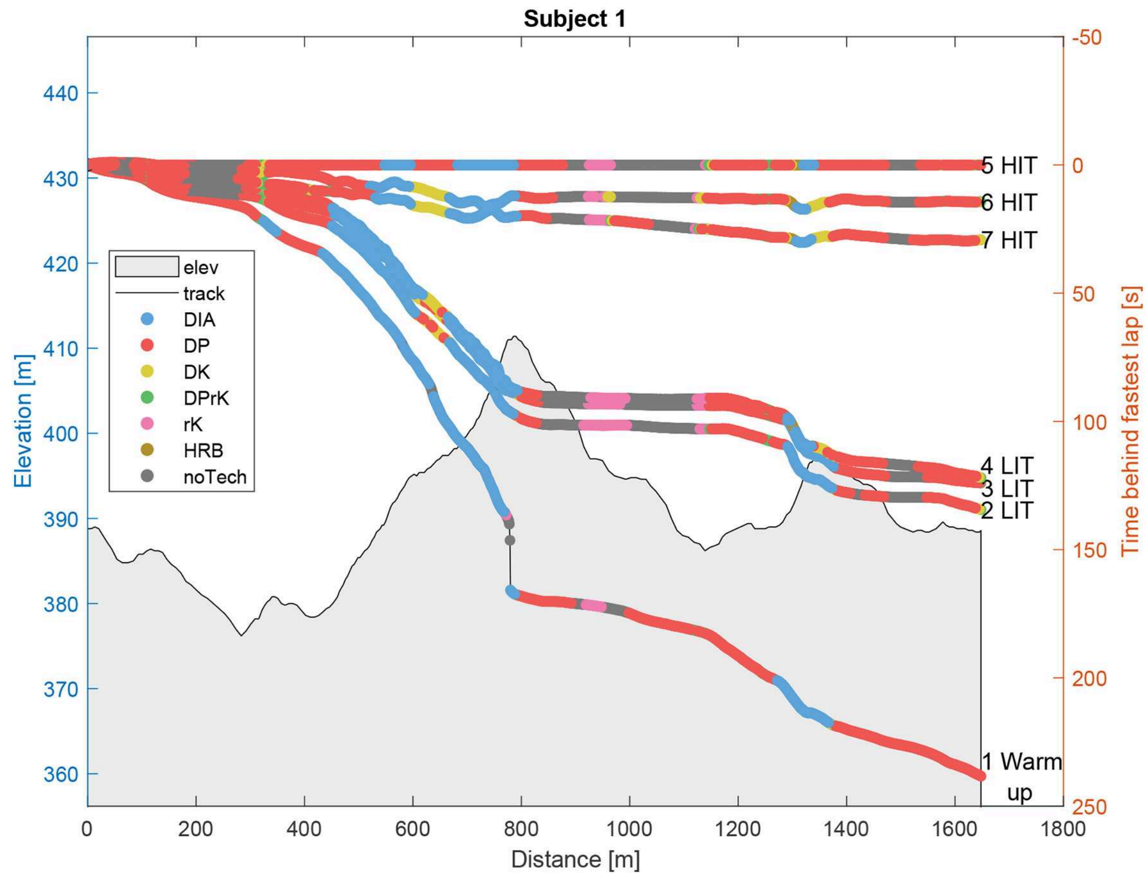


FIGURE 3 | Time behind the fastest lap relative to the distance from the start of the lap. The fastest lap (5) is used as a reference and all data are projected onto this lap through linearly scaled distance measures. The specific sub-techniques and the elevation are displayed along the distance to show the elevation effects. Lap 1 (Warm-up), 2–4 (Low-intensity training, LIT), and 5–7 (High-intensity training, HIT).

inspection of the data sets. The parameter Δt may be considered time varying and is identified by frequency analyzing the arm motion throughout the session, as presented by Rindal et al. (2017). An analysis of the performance sensitivity of this parameter was not conducted in this study, but large values are expected to produce classification errors in transition phases, while small values may produce errors due to lack of discriminating information.

4. RESULTS AND DISCUSSION

In this section, the results from the implementation of the sub-technique classification approach, section 2, is presented and discussed based on data produced by the case study presented in section 3. The discussions underline the motivation for developing a more detailed platform for comparing technique analysis methods, detailing the motion components, preventing unambiguous definitions and allowing more precise discussions and quality assessments of an athlete's technical ability. Such understanding is highly relevant for providing a valid communication platform for researchers in this field, as well as for developing preparation and debriefing tools for coaches and athletes as exemplified below.

4.1. Technique Distribution Overview

Table 3 and **Figures 3**, **4** show the sub-technique distribution for a representative participant's (i.e., Subject 1) session, calculated by the presented approach. The session had seven laps, one warm-up lap, three LIT video validated technique laps (2–4) and three HIT laps (5–7). The fastest lap was the first of the HIT laps marked "5" plotted at the reference zero *"Time behind fastest lap"* along the x-axis *Distance* in **Figure 3**. All other laps, and associated data, are projected onto the distance defined by the fastest lap, in order to allow a proper comparison. **Figure 4** only contains the first LIT lap and the fastest HIT lap in the horizontal plane. This is done to simplify the view of the sub-technique distribution, dependent on intensity, position, and track curvature.

By listing the sub-technique from the lowest to highest gears, **Figures 3**, **4** show how the athlete uses HRB in the steepest part of the track (around 1,300 m); DIA in the moderate to steep hills (400–800 m); DK in moderate incline and transition between DIA and DP (for example 600–700 m); DPrK in turns in moderate to negative incline (at 350 m and track changing parts at approximately 600 m and toward the lap end); DP for example after the top of a hill; rK in the downhill parts, including turns; and finally noTech mainly

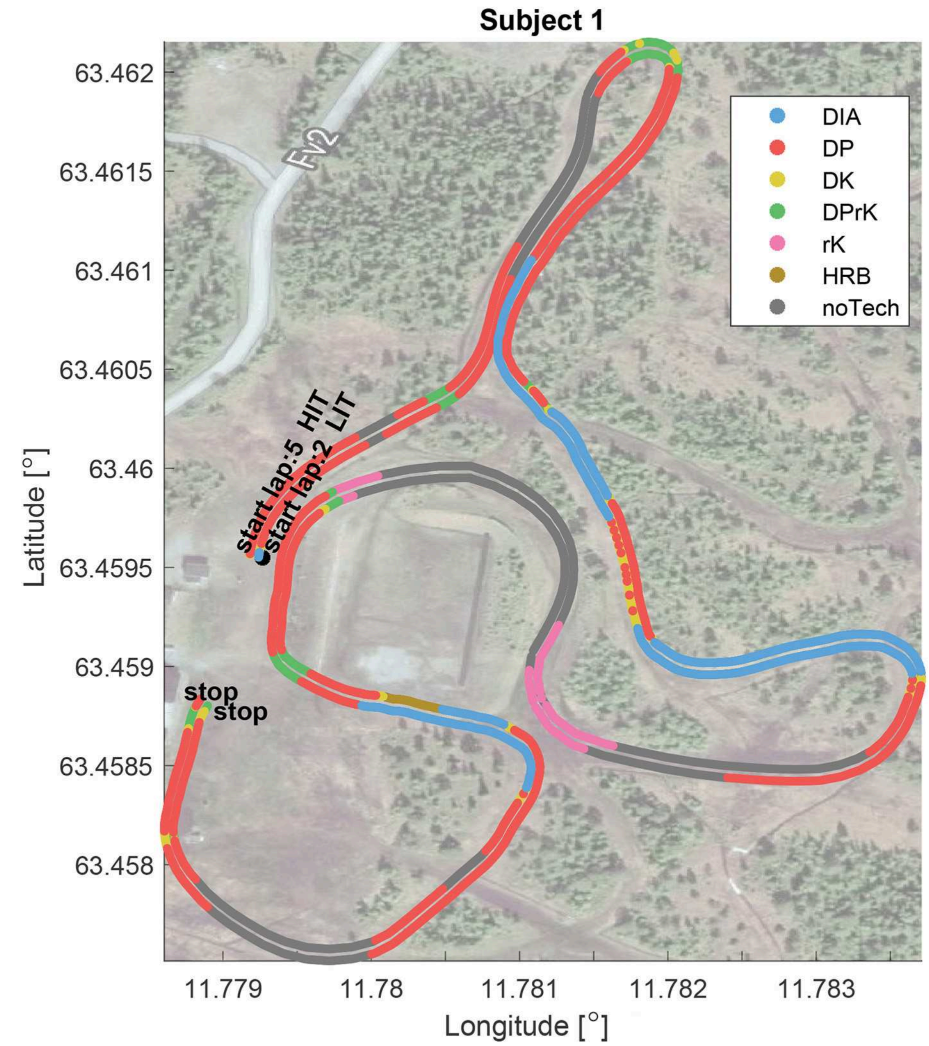


FIGURE 4 | Positional sub-technique distribution. Comparing the sub-technique distribution of the low-intensity (LIT) validated lap 2 with the fastest high-intensity (HIT) lap 5. The HIT lap is projected onto the LIT lap and shifted 0.00006° outwards in order to visualize the relative differences. The plot highlights the sub-technique distribution with dependence on the track turns.

TABLE 1 | Algorithm and estimator sampling parameters.

Data windows and sampling parameters				
Analysis window Δt [s]	**Absolute angle region Δt_{skiOri} [s]**	**Sampling frequency [s^{-1}]**	**Pass low band *lowB* [s^{-1}]**	**Pass high band *highB* [s^{-1}]**
1.3	2.5	20	0.3	3

in the samples where the athlete is racing downhill in the TCK position.

Table 3 summarizes the lap-timing, sub-technique distribution and physiological parameters for Subject 1, which provides a basis to the overall motivation for identifying the sub-technique distribution. It is an example on how information from different sensor systems may be used as a tool by coaches and athletes to evaluate a training session in more details. For example, the transition from LIT to HIT obviously results in higher HR and speed. But comparing the HIT laps internally shows an increased lap time with increased HR. Furthermore, the sub-technique distribution reveals that the subject shifted the use of high gear DP in the first HIT lap (5), to the active leg techniques DIA and DK in the two last HIT laps (6 and 7). Grouping this information may give insight to the athlete's pacing strategies and fatigue, but may also be a result of changes in equipment or other external factors, e.g., snow conditions. In this multiple IMU sensor setup, cycle frequencies are readily available features to be analyzed with the sub-technique distribution. For Subject 1, DIA, DP, and DPrK were performed at similar arm frequencies for the same intensities, but increased from the LIT to the HIT laps. The DK was performed at a lower frequency which is common, and HRB at a higher frequency which is due to steep hills and no ski gliding. The low arm frequency estimates in rK and noTech are less relevant since the arm motion in these techniques was not defined. The frequencies depicted in the table were calculated by cross-correlating the angular rate around each of the arms, and averaging the results. Further work will include the leg motion in the frequency estimation. This ability to collect and combine more detailed information about the session performance and context enables the coaches and athletes to evaluate their racing tactics, training planning, training sessions, skiing equipment, and generally aid researchers in testing new hypotheses coupling physiological, mechanical, and other relevant contextual information both in lab and field conditions (Marsland et al., 2017, 2018; Solli et al., 2018).

The quality of the performed sub-techniques is not evaluated in the classification process *per se*, and both "good" and "bad" sub-technique performance are classified in accordance with the tolerance values. However, increased tolerances and a narrower technique cycle window parameter will enlarge the *noTech* set and reduce the remaining sets of sub-techniques. Such parameter adjustments may be used for "filtering" quality sessions, evaluating the athlete time/distance usage of more "precise" sub-technique classes. This may be a useful tool for high-level XC skiing athletes who typically perform the sub-techniques in interval and race sessions more distinctly. If the goal is to record what "looks like" a sub-technique in a broader sense according to definition 2, comparing a variety of sub-technique implementations spanning recreational to high-level athletes, less restrictive tolerance parameters should be used. The presented results are based on data from high-level XC skiing athletes, but a set of less restrictive parameters was used. These parameters are similar to the tolerances used in Seeberg et al. (2017) for classification of DIA, DP, and DK where the study also included recreational athletes.

In recent years, the classical XC skiing sub-techniques have been extensively debated and new regulations have been introduced, restricting equipment (e.g., pole length) and sub-technique usage along the track (e.g., diagonal zones, where only one pole is allowed in the ground at any time). As such, automated or decision support tools for enforcing these rules require common qualitative detailed definitions of the sub-techniques and also the sub-techniques' distribution around the race track, as exemplified by **Figure 3**, **4**.

4.2. Algorithm Mechanisms

Figures 5–7 display examples of all sub-techniques defined in Equations (5) to (10) and (28), and illustrates how the decision functions from the proof of Proposition 1 can be used together with the implemented motion estimators from section 2.3 to classify the classical XC skiing sub-techniques. Note that the chest sensor data were available and depicted in the figures, but not used in the sub-technique classification. The figures include a single video frame from a full video of the subjects synchronized with the sensor data and motion estimators. An example video is available as **Supplementary Materials**.

TABLE 2 | Algorithm and estimator tolerance parameters.

Tolerance parameter values from the proof of proposition and estimators				
$tol_{armDiagD}$	$tol_{armDiag}$	$tol_{armPole}$	$tol_{legMoST}$	tol_{legMoS}
–0.4	–0.3	0.4	9^2	1.5^2
tol_{armMo}	$tol_{kickRot}$	$tol_{e\psi_{ski}}$	$tol_{armDiagHrb}$	
1e4	2	0.06	–0.3	

The importance of the arm correlation as a motion component is clear when comparing the plots in **Figures 5**, **7B** with the plots in **Figure 6**. The arm double poling motion in DP, DK, and DPrK exhibits a correlation close to one, while the diagonal motions in DIA and HRB give correlations far below zero. This makes the arm correlation a good discriminator together with a measure of the arm motion energy, underlining Remark 3, which also discriminates the rK and noTech sub-techniques classes (see **Figures 7A,C**). The double poling sub-techniques (DP, DK, DPrK), shown in **Figure 6**, are discriminated by the leg work components, *legMoS*, *legMoST*, and *kickRot*. These reflect motion in the sagittal plane, in both sagittal and transversal planes and the rotation around the vertical axes. Other more direct angular rate discriminators, and motion components, could for these cases be implemented. However, the combined leg motion estimators showed robust and well-behaved properties even though the sensors were mounted on the skis instead of the lower legs. It is worth mentioning that with the sensor mounted on the ski, the leg motion was not directly recorded and can only be inferred by the ski motion through the spring-damper hinge connection (binding) between the foot and the ski.

The DIA and HRB sub-techniques are mainly separated by ψ_{Ski}, which in the presented plots is above the threshold only for the HRB case (**Figure 7B**). The arm correlation threshold was set slightly higher for the HRB compared to the DIA case, see Equations (27–29), since less anti-synchronized movement was expected in this sub-technique.

In the noTech example, **Figure 7C**, the athlete is tucking and the **relative** motion components *kickRot* and *armCorr* have significant fluctuations above the parameters threshold, but the **absolute** measures *armMo* and *legMoST* are well below the specified thresholds. This shows that even though **absolute** motion components may be highly dependent on the athlete, the session intensity and sensor placement, it is necessary to include such components to control the signal to noise errors for the **relative** motion components and promote algorithm robustness.

The reason for the large differences between tol_{armMo}, tol_{legMoS}, and $tol_{legMoST}$ is the sensor placement. The arm sensors were placed directly on the arms while the leg sensors were placed on the skis. Since the skis are fixed to the foot through bindings, the angular rate around the lateral axis was significantly less than it would have been if the sensors were placed directly

TABLE 3 | Technique distribution together with lap and physiological parameters.

Subject 1 performance summary							
	Warm-up	LIT			HIT		
	Lap: 1	Lap: 2	Lap: 3	Lap: 4	Lap: 5	Lap: 6	Lap: 7
Time $[h:min:s]$	00:08:20	00:06:36	00:06:26	00:06:23	00:04:21	00:04:36	00:04:51
Total distance $[m]$	1680	1664	1669	1681	1649	1681	1670
Total climb $[m]$	60	59	61	60	54	55	55
Speed $[m \cdot s^{-1}]$	3.36	4.20	4.32	4.38	6.29	6.09	5.73
HR $[beats \cdot min^{-1}]$	123	138	135	135	168	178	180
HR/HR$_{max}$[%]	63.7	71.5	69.9	69.9	87.1	92.3	93.3
Arm frequency(freq) $[s^{-1}]$	0.71	0.67	0.66	0.67	0.85	0.82	0.84
DIA [%] (freq $[s^{-1}]$)	41 (0.77)	39 (0.77)	39 (0.77)	37 (0.78)	19 (0.96)	21 (0.93)	22 (0.95)
DP [%] (freq $[s^{-1}]$)	39 (0.74)	29 (0.70)	30 (0.69)	29 (0.72)	53 (0.96)	43 (0.95)	44 (0.93)
DK [%] (freq $[s^{-1}]$)	01 (0.64)	08 (0.65)	07 (0.63)	09 (0.65)	03 (0.96)	11 (0.75)	11 (0.80)
DPrK [%] (freq $[s^{-1}]$)	04 (0.72)	04 (0.75)	03 (0.75)	03 (0.80)	05 (0.94)	05 (1.00)	06 (0.99)
rK [%] (freq $[s^{-1}]$)	02 (0.62)	02 (0.55)	02 (0.32)	02 (0.36)	02 (0.27)	01 (0.25)	02 (0.33)
HRB [%] (freq $[s^{-1}]$)	00 (NaN)	00 (NaN)	00 (NaN)	01 (0.96)	02 (1.23)	02 (1.12)	01 (1.21)
noTech [%] (freq $[s^{-1}]$)	14 (0.47)	18 (0.40)	19 (0.40)	18 (0.36)	17 (0.37)	17 (0.34)	15 (0.41)
BLa$_{peak}$ $[mmol \cdot L^{-1}]$				1.3			13
RPE [Borg 6 − 20]				11			18

LIT, low-intensity training: Blood lactate concentration (BLa$_{peak}$) < 2.5 $mmol \cdot L^{-1}$, rating of perceived exertion (RPE) < 14 Borg or heart rate (HR) < 81% of maximal heart rate (HR$_{max}$) HIT, high-intensity training: BLa$_{peak}$ > 4.0 $mmol \cdot L^{-1}$, RPE > 16 Borg, HR > 87% of HR$_{max}$.
DIA, DP, DK, DPrK, rK, HRB, and noTech denotes the sub-techniques from section 2. The table values are given by the ratio of the performed sub-technique samples in a lap with respect to all the samples in that lap.

on the legs. The ski to leg mapping threshold is not linear and will depend on athlete sub-technique, equipment and conditions. A more general leg motion estimator , with reference to section 2.3.2, incorporating both gyro and acceleration channels may therefore be more robust and invariant to the lower leg or ski placement. This will be considered in further work.

Skating XC skiing sub-techniques and motion cycles without pole usage are not commonly considered part of the classical XC skiing sub-technique domain (Remark 4). Exceptions are the rotational kick classes which are allowed in turns and when direction changes are necessary. rK will for example also be active when the athlete performs G5, skating without poles, and DPrK will be active during G3, the double dance sub-technique. By including more motion components, further distinctions between sub-technique classes may be defined, and a relaxation of Assumption 1 may be considered. Examples are estimators for the ski-glide/slide motion component, based on acceleration measures, discriminating between HRB and the sliding HRB, also called the diagonal skate sub-technique (G1). Coupling rotational kicks from both legs during a double poling motion will indicate G2 or G4, the paddling or single dance sub-techniques, where further discrimination will require estimates of kinematic timing and similarity of the arm work. Including more motion components may also be aimed at making the classification more precise and robust. The correlation between the angular rate of the arms and legs may for example be used in the DIA definition, but also discriminate the amble gait as suggested in Remark 1.

By introducing other sensor systems like magnetometers, which are common in many IMU packages, ski absolute orientation may be estimated through the electromagnetic field of the earth. The drawback of using this measure directly is due to the local variations of the field. However, the relative orientation between the skis may be robustly identified under the assumption that the skis are in the same but distorted electromagnetic field. Magnetometer information was unfortunately not available for this work, but will be considered in further studies.

The methodology in this work promotes the understanding of the underlying motion mechanisms gained from motion sensors placed on the athlete's extremities. The derived motion components and associated thresholds are used directly in the definition of the sub-technique decision functions. This gives a basis for converging to common definitions by agreeing on the structure, the motion components, and the threshold values for discriminating the sub-technique definitions. Setting the threshold for ski orientation at the point where the DIA sub-technique shifts to HRB, or the threshold for kick rotation or direction to where the DK turns to DPrK, should therefore be a quest for precise and commonly accepted definitions. The parameters can be agreed upon through open discussions in the community or less directly found through an identification process, similar to what would be the case for algorithm calibration, based on labeled data provided by the different parties.

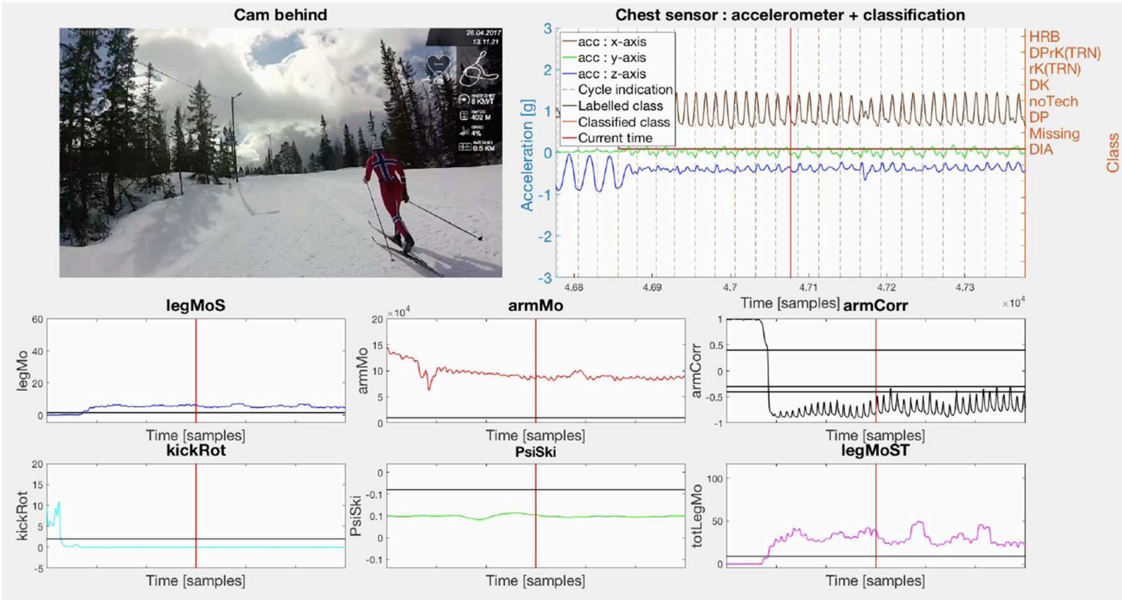


FIGURE 5 | The figure displays a snapshot of the video of subject 1 synchronized with the sensor data and motion estimators. The video is in the first subplot. The second subplot shows the accelerometer data from the chest sensor plotted with the classification of each cycle according to Equations (5) to (10) and (28) together with the manual expert labeling. Subplots 3 to 8 show the motion estimators defined in Equations (19), (13), (11), (21), (24), and (20), respectively. The tolerance value of each motion estimator is plotted as the dark horizontal line in each subplot. The criteria for the DIA definition in Equation (5) is satisfied as is illustrated with (high *legMoS* and *armMo*, low *armCorr*, *kickRot*, and ψ_{ski}) while simultaneously not satisfying the criteria for the HRB definition in Equation (28). The figure is a single video frame from a full video of the subjects synchronized with the sensor data and motion estimators. An example video is available as **Supplementary Materials**.

4.3. Algorithm Results Compared With Domain Expert Labels

In order to show the algorithm identification validity and discuss the challenges with the lack of quantifiable sub-technique definitions, the classification results are compared with expert-labeled data. The main tool for this comparison is the confusion matrices presented in **Figures 8**, **9**, where the manually labeled (Labeled classes) classes are given by the columns and the algorithm labeled classes are arranged in rows (Classified classes). For the confusion matrices in **Figure 8** we use the mapping **a)** of labeled sub-techniques as defined in Definition 3, thus mapping both tDIA and fDIA to DIA. The most significant label disagreement is then type II, false negative, error between algorithm DK and manual DIA labels. See for example **Figure 8C** where 13 cycles were classified as DK, but the expert labeled as DIA. This may seem to be a strange disagreement as the arm correlation is a strong and generally robust discriminant. However, the reason for this disagreement lies within the Definitions 3 and that these cycles are in the transition from DIA to typically DK or DP. These cycles, or half cycles (as they often are shorter), contain mainly correlated arm movement and leg work and are thus in accordance with the presented decision functions classified as DK, which is not in accordance with the fDIA rule in Definition 3 **a)** where these cycles were considered an extension of the DIA class. This is an example at the core motivation for the proposed framework, highlighting the discussion of how new expert-classified sub-technique classes are to be interpreted. In this particular case, the transition techniques are not implemented, but it shows which of the defined motion components are most significant within the cycle. This gives input to the mapping rules in Definition 3, but also suggests that the sub-technique mechanisms need to be better understood such that common and measurable definitions may be derived. However, if we use the mapping rule **b)** in Definition 3, thus mapping the labeled tDIA to DIA and fDIA to DK, we get the confusion matrices shown in **Figure 9**. If we compare the confusion matrices in **Figures 8**, **9** we observe that changing the label improves the precision in the rightmost column for the DK class from 83.1%, 78.2%, 80.9, and 76% for subjects 1, 2, 3, and 4, respectively, to 96.9%, 92.7%, 100, and 100%. Thus, the achieved precision for DK and the overall classification accuracy improve significantly. However, some XC experts might disagree on whether a DK cycle occurs in the transition between DIA and DP even though the algorithm predicts a DK cycle. On the other hand, knowing the definition of a DK cycle from Equation (7), it is a correct prediction—but such single cycles can also simply be filtered out in a post-processing of the classified cycles to agree with an XC expert's opinion. Or, one might argue that the XC expert is wrong, and that more detailed sub-technique definitions and classification algorithms can bring new knowledge into the field.

The comparison of HRB vs. DIA also led to type I and II disagreement, in which the reasons are two-fold. First, the necessary HRB motion components were not directly available from the sensor system, i.e., a model was developed relying on the athlete's usage of the ski edges during HRB. It was however

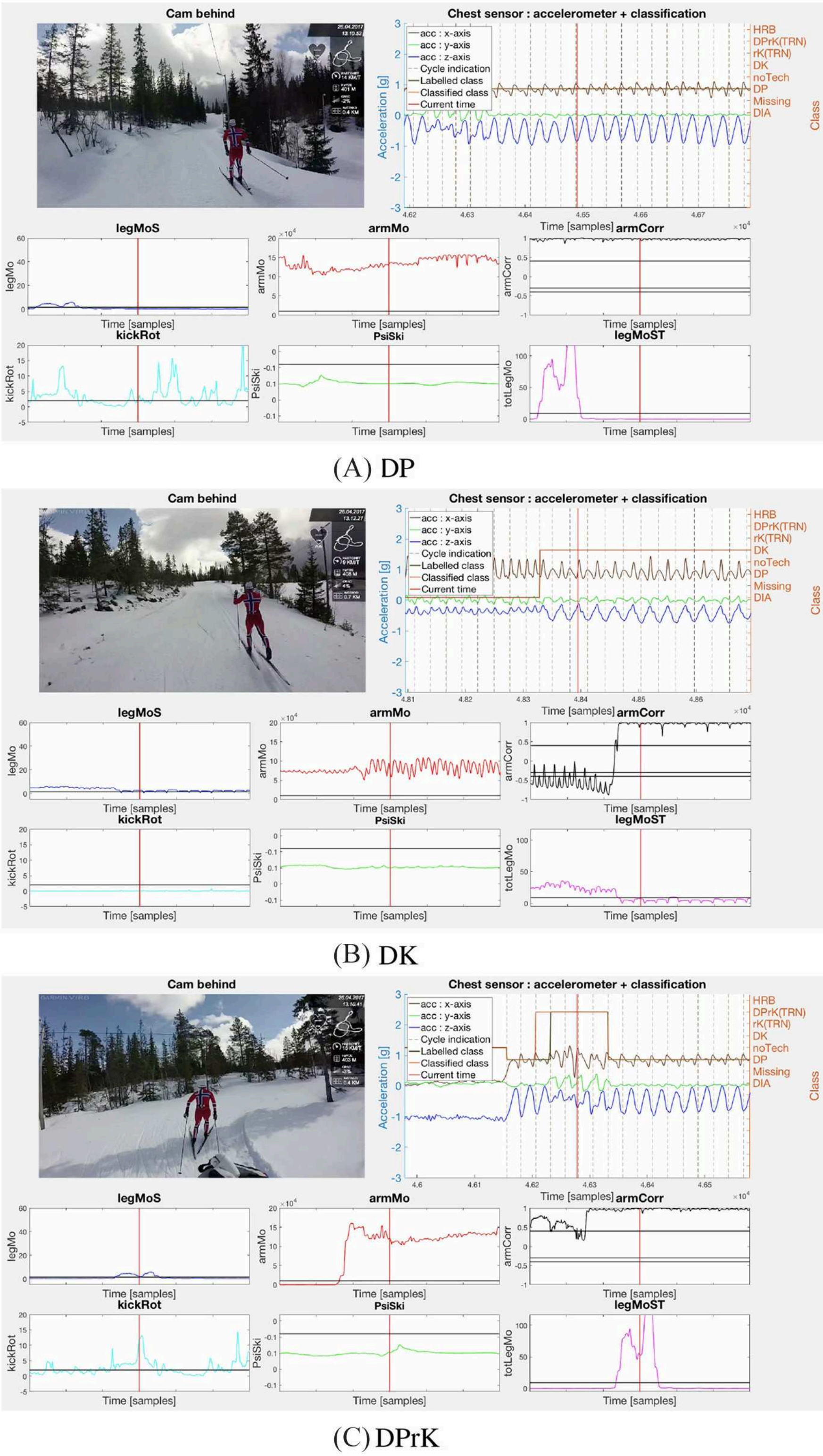
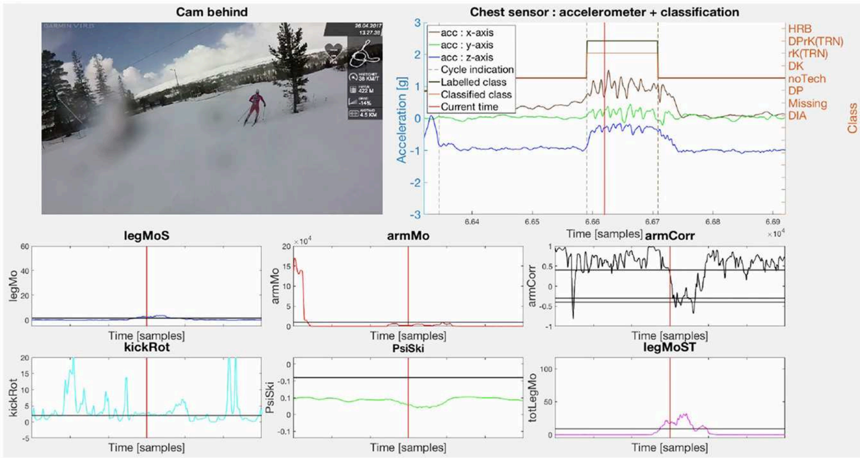
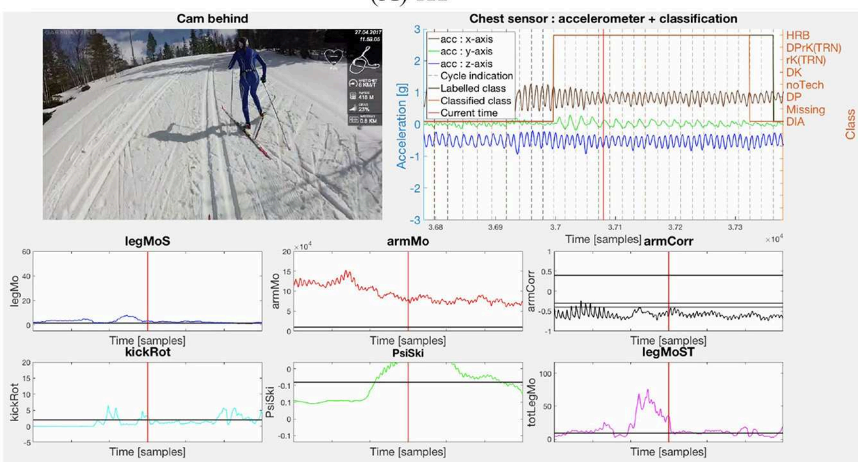


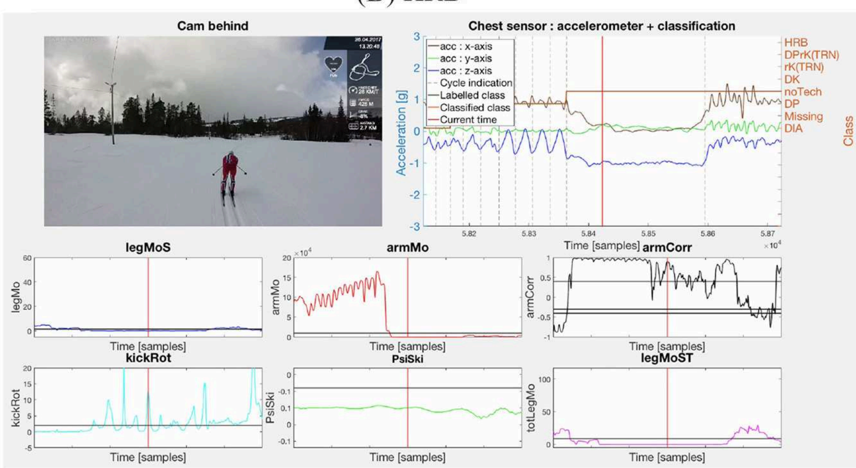
FIGURE 6 | Caption **(A)** displays Subject 1 performing the DP sub-technique as defined by Equation (8) (high *armMo* and *armCorr*, low *legMoS*, and *legMoST*). The second caption, **(B)**, displays subject 1 performing the DK sub-technique as defined by Equation (7) (high *armMo*, *armCorr* , *legMoS*, and *legMoST*) but not satisfying the conditions for DPrK in Equation (6). DPrK is displayed in **(C)** by subject 1 (high *armMo*, *armCorr*, *kickRot*, and *legMoST*). An example video is available as **Supplementary Materials**.



(A) rK



(B) HRB



(C) noTech

FIGURE 7 | The rK sub-technique, performed by subject 1, is displayed in **(A)** with low *armMo* but high *legMoST* and *kickRot* as defined by Equation (9). **(B)** Shows the HRB sub-technique with high *armMo*, *armCorr*, and ψ_{ski} as defined in Equation (28) illustrated by subject 3. Lastly, the noTech class, corresponding to Equation (10), where the motion estimators do not fit any defined sub-technique, is shown in **(C)** by subject 1. Subject 3 was included in this illustration since no video of subject 1 performing HRB was available. The figures are single video frames from a full video of the subjects synchronized with the sensor data and motion estimators. An example video is available in the **Supplementary Materials**.

observed that some athletes edged the skis, seemingly to produce more friction, when climbing a slope in DIA. The second reason is related to the tolerance definitions and specifying the boundary between HRB and DIA legwork (parallel vs. angled skis). The remaining disagreements found in the matrices are also related to tolerances of the arm and leg work in general, i.e., defining the tolerance for leg work between DP, DK, and DPrK (included in the TRN label). In the cases where arm work is not correlated enough to be considered double poling type sub-techniques, nor anti-correlated enough to be considered diagonal type sub-techniques. These tolerances are not systematically tuned but only manually set by inspecting the range of the sensor data. Proper definitions of the sub-techniques require these parameters to be set in an unbiased manner through standardization work involving XC skiing community experts.

The accuracies for the four labeled subjects can be read from the lower right in the confusion matrices in **Figure 9**. A total of 11 cycles were left out of the four data sets, which consists of 3427 cycles, since the XC expert found those cycles to not match any of the sub-techniques. These cycles were unusual movements, such as when the skier was checking the watch on the arm. The data sets from the four subjects received accuracies of 98%, 98%, 97, and 97%, respectively. DIA, DK, and DP exhibited excellent classification accuracies, with sensitivity and precision mostly approaching 100, whereas the TRN, HRB, and noTech classes exhibited somewhat lower sensitivity and precision due to lack of quantitative definitions and indirect motion component measures.

4.4. Framework Discussion

The presented approach is based on describing the mechanisms of classical XC skiing. It is expert and data driven in the sense that the models are derived based on the known kinematics of the sport, as well as the placement and types of sensors used for the motion components. When placing IMU sensors on the body extremities, the data produced is closely related to a video stream in the sense that the angular rates reflect a course estimate of the athlete kinematics. This is advantageous as it will provide a relatively direct and simple mapping, with the decision function description, to manual video analysis labeling for common qualitative sub-technique definitions. This is shown in **Figures 5–7**, where the motion component time series are synchronized with the video frames.

The motion components and decision functions from Definition 1 and the proof of Proposition 1 are used for classification under activity constraints. This means that the results are only valid in the case when the technique style, i.e., classical XC skiing, is known beforehand, see Assumption 1 and Remark 1. A relaxation of these constraints can be considered by extending the motion component set, adding decision functions that describe other definable sub-techniques, for example including the skating XC skiing style, as is also discussed in section 4.2. The framework does not propose a concrete recipe for composing the motion components and decision functions, meaning that different constructions may be considered, as highlighted in Remarks 2 and 3. As an example, different sensor systems can be applied as long as the derived motion components are unique and the decision functions map to an established sub-technique definition.

A main contribution from this paper is to provide a common communication platform for researchers in this field. In addition, clarifying the basic motion components and identifying sub-techniques are of high relevance for coaches and athletes in the development and utilization of digital coaching tools. For example, the Norwegian XC skiing team has systematically used technological tools combining GPS and IMUs to analyze where and why skiers gain or lose time during training and competitions as part of their preparations for major championships in the last years. In this context, detection of sub-techniques and their temporal patterns provides understanding of performance differences related to different pacing strategies, it allows detection of possible effects of training or technique changes and it may help in the optimization of tactical choices in a given track. More detailed understanding of these aspects can provide important decision support both in training and in competition settings, thereby being important coaching tools and parts of the mental strategies when preparing for competitions.

Four IMU sensors, placed on arms and legs, are used to exemplify the methodology presented in this paper. However, pose tracking video analysis or information from marker-based camera systems may also provide sufficient information for estimating the proposed motion components. In cases where a single IMU sensor is used, for example when placed on the sternum, the proposed motion components cannot be estimated directly. However, comparable results can be achieved by building a model, based upon recorded data annotated/labeled in accordance with the sub-technique definitions, motion components and decision functions. In such a case, the motion components will be implicitly represented in the trained model. However, care should be taken when applying a single sensor setup for classification of sub-technique definitions that are based on properties from the movement of more than one segment, as these properties may not in general be observable through the data provided by the one sensor.

In order to perform a proper validation of this implementation, a group of experts representing the main stakeholders in the XC skiing community is required to label the same data sets individually. This may produce data that are less biased and give insight into what the common definitions of the sub-techniques should be, including the formal definitions of the decision functions; the motion components and the constraining tolerances (see Remark 4). The presented approach has similarities to research within the physiotherapy and rehabilitation domain. In order to collect valid, reliable and comparable data on health and disability at both individual and population levels, the WHO has established The International Classification of Functioning, Disability and Health (ICF) standard (World Healt Organization, 2001). Langhammer and Stanghelle (2011) suggests that the Movement Quality Model (MQM) from the work by Skjaerven et al. (2008) relates to *body structures* and *body functions* in the ICF concept. The MQM represented the essential features and characteristics of the movement quality, reflecting a group of physiotherapists. These concepts are analogous to the framework presented in this work and are in line with the suggested need of gathering a group of

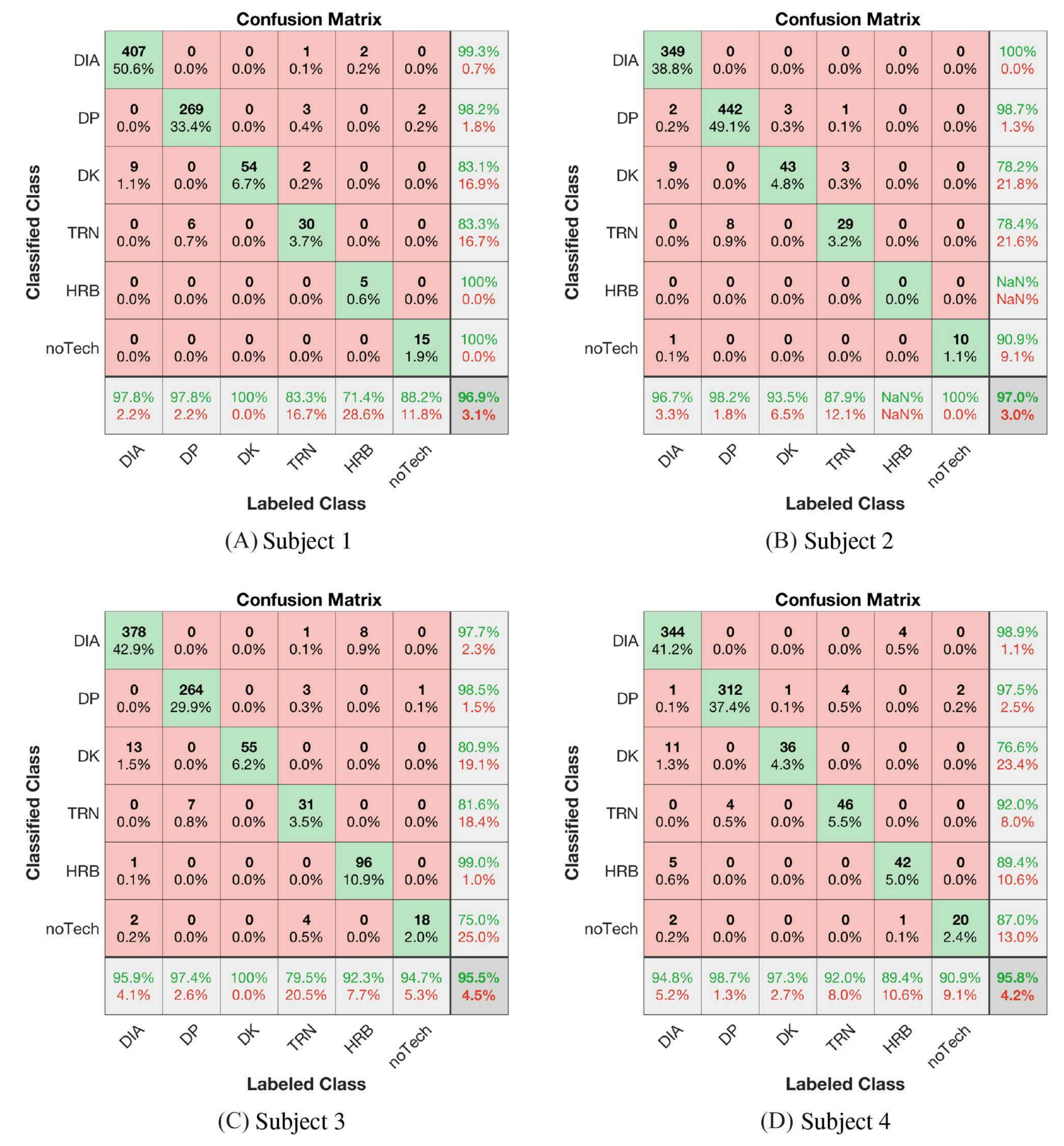


FIGURE 8 | (A–D) Confusion matrices for subjects 1 to 4 with the mapping of the labeled sub techniques fDIA and tDIA to DIA, thus using mapping a) in Definition 3.

XC skiing experts to label and formulate motion components to establish more detailed quantifiable sub-technique descriptions.

The concept may also be taken further in large-scale heterogeneous motion data sets of XC skiing, and sport activities in general, including raw data of video, positioning, and motion information annotated with for example athlete context, cycles, sub-techniques, and motion components. Such openly available data sets may have great impact on research and application development and would be comparable to for example the Common Objects in Context (COCO) project (Lin et al., 2014), which is very successful within the computer vision and pattern recognition domain. 2D video-based pose tracking/estimation

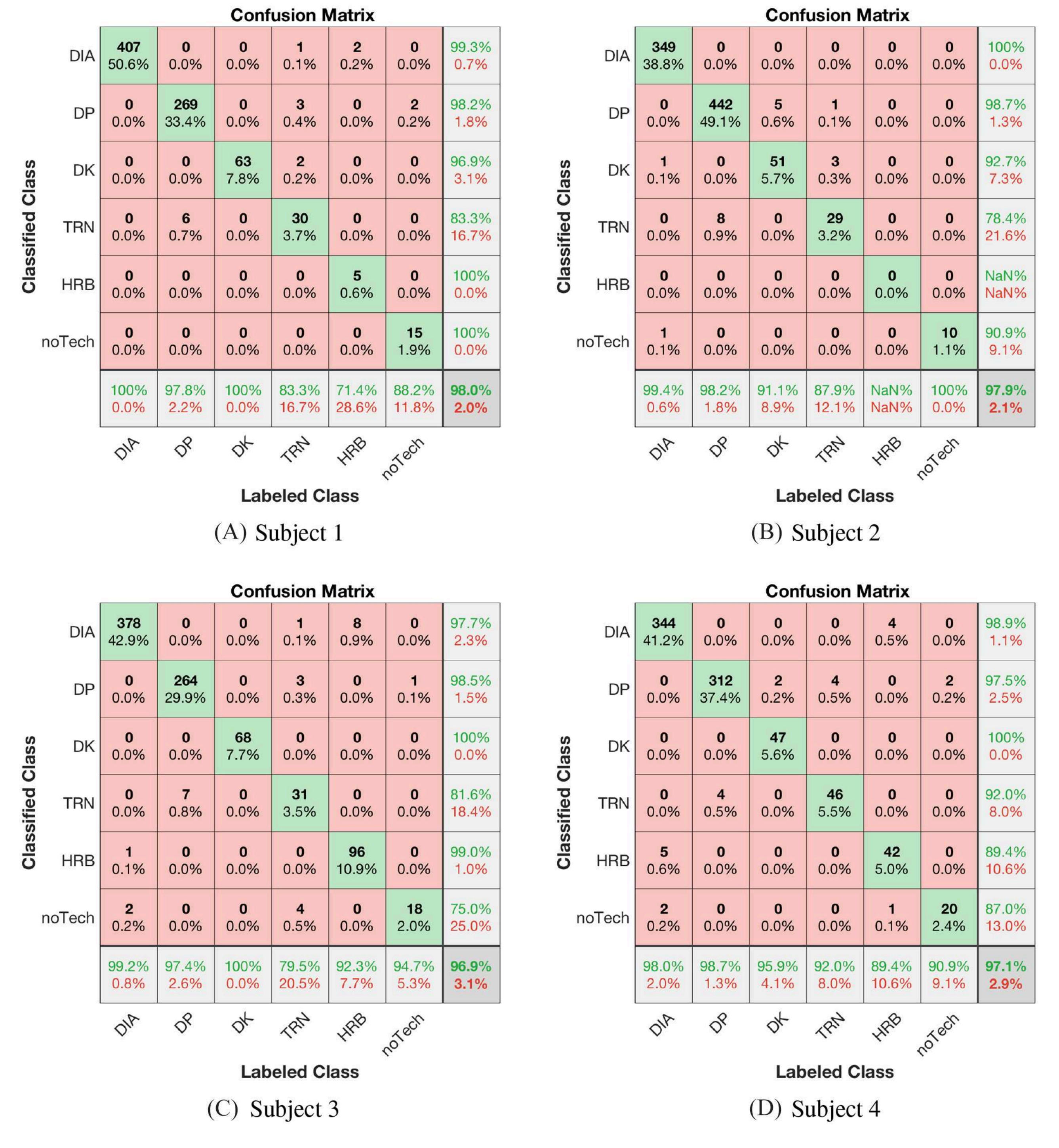


FIGURE 9 | (A–D) Confusion matrices for subjects 1 to 4 with the mapping of the labeled sub techniques tDIA to DIA and fDIA to DK, thus using mapping b) in Definition 3.

have in recent years had great progress, extending image segmentation methods and providing absolute information for human kinematics—see the PoseTrack large-scale benchmark data set (Andriluka et al., 2018) and the DensePose project (Alp Güler et al., 2018). Including pose information as context in a heterogeneous motion data set would also provide absolute information for auto-calibrating of distributed motion sensors and validation of case study protocols. Such data sets and accompanying infrastructure may be hosted open source by the university or institute sector generally for research, or by for example FIS as a basis for building automatic classification decision support in competition regulation.

5. CONCLUSION

This work proposes a framework for building quantitative measurable definitions of the sub-techniques in classical XC skiing. It relies on a definition of motion components and uses the current qualitative definitions of the sub-techniques to produce quantitative decision functions that uniquely map an athlete's motion to each sub-technique class. The structure of this identification process is closely related to the manual video analysis technique annotation given by an expert, as it focuses on measuring and describing the motion and mechanisms in the kinematic patterns of the athlete. The approach is generic and relies on known and understood mechanisms within an activity. On a structural level it also bears similarity to the notion "quality of movement" used both in sports and in the rehabilitation domain, especially in cases where the movement can be considered cyclical. In our specific approaches, the most common sub-technique decision functions (DIA, DK, and DP) were first proposed in Seeberg et al. (2017) and thereafter extended in Solli et al. (2018) to include HRB and TRN techniques. Solli et al. (2018) also present an example on how this detailed sub-technique identification may be used to test new research hypotheses in the field. Here, a holistic presentation of the methodology, including the estimators, is given. In addition, TRN is further refined to DPrK and rK. Finally the framework implementation used in our study is compared with high"fit scores" to a data set independently labeled by a domain expert. However, commonly accepted utilization of automatic tools for sub-technique classification will require work toward more unified and quantifiable definitions of the specific sub-techniques, which has also been the overarching aim of usage for the proposed framework and methodology. Altogether, this understanding contributes to the field by providing a common communication platform of high relevance for researchers in the field, and for the further development of preparation and debriefing tools where combined GPS and IMUs help XC skiing coaches and athletes in their decision-making in training and competitions.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available, but all data relevant for the purpose and conclusions of this study is provided in the article. Requests to access the datasets should be directed to oyvind.sandbakk@ntnu.no.

ETHICS STATEMENT

The study was pre-approved by the Norwegian Centre for Research Data, and conducted in accordance with the Declaration of Helsinki assured by the responsible institution, Norwegian University of Science and Technology. All participants were fully informed of all test protocols and procedures before they provided their written consent to participate.

AUTHOR CONTRIBUTIONS

JT wrote the paper, implemented the algorithms and created figures. TS designed the sensor system and modified the sensors to fit the purpose of this study, and contributed to conducting the field trials and writing the paper. OR contributed to writing the paper, the creation of figures, in algorithm comparison to manual labeling, and by conducting field trials. PH contributed to writing the paper, in the creation of figures, and by conducting field trials and labeling the data sets. ØS provided expert knowledge of the field, and contributed to designing the experiments and writing the paper.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01260/full#supplementary-material

REFERENCES

Alp Güler, R., Neverova, N., and Kokkinos, I. (2018). "Densepose: dense human pose estimation in the wild," in *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* (Salt Lake City, UT), 7297–7306. doi: 10.1109CVPR.2018.00762

Andersson, E., Pellegrini, B., Sandbakk, Ø., Stöggl, T., and Holmberg, H. C. (2014a). The effects of skiing velocity on mechanical aspects of diagonal cross-country skiing. *Sports Biomech.* 13, 267–284. doi: 10.1080/14763141.2014.921236

Andersson, E., Stöggl, T., Pellegrini, B., Sandbakk, Ø., Ettema, G., and Holmberg, H. C. (2014b). Biomechanical analysis of the herringbone technique as employed by elite cross-country skiers. *Scand. J. Med. Sci. Sports* 24, 542–552. doi: 10.1111/sms.12026

Andersson, E., Supej, M., Sandbakk, Ø., Sperlich, B., Stöggl, T., and Holmberg, H. C. (2010). Analysis of sprint cross-country skiing using a differential global navigation satellite system. *Eur. J. Appl. Physiol.* 110, 585–595. doi: 10.1007/s00421-010-1535-2

Andriluka, M., Iqbal, U., Insafutdinov, E., Pishchulin, L., Milan, A., Gall, J., et al. (2018). "Posetrack: a benchmark for human pose estimation and tracking," in *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* (Salt Lake City, UT), 5167–5176. doi: 10.1109/CVPR.2018.00542

Bolger, C. M., Kocbach, J., Hegge, A. M., and Sandbakk, Ø. (2015). Speed and heart rate profiles in skating and classical cross-country skiing competitions. *Int. J. Sports Physiol. Perform.* 10, 873–880. doi: 10.1123/ijspp.2014-0335

Bucher Sandbakk, S., Supej, M., Sandbakk, Ø., and Holmberg, H. C. (2014). Downhill turn techniques and associated physical characteristics in cross-country skiers. *Scand. J. Med. Sci. Sports* 24, 708–716. doi: 10.1111/sms.12063

Dahl, C., Sandbakk, Ø., Danielsen, J., and Ettema, G. (2017). The role of power fluctuations in the preference of diagonal vs. double poling sub-technique at different incline-speed combinations in elite cross-country skiers. *Front. Physiol.* 8:94. doi: 10.3389/fphys.2017.00094

Danielsen, J., Sandbakk, Ø., Holmberg, H. C., and Ettema, G. (2015). Mechanical energy and propulsion in ergometer double poling by cross-country skiers. *Med. Sci. Sports Exerc.* 47, 2586–2594. doi: 10.1249/MSS.0000000000000723

Farrell, J., and Barth, M. (1999). *The Global Positioning System and Inertial Navigation*, Vol. 61. New York, NY: Mcgraw-hill.

Fossen, T. I. (2002). *Marine Control System-Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles*. Trondheim: Marine Cybernetics.

Gløersen, Ø., Kocbach, J., and Gilgien, M. (2018). Tracking performance in endurance racing sports: evaluation of the accuracy offered by three commercial GNSS receivers aimed at the sports market. *Front. Physiol.* 9:1425. doi: 10.3389/fphys.2018.01425

Grøtli, E., Tjønnås, J., Azpiazu, J., Transeth, A., and Ludvigsen, M. (2016). Towards more autonomous ROV operations: scalable and modular localization with experiment data. *IFAC-PapersOnLine* 49, 173–180. doi: 10.1016/j.ifacol.2016.10.339

Haugnes, P., Torvik, P. Ø., Ettema, G., Kocbach, J., and Sandbakk, Ø. (2018). The effect of maximal speed ability, pacing strategy and technique on the finish-sprint of a sprint cross-country skiing competition. *Int. J. Sports Physiol. Perform.* 1, 1–24. doi: 10.1123/ijspp.2018-0507

Holmberg, H. C., Lindinger, S., Stöggl, T., Eitzlmair, E., and Müller, E. (2005). Biomechanical analysis of double poling in elite cross-country skiers. *Med. Sci. Sports Exerc.* 37, 807–818. doi: 10.1249/01.MSS.0000162615.47763.C8

Holst, A., and Jonasson, A. (2013). Classification of movement patterns in skiing. *Front. Artif. Intell. Appl.* 257, 115–124. doi: 10.3233/978-1-61499-330-8-115

Jang, J., Ankit, A., Kim, J., Jang, Y. J., Kim, H. Y., Kim, J. H., et al. (2018). A unified deep-learning model for classifying the cross-country skiing techniques using wearable gyroscope sensors. *Sensors* 18:E3819. doi: 10.3390/s18113819

Langhammer, B., and Stanghelle, J. K. (2011). Can physiotherapy after stroke based on the Bobath concept result in improved quality of movement compared to the motor relearning programme. *Physiother. Res. Int.* 16, 69–80. doi: 10.1002/pri.474

Lin, T.-Y., Maire, M., Belongie, S., Hays, J., Perona, P., Ramanan, D., et al. (2014). Microsoft coco: common objects in context. in *European Conference on Computer Vision* (Zurich: Springer), 740–755. doi: 10.1007/978-3-319-10602-1_48

Lindinger, S. J., Gopfert, C., Stöggl, T., Müller, E., and Holmberg, H. C. (2009a). Biomechanical pole and leg characteristics during uphill diagonal roller skiing. *Sports Biomech.* 8, 318–333. doi: 10.1080/14763140903414417

Lindinger, S. J., Stöggl, T., Müller, E., and Holmberg, H. C. (2009b). Control of speed during the double poling technique performed by elite cross-country skiers. *Med. Sci. Sports Exerc.* 41, 210–220. doi: 10.1249/MSS.0b013e318184f436

Marsland, F., Anson, J., Waddington, G., Holmberg, H. C., and Chapman, D. W. (2018). Macro-kinematic differences between Sprint and Distance cross-country skiing competitions using the classical technique. *Front. Physiol.* 9:570. doi: 10.3389/fphys.2018.00570

Marsland, F., Lyons, K., Anson, J., Waddington, G., Macintosh, C., and Chapman, D. (2012). Identification of cross-country skiing movement patterns using micro-sensors. *Sensors* 12, 5047–66. doi: 10.3390/s120405047

Marsland, F., Mackintosh, C., Anson, J., Lyons, K., Waddington, G., and Chapman, D. W. (2015). Using micro-sensor data to quantify macro kinematics of classical cross-country skiing during on-snow training. *Sports Biomech. Int. Soc. Biomech. Sports* 14, 435–47. doi: 10.1080/14763141.2015.1084033

Marsland, F., Mackintosh, C., Holmberg, H. C., Anson, J., Waddington, G., Lyons, K., et al. (2017). Full course macro-kinematic analysis of a 10 km classical cross-country skiing competition. *PLoS ONE* 12:e0182262. doi: 10.1371/journal.pone.0182262

Mikkola, J., Laaksonen, M. S., Holmberg, H. C., Nummela, A., and Linnamo, V. (2013). Changes in performance and poling kinetics during cross-country sprint skiing competition using the double-poling technique. *Sports Biomech.* 12, 355–364. doi: 10.1080/14763141.2013.784798

Myklebust, H., Gløersen, Ø., and Hallén, J. (2015). Validity of ski skating center-of-mass displacement measured by a single inertial measurement unit. *J. Appl. Biomech.* 31, 492–498. doi: 10.1123/jab.2015-0081

Myklebust, H., Nunes, N., Hallén, J., and Gamboa, H. (2011). "Morphological analysis of acceleration signals in cross-country skiing," in *Proceedings of Biosignals-International Conference on Bio-Inspired Systems and Signal Processing (BIOSTEC 2011)*(Rome), 26–29.

Nilsson, J., Tveit, P., and Eikrehagen, O. (2004). Effects of speed on temporal patterns in classical style and freestyle cross-country skiing. *Sports Biomech.* 3, 85–108. doi: 10.1080/14763140408522832

Pellegrini, B., Zoppirolli, C., Bortolan, L., Holmberg, H. C., Zamparo, P., and Schena, F. (2013). Biomechanical and energetic determinants of technique selection in classical cross-country skiing. *Hum. Mov. Sci.* 32, 1415–1429. doi: 10.1016/j.humov.2013.07.010

Rindal, O. M. H., Seeberg, T. M., Tjønnås, J., Haugnes, P., and Sandbakk, Ø. (2017). Automatic classification of sub-techniques in classical cross-country skiing using a machine learning algorithm on micro-sensor data. *Sensors* 18:75. doi: 10.3390/s18010075

Sakurai, Y., Zenya, F., and Ishige, Y. (2014). Automated identification and evaluation of subtechniques in classical-style roller skiing. *J. Sports Sci. Med.* 13, 651–657.

Sakurai, Y., Zenya, F., and Ishige, Y. (2016). Automated identification and evaluation of subtechniques in skating-style roller skiing. *Sensors* 16, 651–657. doi: 10.3390/s16040473

Sandbakk, Ø., Bucher Sandbakk, S., Supej, M., and Holmberg, H. C. (2014). The velocity and energy profiles of elite cross-country skiers executing downhill turns with different radii. *Int. J. Sports Physiol. Perform.* 9, 41–47. doi: 10.1123/ijspp.2013-0383

Sandbakk, Ø., and Holmberg, H. C. (2014). A reappraisal of success factors for olympic cross-country skiing. *Int. J. Sports Physiol. Perform.* 9, 117–121. doi: 10.1123/IJSPP.2013-0373

Sandbakk, Ø., and Holmberg, H. C. (2017). Physiological capacity and training routines of elite cross-country skiers: approaching the upper limits of human endurance. *Int. J. Sports Physiol. Perform.* 12, 1003–1011. doi: 10.1123/ijspp.2016-0749

Seeberg, T. M., Tjønnås, J., Rindal, O. M. H., Haugnes, P., Dalgard, S., and Sandbakk, Ø. (2017). A multi-sensor system for automatic analysis of classical cross-country skiing techniques. *Sports Eng.* 20, 313–327. doi: 10.1007/s12283-017-0252-z

Skjaerven, L. H., Kristoffersen, K., and Gard, G. (2008). An eye for movement quality: a phenomenological study of movement quality reflecting a group of physiotherapists' understanding of the phenomenon. *Physiother. Theor. Pract.* 24, 13–27. doi: 10.1080/01460860701378042

Smith, G. A. (1992). Biomechanical analysis of cross-country skiing techniques. *Med. Sci. Sports Exerc.* 24, 1015–1022.

Solli, G., Kocbach, J., Seeberg, T., Tjønnås, J., Rindal, O. M. H., Haugnes, P., et al. (2018). Sex-based differences in speed, sub-technique selection, and kinematic patterns during low- and high-intensity training for classical cross-country skiing. *PLoS ONE* 13:e0207195. doi: 10.1371/journal.pone.0207195

Stöggl, T., Holst, A., Jonasson, A., Andersson, E., Wunsch, T., Norström, C., and Holmberg, H. C. (2014). Automatic classification of the sub-techniques (gears) used in cross-country ski skating employing a mobile phone. *Sensors*, 14(11):20589–601.

Stöggl, T. L., and Müller, E. (2009). Kinematic determinants and physiological response of cross-country skiing at maximal speed. *Med. Sci. Sports Exerc.* 41, 1476–1487. doi: 10.1249/MSS.0b013e31819b0516

World Healt Organization (2001). *International Classification of Functioning, Disability and Health: ICF*. Geneva: World Health Organization.

Zory, R., Vuillerme, N., Pellegrini, B., Schena, F., and Rouard, A. (2009). Effect of fatigue on double pole kinematics in sprint cross-country skiing. *Hum. Mov. Sci.* 28, 85–98. doi: 10.1016/j.humov.2008.05.002

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The Validity and Reliability of Live Football Match Statistics From Champdas Master Match Analysis System

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The aim of the present study was to investigate the validity of match variables and the reliability of *Champdas Master System* used by trained operators in live association football match. Twenty professional football coaches voluntarily participated in the validation of match variables used in the System. Four well-trained operators divided into two groups that independently analyzed a match of Spanish La Liga. The Aiken's V averaged at 0.84 ± 0.03 and 0.85 ± 0.03 for the validation of indicators. The high Kappa values (Operator 1: 0.92, 0.90; Operator 2: 0.91, 0.88), high intra-class correlation coefficients (varied from 0.93 to 1.00), and low typical errors (varied from 0.01 to 0.34) between the first and second data collection represented a high level of intra-operator reliability. The Kappa values for the inter-operator reliability of were 0.97 and 0.89. The intra-class correlation coefficients and typical errors ranged from 0.90 to 1.00 and ranged from 0.01 to 0.24 for two independent operators within two data collections. The results suggest that the *Champdas Master system* can be used validly and reliably to gather live football match statistics by well-trained operators. Therefore, the data obtained by the company can be used by coaches, managers, researchers and performance analysts as valid match statistics from players and teams during their professional tasks and investigations.

Keywords: performance analysis, reliability, validity, football, match statistics

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INTRODUCTION

Sport performance analysis during actual competition is one of the main sources of information that are beneficial for the training and coaching process (Sampaio and Leite, 2013). In essence, coaches and athletes could be provided with information of interest that is difficult to be detected throughout their subjective perception, and then refine their training planning and improve athlete's performance purposefully (Hughes and Franks, 2015). Within its domain, the analysis of technical and tactical performance has captured substantial research interest in either individual sports (Reid et al., 2016; Cui et al., 2019), or team sports (Zhang et al., 2018; Zhou et al., 2018), where a set of performance indicators that contains relevant information about players and teams' match performance during competition have been established and collected via observational approaches (Hughes and Bartlett, 2002; Lames and McGarry, 2007; Hughes and Franks, 2015). Fundamentally, it is mainly based on systematic observation, understood as an organized recording and quantification of sport behaviors in their natural context (O'Donoghue and Mayes, 2013; Sampaio and Leite, 2013). To achieve this purpose, both a well-designed notational system and valid, precise and objective performance indicators are required so that technical-tactical aspects of match performance could be easily gathered and used for the subsequent analysis and practical applications (Bradley et al., 2007; Carling et al., 2007; O'Donoghue, 2007).

Therefore, as a prerequisite for any performance analysis research that uses novel system or instrument, the repeatability and accuracy of this new tool, and the validity of performance indicators used should be validated, before collecting and analyzing players and teams' performances (O'Donoghue, 2014; Chacón-Moscoso et al., 2018). Despite that currently there are some automatic player tracking system available for performance analysis, most of observational studies or practices in sport field are still done with computerized notational systems where performance analysts are required to manually code sport performance indicators with predetermined short-cut keys (Bradley et al., 2007; Hizan et al., 2010; Liu et al., 2013; Beato et al., 2018). From a theoretical and applied perspective, a performance indicator should help to explain the match outcome; and thus advance understanding, providing for meaningful insights of game behavior (O'Donoghue, 2009). The use of precise operational definitions and the validity of performance indicators are related to reliability of data collection in performance analysis and therefore have a strong impact on the correct interpretation of match performances (McGarry, 2009).

Validity is generally referred to as the ability of a measurement tool to reflect what it is designed to measure (Atkinson and Nevill, 1998), and usually for performance analysis instrument, it can be determined through expert coaches' opinions in each sports category (Hraste et al., 2008; Cupples and O'Connor, 2011; Larkin et al., 2016; Torres-Luque et al., 2018). For instance, Larkin et al. (2016) validated a coding instrument of assessing movement awareness and technical skills for soccer players with a panel of nine experts. Similarly, with the review and confirmation of eleven experts, Torres-Luque et al. (2018) validated an observational instrument for analyzing the technical-tactical match performance in tennis. Further, the reliability of a sport notational system is as important as its validity (Hayen et al., 2007). It refers to the reproducibility of values of a test, assay or other measurement in repeated trials on the same individuals (intra-observer reliability) (O'Donoghue, 2009), and repeatability over different observers (inter-observer reliability) (Hopkins, 2000). Sports notational system may be limited in reliability due to manual errors, observer's inexperience, number of observers (Beato et al., 2018) so that its results will mislead coaches or performance analysts to make poor decisions about training and match preparation.

In recent years, the development of semi-automatic match analysis systems in elite football has enhanced the accessibility to match information related to match events and movements (Carling et al., 2007; Mackenzie and Cushion, 2013). And as a result, performance directors, coaches and researchers frequently utilize these systems to gain insights into football match performance. Concurrently, the accuracy and reliability of some widely used systems from various commercial football match statistics providers have been validated and verified, such as AMISCO® system (Carling et al., 2008; Zubillaga et al., 2009; Lago et al., 2010; Dellal et al., 2011; Castellano et al., 2014), PROZONE Sports Ltd.® (Bradley et al., 2007, 2011; Castellano et al., 2014), SportsCode (Hughes, 2004; Reed and Hughes, 2006; O'Donoghue and Holmes, 2014), OPTA Sportsdata (Oberstone, 2009, 2010, 2011; Liu et al., 2013), SICS (Rampinini et al., 2009; Osgnach et al., 2010; Beato and Jamil, 2017), Dartfish (Eltoukhy et al., 2012; Padulo et al., 2015; Larkin et al., 2016; Li et al., 2016), and Nacsports (Clear et al., 2017). Indeed, these systems have presented both coder-friendly operating platform and high reliability in measuring technical-tactical performance indicators. Yet, there remain some limitations concerning the above-mentioned studies and measures. Most of them only studies the test-retest reliability of these systems, not considering the content validity of performance events or indicators included. Besides, some systems were mainly focused on the successful or unsuccessful outcome of technical performance events, such as shoots, dribbles, crosses (Larkin et al., 2016), so that tactical information related to pass directions and network is not able to be gathered, which helps to understand complex match characteristics of this invasion sport and becomes one of the recent research topics for football investigators (Gonçalves et al., 2017; Pollard, 2019; Praça et al., 2019).

In comparison with the previous existing systems, *Champdas Master System*, a semi-automatic match analysis system developed by the Champion Technology Co., Ltd., (a leading Chinese sport data company founded in 2004), has been employed to provide match data services for the majority of professional teams from Chinese Football Super League (first division) and Chinese Football Association China League (second division), China National Youth Super League (U13–U19 divisions), China Men's National Team, clubs from Korean K-league (first division). Meanwhile, the company has also been cooperating with major Chinese online sport video media (PPTV), by collecting, storing, analyzing and visualizing professional football match data of the first leagues in Korea, Spain and United Kingdom (first leagues) during online match broadcasting. In a word, most of match reports and analyses provided by the system are widely used by Asian professional football clubs, coaches, media, and governing organizations. Furthermore, what stands the system out is that it not only allows for common match performance indicators as its peers do, but also includes a more complex classification of players' passing directions, which is seldom found in other systems. As noted above, passing behaviors reveal great extent of tactical information about football, because some teams try to create opportunities by long direct passes, whereas other teams are characterized by possession-style type of play (Larkin et al., 2016; Goes et al., 2019). Players are most likely more successful when passing the ball backward or sideways than attempting forward passes, but the latter has been regarded as a key performance indicator when evaluating penetration of offensive actions and assessing players' performance (Goes et al., 2019). However, given a wide range of professional leagues, clients and audience it serves, little is known about whether match performance indicators used in the *Champdas Master System* are valid and the live match data collecting process is reliable among its trained operators.

Consequently, it is imperative to execute a thorough validity and reliability analysis of the system, so that its statistics would be trustworthy for research, coaching and broadcasting purposes. Therefore, the present study was aimed: (i) to identify the validity of match performance variables used by *Champdas Master System*; (ii) to verify the intra- and inter-operator reliability of *Champdas Master System* used by well-trained operators to collect match statistics in live association football match.

MATERIALS AND METHODS

Validity of Performance Variables Used by *Champdas Master System*

At the first stage of the study, a panel of experts constituted by 20 coaches or assistant coaches from China, Spain, Portugal, Germany, and Ireland voluntarily participated and completed the questionnaire that was aimed to validate the performance variables used in *Champdas Master System*. The inclusion criteria of the coaches were as follows: (i) Having coached professional teams of a level equivalent to the first and second divisions in Asian Football Confederation (AFC) or Union of European Football Associations (UEFA) or coached in a semi-professional level, equivalent to AFC or UEFA third division; and (ii) Owning coach licenses equivalent or higher than AFC-B or UEFA-A level. The participating coaches had an average coaching experience of 13.3 $\pm$ 7.1 years, and among twenty of them, five had UEFA-Pro license, five had UEFA-A license, nine had AFC-A license and one had AFC-B license. Prior to the filling of questionnaire and sign the voluntary informed consent, the study purpose and the anonymously academic use of their answers were explained to each coach.

Performance Variables and Operational Definitions

The questionnaire was based on performance variables used by *Champdas Master System* and they were divided into three domains: (i) Attacking-related performance; (ii) Passing-related performance, and (iii) Defending-and-Goalkeeper-related performance. The criterion of selecting these variables were mainly based on two categories of existing literature, namely, studies that examined the validity of other match analysis systems and analyzed variables (Valter et al., 2006; Bradley et al., 2007; Liu et al., 2013; Castellano et al., 2014; Beato et al., 2018); and studies that focused on tactical patterns and passing behaviors of football players (Rein et al., 2017; Goes et al., 2019; Pollard, 2019). Within all variables, the inclusion of two variables should be highlighted. First of all, considering the width of the pitch and different pitch paths (left, center, and right) and their actual usefulness in interpreting offensive behaviors (Sgrò et al., 2017), we included the "attacking shift" as a performance variable, revealing a quick ball transition from side to side. This corroborates with the findings of Rein et al. (2017) in that more successful teams could increase space control in the attacking zone through passing, creating defensive disadvantages for the opposing teams. Secondly, passing directions were established calculating the angles from current passes to the next events in relation to the sideline and attacking direction (see **Figure 1**; Serpiello et al., 2017; Goes et al., 2019).

Attacking-Related Performance

Attacking shift

The situation takes place in midfield or attacking third where the attacking players take the initiative to transfer the ball from one sideway to the other (done with no more than three passes), for creating better attacking space.

Enter into attacking third

(Pitch is divided into three zones, including attacking third, middle third and defending third. Enter into offensive zone means entering into attacking third). It includes the following conditions: (1) After players enter into the attacking third, a transition of ball possession is realized (including possession gained by defensive actions or opponent's turnover); (2) A dead ball occurs.

Dribble

A dribble is an attempt by a player to beat an opponent in possession of the ball. A successful dribble means the player beats the defender while retaining possession; unsuccessful ones are where the dribbler is tackled.

Shot

An attempt to score a goal, made with any (legal) part of the body, either on or off target. The outcomes of shot could be: goal, shot on target, shot off target, blocked shot, post.

Shot on target

The definition of a "shot on target" or a "shot on goal" (SOG) is goal or any shot attempt to goal, which required intervention to stop it going in or resulted in a goal if left unblocked.

Possession gained

The total number of possession regained by active defending (tackle, interception), or by passive recovery (ball cleared by the opponents).

Aerial Duel

Aerial Duel can be also called as heading duel. Two players competing for a ball in the air, for it to be an aerial both players must jump and challenge each other in the air and have both feet off the ground. The player who wins the duel gets the Aerial Won, and the player who doesn't get an Aerial Lost.

Passing-Related Performance

Pass

Any pass attempted from one player to another. Excluding free kicks, corners, throw-ins, and goal kicks.

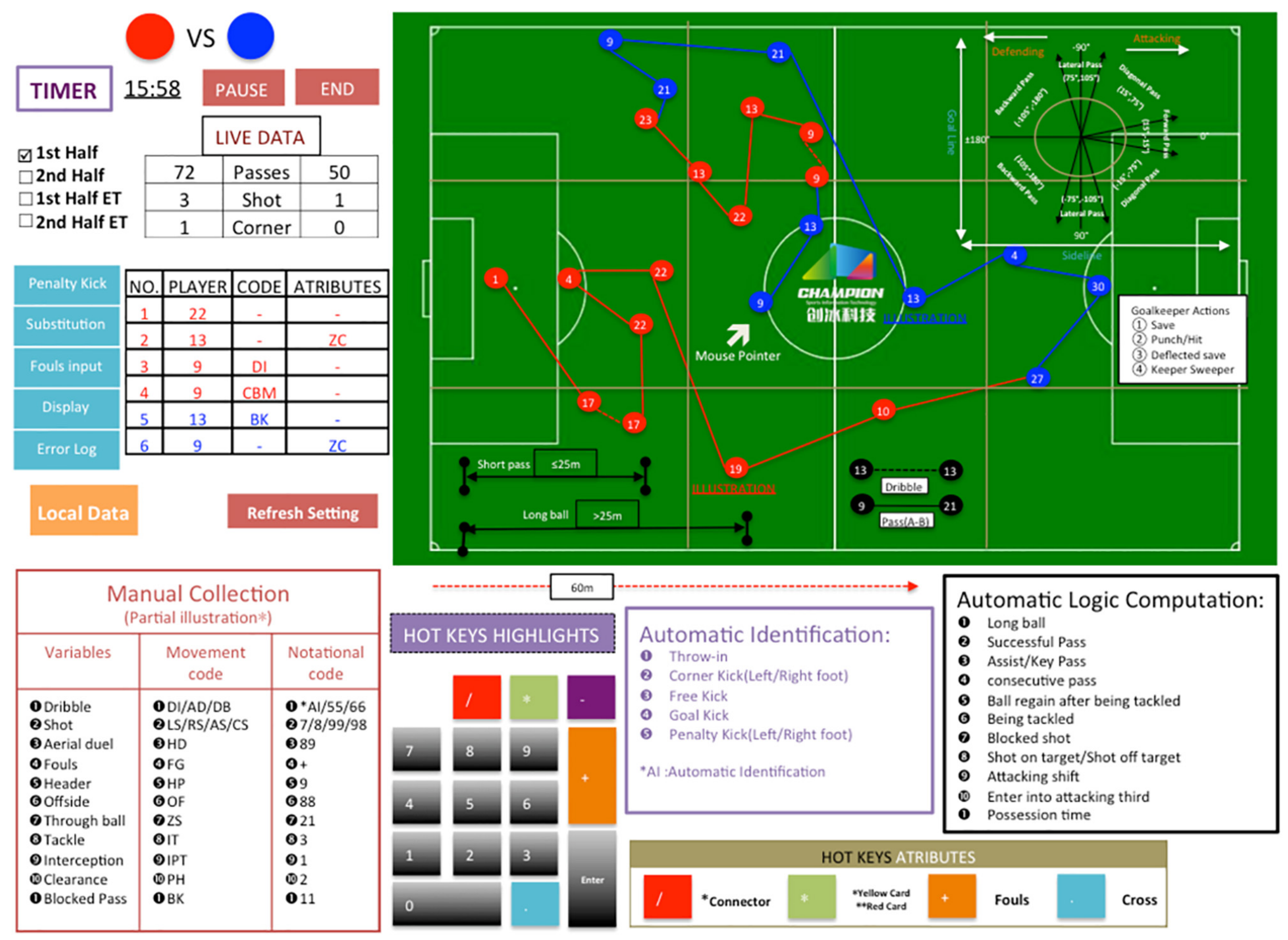

FIGURE 1 | Illustration of *Champdas Master System* operation interface diagram.

Successful pass
Any pass successfully reached from one player to another. Excluding free kicks, corners, throw-ins, and goal kicks.

Forward pass
Forward pass (The angle between pass direction and the parallel of sideline is $<15°$).

Through ball
Ball passed through the last line of defense.

Lateral pass
The lateral pass to the left or right (the angle between pass direction and the parallel of goal line $\leq 15°$).

Diagonal pass
The pass with the angle between pass direction and the parallel of sideline is $\{(15°, 75°), (105°, 165°)\}$.

Backward pass
The pass with the angle between backward pass route and side line $\leq 75°$.

Long pass
The distance of pass > 25 m.

Short pass
The distance of pass ≤ 25 m.

Assist
The final pass or cross leading to goal-scoring.

Consecutive pass
The total number of passes that a team realizes without losing ball possession or causing a dead ball.

Key pass
The final pass or cross leading to the recipient of the ball that attempts to make a goal, but fails.

Cross
Any pass that delivers the ball into the penalty area by the attacking team, from lateral areas of the attacking third (not played inside of the penalty area).

Defending-and-Goalkeeper-Related Performance

Tackle

When the opposing player is in possession of the ball, but has no intention to pass, the defending player acts dispossessing the ball. A tackle won is given during following conditions: when a player makes a tackle and possession is retained by either himself or one of his teammates; when the tackle results in the ball leaving the field of play.

Interception

When a player intercepts any pass event between opposition players and prevents the ball reaching its target. Note: Defending player should be close to the receiver.

Clearance

Player under pressure gets the ball clear of the danger zone or/and out of play. If the ball is intentionally played into another teammate, it is not considered as a clearance, but a pass.

Blocked pass

Similar to interception but the opposing player is already very close to ball and successfully block the pass from passing player. It usually happens when player consciously or unconsciously blocks the pass immediately when the ball is attempted from one player to another.

Blocked shot

A defensive block, blocking a shot going on target. This must be awarded to the player who blocks the shot.

Save

The goalkeeper prevents the ball from entering the goal with any part of his body.

Punch

The goalkeeper punches/hits any ball played into the box.

Deflected save

When goalkeeper saves a shot, but does not catch the ball.

Keeper sweeper

When the goalkeeper runs out from the goal line to either intercept a pass or close down an attacking player.

Questionnaire Design and Quantitative Evaluation

In order to make sure that variables were precisely defined and validly represented certain aspect match behavior (O'Donoghue, 2007), the questionnaire was designed to quantitatively evaluate: (i) the level of correct definitions of the performance variables, and (ii) the level of variable pertinence to match behaviors. This evaluation was comprised of a scale from 1 to 10, and an example of the questionnaire is presented in **Table 1**. There was no time limit to complete the questionnaire and the average time the coaches used to fill out the questionnaire was 20 min.

Afterward, their answers were collected and analyzed to calculate the content validity for each variable. To achieve this, the Aiken's V coefficient of each item and its respective 95% confidence interval were used (Aiken, 1980; Penfield et al., 2004).

TABLE 1 | Illustration of questionnaire sent to experts.

Dribble
(1) Definition: A dribble is an attempt by a player to beat an opponent in possession of the ball. A successful dribble means the player beats the defender while retaining possession; unsuccessful ones are where the dribbler is tackled
Poorly defined 1-2-3-4-5-6-7-8-9-10 **Correctly defined**
(2) Pertinence: Does this variable seem pertinent to the match performance?
None 1-2-3-4-5-6-7-8-9-10 **Maximum**

The magnitude of this coefficient was from 0 to 1, with 1 being the greatest possible magnitude that indicates a perfect agreement among the judges regarding the highest validity score "10" of the contents evaluated in the scale. An item was determined to be valid if its Aiken's V coefficient exceeds the exact critical value calculated by the following formula that takes into account the number of judges and items in the questionnaire sample was used (Aiken, 1985):

$$\bar{V} = 0.5 + \left(z\ .2\sqrt{\frac{3mn(c-1)}{c+1}} \right)$$

where z is the level of significance, m the number of items that the experts should evaluate, n is the number of expert judges that participate in the study, and c the maximum value that can evaluate an item. The exact critical value was then calculated to be 0.52 via the formula at a statistical significance level of $p < 0.05$.

Intra- and Inter-Operator Reliability Test for the *Champdas Master System*

Champdas Master System is a computerized match analysis system developed by Champion Technology Co., Ltd., to generate live match statistics for professional association football matches. Any performance analyst using the System has to firstly go through a rigorous learning process to get comprehensively familiarized with the definitions of all match actions or events, live coding mode, hot-keys, on-screen manual positioning with mouse, and movement characteristics (see the illustration in **Figure 1**). Later, they are required to practice the learned knowledge and skills within various trial matches so as to be capable of collecting formal live match statistics.

Main data capture mode combines hot-keys of keyboard and on-screen positioning to represent events and labels. The on-screen positioning functions by using mouse markings on a scaled-down version of football pitch, which is employed for tracking players. The movements of mouse and codes correspond to the actual actions performed by players in the actual match.

Event buttons/labels represent match events that are to be recorded over the course the match. Some events may have multiple levels of information, so that some short-cut keys or combination of keys recording different aspects of the same event are used and synchronized by the system.

Two categories of data source are automatically input into the system once manually coding match events. The first category includes corner, free kick and throw-in, etc., events that can be automatically identified given the marking locations on the simulated pitch; the other category is composed of long ball, successful pass, consecutive pass, attacking shift, etc., actions that can be automatically and logically generated from the relationship of players and pitch zones. The corresponding time of the event is also recorded automatically once an event is notated. Meanwhile, the marked event locations would be later integrated to generate additional tactical performance information.

Live Data Collection and Sampled Match

To test the system reliability, four well-trained operators (experience = 1.5, 1.5, 2, and 2 years) from Champion Technology Co., Ltd., collected twice (with an interval of 2 weeks) the match data of the 19th round of Spanish La Liga Santander between Real Madrid and Villarreal contested in January 13, 2018 (Live broadcast from a conventional TV coverage). The number of match used and the coding procedure followed the routine of previous studies that validated similar systems (Bradley et al., 2007; Choi et al., 2007; Liu et al., 2013; Beato et al., 2018).

The operators were separated into two groups and observed the match independently. To be capable of formally operating the system, new operators should take part in a training process that consists of five parts: (i) definition learning, (ii) actions coding, (iii) practice in test server, (iv) played-match coding, and (v) live match coding (Champion Technology Co., Ltd., 2018). Normally, during months of training process, new operators were required to get familiar with all match actions, events and corresponding codes, and gradually develop the accuracy and proficiency in data collection. During the live match coding, there was only one principal operator from each group who was in charge of coding all match events. While the other was responsible for checking the completeness of whole dataset, amending any major inconsistence of statistics wherever needed, and then the final report was usually regarded as one-operator work. Therefore, in the current study, Operator 1 and Operator 2 were used to represent each coding group. A total of 27 players were observed, which included 22 starters, 5 substitutes, and 2 goalkeepers. The data collection was officially authorized and supported by Champion Technology Co., Ltd., and the institutional ethics committee from the Technical University of Madrid approved the study.

After the data collection, the raw data were output into Microsoft Excel with their corresponding timeline. As there were large differences in players' action counts due to different on-field time, the agreement of match actions and events coded by independent operators was analyzed by considering the same three number of groups used during validation stage: (i) attacking related actions: dribble won, dribble lost, corner, attacking shift, possession gained, free kick, goal, header, shot, shot on target, shot off target, shot saved, throw-in, offside, and enter into attacking third; (ii) passing-related actions: pass, successful pass, forward pass, through ball, lateral pass, diagonal pass, backward pass, long pass, short pass, assist, consecutive pass, key pass, and cross; and (iii) defending and goalkeeper related actions: blocked pass, blocked shot, clearance, interception, tackle won, tackle lost, aerial won, aerial lost, yellow card, keeper sweeper, save, punch, and deflected save.

Statistical Analysis

The intra- and inter-operator reliability of collected match statistics were determined using weighted *Kappa* statistic (Altman, 1990; O'Donoghue, 2010), mean, change in the mean, standardized typical error (TE) and intra-class correlation (ICC) (Hopkins, 2000). The *kappa* statistic was interpreted according to Altman's evaluation scheme (Altman, 1990): $\kappa \leq 0.2$ poor agreement; $0.2 \leq \kappa < 0.4$ fair agreement; $0.4 \leq \kappa < 0.6$ moderate agreement; $0.6 \leq \kappa < 0.8$ good agreement; $\kappa \geq 0.8$ very good agreement. The value of standardized typical error should be doubled and the thresholds for the levels of disagreement are as follow: < 0.20 trivial; 0.21–0.60 small; 0.61–1.20 moderate; 1.21–2.00 large; 2.01–4.00 very large; >4.00 extremely large (Hopkins, 2000; Smith and Hopkins, 2011). The mean, change in the mean and standardized TE and ICC were calculated using the spreadsheet developed by Hopkins (2000).

RESULTS

Based on the evaluation of twenty professional coaches over 31 variables, the result of Aiken's V averaged at 0.84 ± 0.03 for the degree of variable pertinence to match performance and 0.85 ± 0.03 for the correct definition of variable, showing high values in relation to content validity of all variables (see **Table 2**).

Table 3 showed that there were in total 5,430 events agreed by two independent operators within two collections for Real Madrid, and 4,065 for Villarreal. Comparing intra-operator data collections between the first and second collection, the average time difference of event-coding was 0.91 ± 0.94 s for Operator 1 and 0.81 ± 0.88 s for Operator 2, respectively. While average time difference was 0.89 ± 0.88 s between Operator 1 and Operator 2 for inter-operator data collections. Details can be seen from **Figures 2**, **3**. The *Kappa* statistics for the events of two teams were 0.97 and 0.89, showing a very good agreement between independent operators.

Table 4 showed that there were in total 2,619 events agreed by Operator 1 within two collections for Real Madrid, and 1,948 for Villarreal. The Kappa values for the events of two teams were 0.91 and 0.93. While **Table 4** showed that there were in total 2,781 events agreed by Operator 2 within two collections for Real Madrid, and 1,953 for Villarreal. The Kappa values for the events of two teams were 0.91 and 0.87. These results demonstrated a very good intra-operator agreement (see **Supplementary Tables 1–4**).

Table 5 shows that the intra-class correlation coefficients (ICC) ranged from 0.98 to 1.00 and the standardized typical errors (TE) varied from 0.01 to 0.15 for different groups of match actions coded by the same operator within two data collections, showing very good intra-operator reliability. The ICC ranged from 0.93 to 1.00, and TE varied from 0.01 to 0.29 for different match actions coded by different operators within two data collections, showing high level of inter-operator reliability. Furthermore, an empirical comparison was made

TABLE 2 | Evaluation by 20 expert judges of the pertinence and definition of performance variables.

	Pertinence to match performance			Correct definition of variable		
	Mean (SD)	**Aiken's V**	**95% CL**	**Mean (SD)**	**Aiken's V**	**95% CL**
Attacking shift	8.3 (1.4)	0.81	0.806–0.815	8.2 (1.6)	0.79	0.789–0.799
Enter into attacking third	8.5 (1.6)	0.83	0.823–0.832	8.4 (1.7)	0.82	0.817–0.826
Possession time	8.9 (1.8)	0.87	0.868–0.875	9.1 (1.6)	0.89	0.89–0.897
Dribble	8.5 (1.8)	0.83	0.823–0.831	8.7 (1.5)	0.85	0.845–0.854
Shot	9.3 (1.2)	0.92	0.918–0.925	9.4 (1.0)	0.93	0.929–0.936
Shot on target	9.0 (1.4)	0.88	0.878–0.887	9.0 (1.3)	0.88	0.878–0.887
Possession gained	9.0 (1.3)	0.89	0.884–0.892	9.1 (1.1)	0.90	0.895–0.903
Aerial Duel	8.5 (2.0)	0.83	0.823–0.831	8.6 (1.7)	0.84	0.84–0.848
Pass	8.5 (2.8)	0.83	0.824–0.831	8.8 (2.4)	0.87	0.863–0.869
Successful pass	8.6 (2.5)	0.84	0.841–0.847	8.7 (2.4)	0.86	0.852–0.858
Forward pass	9.0 (1.6)	0.88	0.879–0.887	9.1 (1.4)	0.89	0.89–0.898
Through ball	8.4 (2.4)	0.82	0.818–0.825	8.6 (2.3)	0.84	0.835–0.842
Lateral pass	8.7 (1.7)	0.85	0.845–0.854	8.7 (1.6)	0.86	0.851–0.859
Diagonal pass	8.7 (1.7)	0.85	0.845–0.854	8.7 (1.5)	0.86	0.851–0.859
Backward pass	8.5 (1.8)	0.83	0.823–0.831	8.7 (1.6)	0.85	0.845–0.854
Long pass	8.7 (1.8)	0.85	0.845–0.853	8.8 (1.7)	0.86	0.856–0.865
Short pass	8.8 (1.9)	0.87	0.862–0.87	9.0 (1.6)	0.88	0.879–0.886
Assist	8.9 (2.5)	0.87	0.869–0.875	8.9 (2.4)	0.88	0.874–0.88
Consecutive pass	8.5 (2.5)	0.83	0.824–0.831	8.5 (2.4)	0.83	0.829–0.836
Key pass	8.5 (2.5)	0.83	0.83–0.836	8.6 (2.4)	0.84	0.841–0.847
Cross	8.4 (1.5)	0.82	0.817–0.826	8.5 (1.5)	0.83	0.828–0.837
Tackle	8.5 (1.5)	0.83	0.823–0.832	8.5 (1.4)	0.83	0.828–0.837
Interception	8.9 (1.1)	0.87	0.867–0.876	9.0 (0.9)	0.89	0.883–0.893
Clearance	8.8 (1.5)	0.87	0.862–0.87	8.9 (1.3)	0.88	0.873–0.881
Ball regain after being tackled	8.3 (2.5)	0.81	0.807–0.814	8.5 (2.3)	0.83	0.829–0.836
Blocked pass	8.3 (2.4)	0.81	0.807–0.814	8.5 (2.2)	0.83	0.824–0.831
Blocked shot	8.7 (2.3)	0.85	0.846–0.853	8.7 (2.4)	0.85	0.846–0.853
Save	8.6 (2.4)	0.84	0.835–0.842	8.6 (2.3)	0.84	0.84–0.847
Punch	8.3 (2.7)	0.81	0.802–0.808	8.5 (2.4)	0.83	0.829–0.836
Deflected save	8.4 (2.3)	0.82	0.818–0.825	8.6 (2.3)	0.84	0.835–0.842
Keeper sweeper	8.6 (2.4)	0.84	0.835–0.842	8.6 (2.3)	0.84	0.84–0.847

between match statistics provided by OPTA Sports[1] and Operator 1 and 2 from Champdas Master System, concerning the same match events that both systems comprise (see **Table 6**). It is shown that generally both operators demonstrated an acceptable agreement with OPTA in all compared variables, expect for a slight discrepancy in short passes.

[1]http://www.whoscored.com

TABLE 3 | Number of events coded by different operators during two data collections.

	Agreement	Operator 1		Operator 2		*Kappa*
		Total	**Disagreed**	**Total**	**Disagreed**	
Real Madrid	5,430	5,518	88	5,519	89	0.97
Villarreal	4,065	4,393	328	4,391	326	0.89

All event numbers presented in the table are sum of two data collections.

DISCUSSION

This study has examined the validity and the inter- and intra-operator reliability of *Champdas Master System* operated by different well-trained operators, who were unaware of study purpose. The validation process of this system is important for scientific acknowledgment and credibility. From professional football coaches' evaluation, match variables included in the system had high levels of content validity. Operators separately coded more than 4,000 events in each data collection, which was higher than the values from previous studies applying other systems such as Prozone, OPTA and Digital.Stadium (Bradley et al., 2007; Liu et al., 2013; Beato et al., 2018). Moreover, results reported in this study showed that *Champdas Master System* had high levels of absolute and relative reliability. This reveals that the system is capable of measuring football match events reliably and provide more technical-tactical performance details than its peer systems.

Real Madrid	Operator 2																																												
Operator 1	Foul	DW	DL	Corner	AS	Goal kick	PG	Free Kick	Goal	Header	Shot	SO	ST	SS	Throw-in	Offside	EAT	Pass	SP	FP	TB	LP	DP	BP	Long	Short	Assist	CP	KP	Cross	BP	BS	Clearance	Interception	TW	TL	AW	AL	YC	KS	Save	Punch	DS	None	Total
Foul	22																																											0	22
DW		14											1																						1									5	21
DL			7																																									5	12
Corner				22																																								0	22
AS					7																									1														0	8
Goal kick						10																																						1	11
PG							85			1																				1					5									0	92
Free Kick								26																																				0	26
Goal									0																																			0	0
Header										40																								4			2							0	46
Shot											54																																	0	54
SO												21																																0	21
ST													14																															0	14
SS														19																														0	19
Throw-in															38																													0	38
Offside																6																												0	6
EAT																	160																											15	175
Pass																		1243																										0	1243
SP																			1046																									0	1046
FP																				81																								0	81
TB																					2																							0	2
LP																						176	2																					0	178
DP																							471												1									0	472
BP																								315																				0	315
Long					5																				44	3																		0	52
Short																										994																		0	994
Assist																											0																	0	0
CP																										4		219																5	228
KP																													50															0	50
Cross																														80														0	80
BP																															5													0	5
BS																																6												0	6
Clearance																										3							16	2										0	21
Interception																																		23	1									0	24
TW																																			35									0	35
TL																																				33								0	33
AW										7																											17							0	24
AL										8																												18						5	31
YC																																							4					0	4
KS																																								1				0	1
Save																																									4			0	4
Punch																																										2		0	2
DS																																											0	0	0
None	1	8	3	0	0	0	6	0	0	0	0	0	0	0	0	0	0	4	2	1	0	0	1	0	0	0	0	0	0	2	1	0	0	1	5	2	0		0	0	0	0	0		37
Total	23	22	10	22	12	10	91	26	0	56	54	21	15	19	38	6	160	1247	1048	82	2	176	474	315	44	1004	0	219	50	84	6	6	16	30	48	35	19	18	4	1	4	2	0	36	5555

FIGURE 2 | Frequency of Real Madrid's events recorded by the two independent operators in two collections. DW, dribble won; DL, dribble lost; AS, attacking shift; PG, possession gained; SO, shots off target; ST, shot on target; SS, shot saved; EAT, enter into attacking third; SP, successful pass; FP, forward pass; TB, through ball; LP, lateral pass; DP, diagonal pass; BP, backward pass; CP, consecutive pass; KP, key pass; BP, blocked pass; BS, blocked shot; TW, tackle won; TL, tackle lost; AW, aerial won; AL, aerial lost; YC, yellow card; KS, keeper sweeper; DS, deflected save.

Villarreal	Operator 2																																												
Operator 1	Foul	DW	DL	Corner	AS	Goal kick	PG	Free Kick	Goal	Header	Shot	SO	ST	SS	Throw-in	Offside	EAT	Pass	SP	FP	TB	LP	DP	BP	Long	Short	Assist	CP	KP	Cross	BP	BS	Clearance	Interception	TW	TL	AW	AL	YC	KS	Save	Punch	DS	None	Total
Foul	22																																											0	22
DW		13	1																																									6	20
DL			8																																									3	11
Corner				0																																								0	0
AS					2																																							0	2
Goal kick						24																																						0	24
PG							76			2																					1		1	1	2									12	95
Free Kick								28																																				0	28
Goal									1																																			0	1
Header			1				1			59																											2							4	67
Shot											18																																	0	18
SO												6																																0	6
ST													4																															0	4
SS														6																														0	6
Throw-in															22																													0	22
Offside																2																												0	2
EAT																	100																											0	100
Pass																		908																										0	908
SP																			758																									0	758
FP																				77			25																					8	110
TB																					3																							0	3
LP																						86	24	15																				5	130
DP																				26		30	311	2																				9	378
BP																						18	3	262																				10	293
Long																									74																			6	80
Short																										807																		21	828
Assist																											1																	0	1
CP																												130																0	130
KP																													13	1														0	14
Cross																														12														0	12
BP							1																								45		1	1										2	50
BS																																17	1											0	18
Clearance							6			2																					2		55	5										11	81
Interception																															1			10	1									5	17
TW							2																												21									4	27
TL																															1					31								7	39
AW										10																											18	4						2	34
AL										3																							1				1	9						11	25
YC																																							2					0	2
KS																																								0				2	2
Save																																									14			0	14
Punch																																										10		0	10
DS																																											0	0	0
None	0	8	3	0	0	0	11	0	0	5	0	0	0	0	0	0	0	0	0	0	1	8	17	8	5	26	0	0	0	0	7	0	4	3	3	12	1	5	0	0	0	0	0		127
Total	22	21	13	0	2	24	97	28	1	81	18	6	4	6	22	2	100	908	758	103	4	142	380	287	79	833	1	130	13	13	57	17	63	20	27	43	22	18	2	0	14	10	0	128	4519

FIGURE 3 | Frequency of Real Madrid's events recorded by the two independent operators in two collections. DW, dribble won; DL, dribble lost; AS, attacking shift; PG, possession gained; SO, shots off target; ST, shot on target; SS, shot saved; EAT, enter into attacking third; SP, successful pass; FP, forward pass; TB, through ball; LP, lateral pass; DP, diagonal pass; BP, backward pass; CP, consecutive pass; KP, key pass; BP, blocked pass; BS, blocked shot; TW, tackle won; TL, tackle lost; AW, aerial won; AL, aerial lost; YC, yellow card; KS, keeper sweeper; DS, deflected save.

A practical measure with high validity must have high reliability in the meantime. While a measure with high reliability may have low validity. But only the valid and reliable performance indicators can be reliable used in sports performance profiling (O'Donoghue, 2007; McGarry et al., 2013). Therefore, the study initially examined the validity of performance indicators by evaluating experts' opinions according to the previous literature (Trniniæ et al., 2000; Hraste et al., 2008; Larkin et al., 2016). Based on the high values of Aiken's V calculated for twenty professional coaches' responses to the pertinence (0.84 ± 0.03) and definition

TABLE 4 | Agreement of team events coded by intra-operators.

		Agreement	First data collection		Second data collection		Kappa value
			Total	Disagreed	Total	Disagreed	
Operator 1	Real Madrid	2,619	2,769	150	2,782	163	0.91
	Villarreal	1,948	2,049	101	2,045	97	0.93
Operator 2	Real Madrid	2,781	2,959	178	2,980	199	0.91
	Villarreal	1,953	2,124	171	2,136	183	0.87

TABLE 5 | Intra-operator and inter-operator reliability of match actions coded within two data collection.

		Real Madrid				Villarreal			
	Variables	Mean (SD)	Change in the mean (CL)	Standardized typical error	ICC	Mean (SD)	Change in the mean (CL)	Standardized typical error	ICC
Operator 1 (1st vs. 2nd)	Attacking	17(21)	−4.4(5.4)	0.03	1.00	12(15)	−0.4(1.0)	0.09	0.99
	Passing	182(219)	1.6(1.5)	0.01	1.00	128(161)	−0.1(1.6)	0.01	1.00
	Defending and goalkeeper	7.4(6.9)	−0.4(0.8)	0.14	0.99	12(11)	−0.3(1.0)	0.07	0.99
	All actions	64(142)	0.14(0.49)	0.01	1.00	48(102)	−0.35(0.50)	0.01	1.00
Operator 2 (1st vs. 2nd)	Attacking	17(19)	−0.3(1.0)	0.07	1.00	13(16)	0.0(0.5)	0.05	1.00
	Passing	182(221)	2.3(1.9)	0.01	1.00	129(163)	0.8(2.1)	0.02	1.00
	Defending and goalkeeper	7.2(7.5)	0.40(0.90)	0.15	0.98	10.8(9.7)	−0.1(1.0)	0.14	0.99
	All actions	64(142)	0.70(0.64)	0.01	1.00	48(103)	0.21(0.58)	0.02	1.00
Operator 1vs. Operator 2	Attacking	34(40)	−0.1(2.5)	0.08	0.99	25(31)	0.8(1.4)	0.06	1.00
	Passing	364(441)	0.4(3.0)	0.01	1.00	257(323)	1.4(2.9)	0.01	1.00
	Defending and goalkeeper	14(14)	−0.4(3.3)	0.29	0.93	22(20)	−2.4(3.9)	0.24	0.95
	All actions	128(285)	−0.05(1.31)	0.01	1.00	95(206)	0.05(1.57)	0.02	1.00

1st, First data collection; 2nd, second data collection; CL, 95% confidence limits; ICC, intra-class correlation.

TABLE 6 | Match events provided by OPTA Sports and *Champdas Master System*.

	OPTA	Real Madrid				OPTA	Villarreal			
Variables		***Champdas Master System***					***Champdas Master System***			
		Operator 1-1st	Operator 1-2nd	Operator 2-1st	Operator 2-2nd		Operator 1-1st	Operator 1-2nd	Operator 2-1st	Operator 2-2nd
Shots	28	27	27	26	28	10	9	9	8	8
Shots on target	7	7	7	7	7	4	2	2	2	2
Goals	0	0	0	0	0	1	1	1	1	1
Pass success %	89%	84%	84%	84%	84%	84%	83%	84%	84%	83%
Aerial duel success	45%	43%	44%	44%	48%	55%	57%	56%	61%	59%
Dribbles won	8	12	9	10	12	7	11	8	9	12
Tackles	19	19	16	25	23	14	13	13	14	15
Passes	650	620	623	621	626	467	455	453	455	459
Crosses	44	40	40	41	43	7	6	6	6	7
Through balls	0	1	1	1	1	2	1	2	2	2
Short passes	574	495	499	589	592	393	357	356	414	421

1st and 2nd stand for the first and second match data collections.

(0.85 ± 0.03) of match variables, it was revealed that the variables comprised in the system have appropriate operational definitions and are able to represent match events and player actions during data gathering and analysis.

As previously argued, valid operational definition is not sufficient to guarantee a reliable observation, because it is frequent that human error affects the repeatability of the data. (Williams and O'Donoghue, 2006; O'Donoghue, 2007; Beato et al., 2018). Therefore, the current study verified that after rigorous training and large quantity of practice using *Champdas Master System*, operators could achieve high intra- and inter-operator reliability when coding live football match events, and the data provided were reliable, which was supported by the high Kappa values, high intra-class correlation coefficients and low standardized typical errors. The findings were similar to the previously tested Prozone MatchViewer System (Bradley et al., 2007), OPTA Client System (Liu et al., 2013), and Data.Stadium System (Beato et al., 2018). This suggests that the semi-automatic operation errors in collection with the system were extremely limited. Besides, it should be noted that former research focused on the measurements of typical technical-tactical variables that were mainly notated via shortcut keys (Liu et al., 2013). Nonetheless, compared with its counterparts, the current system is operated via both shortcut keys and mouse clicking on a simulated pitch. On the account, the system not only produces more data related to attacking and passing behaviors, but also effectively provides tactical information, considering pitch zones where match performance took place. This allows more comprehensive technical-tactical match statistics for performance analysis and broadcasting purposes.

However, there were several limitations that should addressed. First of all, more matches may be needed to test the generalization of the system and operator reliability. Additionally, it is admitted that occasions of discrepancy existed in some match actions related to passing directions, short/long pass. This phenomenon happens when comparing OPTA Sport and *Champdas Master System*, as well as assessing intra- and inter operators reliability. This may be explained from two perspectives. Primarily, the inconsistence between OPTA Sport and *Champdas Master System* in short pass might be caused by different definition of the length. This is supported by the similar total number of passes both systems recorded in the current match. Moreover, after a round of retrospection with participating operators, we were informed that the disagreements in determining the lengths and directions of passes mainly originated from plotting errors and entry errors. These types of errors were due to the manual marking discrepancy when operating on the miniaturized on-scree pitch. For example, for the passing direction related variables, the system would automatically recognize a pass as lateral pass even if a player made a forward pass (the angle between pass direction and the parallel of sideline is $< 15°$) to his teammate who is located at the left front of him. Therefore, if operators could not observe or notate properly similar pass directions on the screen as what are actually taking place on the field, disagreements in passing categories would occur. In fact, this issue was also reported in ProZone MatchViewer system (Bradley et al., 2007; Castellano et al., 2014) and Trakperformance system (Burgess et al., 2006; Edgecomb and Norton, 2006; Carling et al., 2008), which used a similar approach. Furthermore, operator's observation would be affected while gathering data from live TV coverage, as Tenga and Albin (Tenga, 2010) found that camera angles, image sizes and feature film could be blurry when accurate event location is expected. Consequently, more precision problems appear especially when operators are notating positions, distances and angles related match events.

In a word, the largest technical problem was that operators had difficulty in consistently plotting the X/Y coordinates of the events on the miniaturized pitch. In light of these issues, it is suggested that simplification in passing directions be considered. Instead of including diagonal pass (**Figure 1**), four types of categories could be established with angle interval of 90° (Goes et al., 2019): forward, left and right sideways, and backward. Meanwhile, automatic player tracking instruments should be further developed and integrated in the data collection process so that operators could avoid subjective determination of directions, lengths and outcomes of passes (Beato and Jamil, 2017). Nonetheless, the current results show that the match statistics could be deemed acceptable so long as operators undergo adequate training and practice in maneuvering the system and identifying specific match events.

The quality of data provided plays a prominent role in performance analysis, sport coaching, media reporting, and scientific research (O'Donoghue, 2009, 2014; O'Donoghue et al., 2017). The study reveals a high level of validity and reliability using *Champdas Master System* to measure live football match statistics. From a theoretical and practical perspective, coaches, sport scientists, and media could benefit from the application of the system to gain reliable technical-tactical performance information. Additionally, future studies could evaluate the generalization of system with a larger sample in similar or distinct leagues, as well as under distinct light conditions.

CONCLUSION

The analysis of football expert panel opinions evidenced the validity of tactical and technical match performance variables from *Champdas Master system*. Moreover, high Kappa values, high intra-class correlation coefficients and low standardized typical errors demonstrated a high level of intra- and inter-operator reliability using the *system* to collect sampled match events. Although, slight discrepancy was shown in the identification of players' passing directions, our results suggest that the *Champdas Master system* can be used validly and reliably to collect live football match statistics by well-trained operators. The system and statistics generated could be trustworthy for coaching, academic research and media report.

ETHICS STATEMENT

We state clearly that written informed consent was obtained from the participants of all phases of the study, and the study was approved by the Ethics Committee of the Technical University of Madrid.

AUTHOR CONTRIBUTIONS

M-ÁG, BG, and YC designed the experiments. YC, YG, and QY performed the statistical analysis. BG wrote and revised the manuscript. M-ÁG supervised the design and reviewed the manuscript. All authors have made a substantial and direct contribution to manuscript, and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01339/full#supplementary-material

REFERENCES

Aiken, L. R. (1980). Content validity and reliability of single items or questionnaires. *Educ. Psychol. Meas.* 40, 955–959. doi: 10.1177/001316448004000419

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educ. Psychol. Meas.* 45, 131–142. doi: 10.1177/0013164485451012

Altman, D. G. (1990). *Practical Statistics for Medical Research*. Boca Raton, FL: CRC press.

Atkinson, G., and Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med.* 26, 217–238. doi: 10.2165/00007256-199826040-00002

Beato, M., and Jamil, M. (2017). Intra-system reliability of SICS: video-tracking system (Digital. Stadium®) for performance analysis in football. *J. Sports Med. Phys. Fit.* 58, 831–836.

Beato, M., Jamil, M., and Devereux, G. (2018). The reliability of technical and tactical tagging analysis conducted by a semi-automatic video-tracking system (Digital.Stadium®) in soccer. *J. Hum. Kinet.* 62, 103–110. doi: 10.1515/hukin-2017-0162

Bradley, P., O'Donoghue, P., Wooster, B., and Tordoff, P. (2007). The reliability of ProZone MatchViewer: a video-based technical performance analysis system. *Int. J. Perform. Anal. Sport* 7, 117–129. doi: 10.1080/24748668.2007.11868415

Bradley, P. S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., et al. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *J. Sports Sci.* 29, 821–830. doi: 10.1080/02640414.2011.561868

Burgess, D., Naughton, G., and Norton, K. I. (2006). Profile of movement demands of national football players in Australia. *J. Sci. Med. Sport* 9, 334–341. doi: 10.1016/j.jsams.2006.01.005

Carling, C., Bloomfield, J., Nelsen, L., and Reilly, T. (2008). The role of motion analysis in elite soccer. *Sports Med.* 38, 839–862. doi: 10.2165/00007256-200838100-00004

Carling, C., Reilly, T., and Williams, A. M. (2007). *Handbook of Soccer Match Analysis: A Systematic Approach to Improving Performance*. Abingdon: Routledge.

Castellano, J., Alvarez-Pastor, D., and Bradley, P. S. (2014). Evaluation of research using computerised tracking systems (Amisco® and Prozone®) to analyse physical performance in elite soccer: a systematic review. *Sports Med.* 44, 701–712. doi: 10.1007/s40279-014-0144-3

Chacón-Moscoso, S., Sanduvete-Chaves, S., Anguera, M. T., Losada, J. L., Portell, M., and Lozano-Lozano, J. A. (2018). Preliminary checklist for reporting observational studies in sports areas: content validity. *Front. Psychol.* 9:291. doi: 10.3389/fpsyg.2018.00291

Champion Technology Co., Ltd. (2018). *Champdas Master System Training Manual 3.0.".* Baton Rouge, LA: Champion Technology Co., Ltd.

Choi, H., O'Donoghue, P., and Hughes, M. (2007). An investigation of inter-operator reliability tests for real-time analysis system. *Int. J. Perform. Anal. Sport* 7, 49–61. doi: 10.1080/24748668.2007.11868387

Clear, C., Hughes, M., and Martin, D. (2017). Attacking profiles in elite hurling. *Int. J. Perform. Anal. Sport* 17, 319–333. doi: 10.1080/24748668.2017.1338074

Cui, Y., Gómez, M. -Á, Gonçalves, B., and Sampaio, J. (2019). Clustering tennis players' anthropometric and individual features helps to reveal performance fingerprints. *Eur. J. Sport Sci.* 1–13. doi: 10.1080/17461391.2019.1577494

Cupples, B., and O'Connor, D. (2011). The development of position-specific performance indicators in elite youth rugby league: a coach's perspective. *Int. J. Sports Sci. Coach.* 6, 125–141. doi: 10.1260/1747-9541.6.1.125

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., et al. (2011). Comparison of physical and technical performance in European soccer match-play: FA premier league and La Liga. *Eur. J. Sport Sci.* 11, 51–59. doi: 10.1080/17461391.2010.481334

Edgecomb, S. J., and Norton, K. I. (2006). Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. *J. Sci. Med. Sport* 9, 25–32. doi: 10.1016/j.jsams.2006.01.003

Eltoukhy, M., Asfour, S., Thompson, C., and Latta, L. (2012). Evaluation of the performance of digital video analysis of human motion: Dartfish tracking system. *IJSER* 3, 1–6.

Goes, F. R., Kempe, M., Meerhoff, L. A., and Lemmink, K. A. (2019). Not every pass can be an assist: a data-driven model to measure pass effectiveness in professional soccer matches. *Big Data* 7, 57–70. doi: 10.1089/big.2018.0067

Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jiménez, S., and Sampaio, J. (2017). Exploring team passing networks and player movement dynamics in youth association football. *PLoS One* 12:e0171156. doi: 10.1371/journal.pone.0171156

Hayen, A., Dennis, R. J., and Finch, C. F. (2007). Determining the intra-and inter-observer reliability of screening tools used in sports injury research. *J. Sci. Med. Sport* 10, 201–210. doi: 10.1016/j.jsams.2006.09.002

Hizan, H., Whipp, P. R., and Reid, M. (2010). Validation of match notation (A coding system) in tennis. *J. Quant. Anal. Sports* 6, 1–13.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Med.* 30, 1–15. doi: 10.2165/00007256-200030010-00001

Hraste, M., Dizdar, D., and Trniniæ, V. (2008). Experts opinion about system of the performance evaluation criteria weighted per positons in the water polo game. *Coll. Antropol.* 32, 851–861.

Hughes, M. (2004). Performance analysis–a 2004 perspective. *Int. J. Perform. Anal. Sport* 4, 103–109. doi: 10.1080/24748668.2004.11868296

Hughes, M., and Franks, I. (2015). *Essentials of Performance Analysis in Sport*. London: Routledge.

Hughes, M. D., and Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *J. Sports Sci.* 20, 739–754. doi: 10.1080/026404102320675602

Lago, C., Casais, L., Dominguez, E., and Sampaio, J. (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *Eur. J. Sport Sci.* 10, 103–109. doi: 10.1080/17461390903273994

Lames, M., and McGarry, T. (2007). On the search for reliable performance indicators in game sports. *Int. J. Perform. Anal. Sport* 7, 62–79. doi: 10.1080/24748668.2007.11868388

Larkin, P., O'Connor, D., and Williams, A. M. (2016). Establishing validity and reliability of a movement awareness and technical skill (MATS) analysis instrument in soccer. *Int. J. Perform. Anal. Sport* 16, 191–202. doi: 10.1080/24748668.2016.11868880

Li, Y., Alexander, M., Glazebrook, C., and Leiter, J. (2016). Quantifying inter-segmental coordination during the instep soccer kicks. *Int. J. Exerc. Sci.* 9, 646.

Liu, H., Hopkins, W., Gómez, A. M., and Molinuevo, S. J. (2013). Inter-operator reliability of live football match statistics from OPTA Sportsdata.

Int. J. Perform. Anal. Sport 13, 803–821. doi: 10.1080/24748668.2013.11868690

Mackenzie, R., and Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *J. Sports Sci.* 31, 639–676. doi: 10.1080/02640414.2012.746720

McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in sport: scientific issues and challenges. *Int. J. Perform. Anal. Sport* 9, 128–140. doi: 10.1080/24748668.2009.11868469

McGarry, T., O'Donoghue, P., de Eira Sampaio, A. J., and Sampaio, J. (2013). *). Routledge Handbook of Sports Performance Analysis*. Abingdon: Routledge.

Oberstone, J. (2009). Differentiating the top English premier league football clubs from the rest of the pack: Identifying the keys to success. *J. Quant. Anal. Sports* 5, 1–29.

Oberstone, J. (2010). Comparing English premier league goalkeepers: identifying the pitch actions that differentiate the best from the rest. *J. Quant. Anal. Sports* 6:9.

Oberstone, J. (2011). Comparing team performance of the English premier league, Serie A, and La Liga for the 2008-2009 season. *J. Quant. Anal. Sports* 7:2.

O'Donoghue, P. (2007). Reliability issues in performance analysis. *Int. J. Perform. Anal. Sport* 7, 35–48. doi: 10.1080/24748668.2007.11868386

O'Donoghue, P. (2009). *Research Methods for Sports Performance Analysis*. Abingdon: Routledge.

O'Donoghue, P. (2010). "Measurement issues in performance analysis," in *Research Methods for Sports Performance Analysis*. ed. P. O'Donoghue (Abingdon: Routledge), 149–177.

O'Donoghue, P. (2014). *An Introduction to Performance Analysis of Sport*. Abingdon: Routledge.

O'Donoghue, P., and Holmes, L. (2014). *Data Analysis in Sport*. Abingdon: Routledge.

O'Donoghue, P., Holmes, L., and Robinson, G. (2017). *Doing a Research Project in Sport Performance Analysis*. Abingdon: Routledge.

O'Donoghue, P., and Mayes, A. (2013). "Performance analysis, feedback and communication in coaching," in *Routledge Handbook of Sports Performance Analysis*. eds T. McGarry, P. O'Donoghue, and J. Sampaio (Abingdon: Routledge), 155–164.

Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R., and Di Prampero, P. E. (2010). Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med. Sci. Sports Exerc.* 42, 170–178. doi: 10.1249/MSS.0b013e3181ae5cfd

Padulo, J., Haddad, M., Ardigo, L., Chamari, K., and Pizzolato, F. (2015). High frequency performance analysis of professional soccer goalkeepers: a pilot study. *J. Sports Med. Phys. Fit.* 55, 557–562.

Penfield, R. D., Peter, R., and Giacobbi, J. (2004). Applying a score confidence interval to aiken's item content-relevance index. *Meas. Phys. Educ. Exerc. Sci.* 8, 213–225. doi: 10.1207/s15327841mpee0804_3

Pollard, R. (2019). Invalid interpretation of passing sequence data to assess team performance in football: repairing the tarnished legacy of charles reep. *Open Sports Sci. J.* 12, 17–21. doi: 10.2174/1875399x01912010017

Praça, G. M., Lima, B. B., Bredt, S. D. G. T., Sousa, R. B. E., Clemente, F. M., and Andrade, A. G. P. D. (2019). Influence of match status on players' prominence and teams' network properties During 2018 FIFA World Cup. *Front. Psychol.* 10:695. doi: 10.3389/fpsyg.2019.00695

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., and Wisløff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *J. Sci. Med. Sport* 12, 227–233. doi: 10.1016/j.jsams.2007.10.002

Reed, D., and Hughes, M. (2006). An exploration of team sport as a dynamical system. *Int. J. Perform. Anal. Sport* 6, 114–125. doi: 10.1080/24748668.2006.11868377

Reid, M., Morgan, S., and Whiteside, D. (2016). Matchplay characteristics of Grand Slam tennis: implications for training and conditioning. *J. Sports Sci.* 34, 1791–1798. doi: 10.1080/02640414.2016.1139161

Rein, R., Raabe, D., and Memmert, D. (2017). "Which pass is better?" Novel approaches to assess passing effectiveness in elite soccer. *Hum. Move. Sci.* 55(Suppl. C), 172–181. doi: 10.1016/j.humov.2017.07.010

Sampaio, J., and Leite, N. (2013). "Performance indicators in game sports," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (Abingdon: Routledge), 115–126.

Serpiello, F. R., Cox, A., Oppici, L., Hopkins, W. G., and Varley, M. C. (2017). The Loughborough Soccer passing test has impractical criterion validity in elite youth football. *Sci. Med. Football* 1, 60–64. doi: 10.1080/02640414.2016.1254810

Sgrò, F., Aiello, F., Casella, A., and Lipoma, M. (2017). The effects of match-playing aspects and situational variables on achieving score-box possessions in Euro 2012 Football Championship. *J. Hum. Sport Exerc.* 12, 58–72. doi: 10.14198/jhse.2017.121.05

Smith, T. B., and Hopkins, W. G. (2011). Variability and predictability of finals times of elite rowers. *Med. Sci. Sports Exerc.* 43, 2155–2160. doi: 10.1249/MSS.0b013e31821d3f8e

Tenga, A. (2010). *Reliability and Validity of Match Performance Analysis in Soccer: A Multidimensional Qualitative Evaluation of Opponent Interaction*. Ph. D thesis. Oslo: Norwegian School of Sports Sciences.

Torres-Luque, G., Fernández-García, ÁI., Cabello-Manrique, D., Giménez-Egido, J. M., and Ortega-Toro, E. (2018). Design and validation of an observational instrument for the technical-tactical actions in singles Tennis. *Front. Psychol.* 9:2418. doi: 10.3389/fpsyg.2018.02418

Trniniæ, S., Dizdar, D., and Dežman, B. (2000). Empirical verification of the weighted system of criteria for the elite basketball players quality evaluation. *Coll. Antropol.* 24, 443–465.

Valter, D. S., Adam, C., Barry, M., and Marco, C. (2006). Validation of Prozone®: a new video-based performance analysis system. *Int. J. Perform. Anal. Sport* 6, 108–119. doi: 10.1080/24748668.2006.11868359

Williams, L., and O'Donoghue, P. (2006). Defensive strategies used by international netball teams. *Perform. Anal. Sport* 7, 474–479.

Zhang, S., Lorenzo, A., Zhou, C., Cui, Y., Gonçalves, B., and Angel Gómez, M. (2018). Performance profiles and opposition interaction during game-play in elite basketball: evidences from National Basketball Association. *Int. J. Perform. Anal. Sport* 19, 28–48. doi: 10.1080/24748668.2018.1555738

Zhou, C., Zhang, S., Lorenzo Calvo, A., and Cui, Y. (2018). Chinese soccer association super league, 2012–2017: key performance indicators in balance games. *Int. J. Perform. Anal. Sport* 18, 645–656. doi: 10.1080/24748668.2018.1509254

Zubillaga, A., Gorospe, G., Hernandez, A., and Blanco, A. (2009). "Comparative analysis of the high-intensity activity of soccer players in top level competition," in *Science and Football VI*, eds H. Reilly and F. Korkusuz (Milton Park: Taylor & Francis Group), 182–185.

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Relative Age Influences Performance of World-Class Track and Field Athletes Even in the Adulthood

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The relative age effect (RAE) is a common phenomenon observed in youth sports and is characterized by a significant over-representation of athletes born close to the date of selection. However, there is a lack of research on RAE in world-class track and field athletes and it is not clear if this effect persists into adulthood. Thus, this study examined for the first time the prevalence and magnitude of RAE at world class level in all track and field disciplines. Birthdates of 39,590 athletes (51.6% females) ranked in the International Association of Athletics Federations top 100 official lists between 2007 and 2018 season of Under 18, Under 20, and Senior categories were collected. Under 18 and Under 20 athletes born in the first week of the year are about 2 to 3.5 times more likely to be included in the top-100 ranking than the athletes born in the last week of the year. RAE was overall larger in male compared to female athletes. In some disciplines (e.g., throwing events) RAE persists in Senior category. These findings suggest that in some disciplines relatively younger athletes may have less chances of reaching world-class performances even in the adulthood. Governing bodies should reflect upon their policies for athlete support and selection to minimize the RAE.

Keywords: relative age effect, birthdate distribution, selection bias, talent, athlete development

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INTRODUCTION

In sports systems, young athletes are generally grouped according to their birth year with the purpose to provide equal opportunities and experiences during competitions (Cobley et al., 2009; Kearney et al., 2018). However, in accordance with the maturation-selection hypothesis, relatively older athletes may have more favorable anthropometric and physical characteristics in comparison with relatively younger peers (Cobley et al., 2009; Lovell et al., 2015; Romann and Cobley, 2015). Additionally, relative older athletes may be advanced in term of cognitive development (e.g., decision-making, abstract thinking, and creativity) and psychological factors (e.g., motivation, self-efficacy, and self-esteem) (Musch and Grondin, 2001; Cobley et al., 2009; Baker et al., 2014).

Therefore, as a result of the assignment to categories based upon chronological age, athletes born close to the cut-off date of selection are supposed to be advantaged in sports performance (Smith et al., 2018) and in the process of talent identification, because they are older than their peers born far from the cut-off date. Moreover, the talent identification could be influenced by environmental factors, concerning social constructs (Wattie et al., 2015) like physical and sociocultural environment policies and social agents such as parents, coaches, or athletes (Hancock et al., 2013). The term relative age effect (RAE) refers to an asymmetry in the birth distribution of a population where there is an over-representation of athletes born close to the date of selection (Cobley et al., 2009; Boccia et al., 2017b). The RAE was first observed in Canadian ice hockey (Barnsley et al., 1985) and subsequently in many other team sports, such as soccer (Steingröver et al., 2017; Brustio et al., 2018; Cumming et al., 2018; Doyle and Bottomley, 2018; Peña-González et al., 2018), Australian football (Haycraft et al., 2018), basketball (Arrieta et al., 2016), and rugby (Till et al., 2010), as well as in individual sports, such as swimming (Cobley et al., 2018) alpine ski (Müller et al., 2016; Bjerke et al., 2017) wrestling (Fukuda et al., 2017), and track and field (Romann and Cobley, 2015; Brazo-Sayavera et al., 2017, 2018; Kearney et al., 2018; Romann et al., 2018).

In many nations track and field events are characterized by a significant over-representation of athletes born close to the date of selection (Romann and Cobley, 2015; Brazo-Sayavera et al., 2017; Kearney et al., 2018; Romann et al., 2018). For example, Brazo-Sayavera et al. (2017) highlighted the influential role of the RAE, mediated by age and gender, on the selection in Spanish National Athletics Federation training camps. In an extensive study on UK athletes, Kearney et al. (2018) showed a large over-representation of female and male athletes born close to the date of selection in the majority of considered disciplines (i.e., 100-m, hurdles, 800-m, 1,500-m, high jump, shot put, discus throw, and javelin throw) and age categories (i.e., Under 13, 15, 17, 20, and Senior Category). As expected, the effect was larger for younger categories than for senior levels and it was even larger for athletes ranked in the top 20 nationally compared to the others.

Despite this consistent finding at national level, there is a paucity of data regarding the international context. Hollings et al. (2014) evaluated the RAE in three event groups (i.e., sprints and hurdles, jumps, and throws) within an international context focusing only on finalists of Under 18 (athletes aged 16–17 years) and Under 20 (athletes aged 18–19 years) World Athletics Championships and found a significant RAE in both categories with a stronger effect for Under 18 groups compared to Under 20 ones. However, the selection for World Athletics Championships is not only based on individual performances, but also on technical choice of national athletics federations. Consequently, even if the data about participations in World Athletics Championship are of interest, they do not represent the whole sample of individuals competing at international levels. Thus, a more comprehensive analysis of RAE at international level, considering both youth and senior categories, is warranted. Indeed, an extensive evaluation of RAE across ages would be able to identify if the possible RAE in youth categories is transient or if it persists in adult categories (Cobley et al., 2018). Therefore, to address the aforementioned gap, we aimed to comprehensively quantify the prevalence and magnitude of RAE at world class level in all track and field disciplines. While we hypothesized that RAE would decrease as age increased (Hollings et al., 2014), no prediction would be possible due to lack of data about international level adult athletes. Moreover, according to previous studies (Hollings et al., 2014; Romann and Cobley, 2015; Brazo-Sayavera et al., 2017, 2018; Kearney et al., 2018) we expected to observe a stronger RAEs within male athletes and in disciplines with a greater emphasis on speed and/or strength.

MATERIALS AND METHODS

Design

Data were collected from the publically available web-site of IAAF (International Association of Athletics Federations; https://www.iaaf.org/home). This database provides information about track and field athletes' performances and rankings for both genders. The web-site reports the results of three different categories: Under 18, Under 20, and Senior categories. According to the technical rules of IAAF the Under 18 category is composed of athletes aged 16 and 17 years, while the Under 20 category of athletes aged 18 to 19 years. This study was approved by the local ethics committee of the University of Turin (Italy) and involved access to public available databases. Therefore, no informed consent was sought.

Procedure

Birthdates of athletes ranked in the top 100 official lists in each season from 2007 to 2018 were collected. Since the data from 2007 to 2009 were not available for Under 18 and Under 20, these categories were analyzed only from 2010 to 2018. Only results obtained in outdoor competitions and with legal wind speed (i.e., $\leq$2 m/s) were included. As previously suggested (Kearney et al., 2018), each athlete was only counted once per age category. The following track and field disciplines were considered: 100-m, 100-m hurdles, 200-m, 400-m, 400-m hurdles, 800-m, 1,500-m, 3,000-m steeplechase, 5,000-m, high jump, pole vault, long jump, triple jump, shot put, discus throw, hammer throw, and javelin throw.

Athletes selected for this study were classified in accordance with their birthdate. According to IAAF rules the competition year was from 1st January to 31st December. First, the birth week (W_B) of each athlete was calculated. For example, an athlete born between 1st and 7th January was categorized in W_B 1, athletes born between 8th and 14th January were categorized in W_B 2 and so. Afterward, the time of birth (T_B) i.e., how far from the beginning of the year a athletes was born (ranged between 0 and 1), was computed according to the formula $T_B = (W_B - 0.5)/52$ where $(W_B - 0.5)$ corresponds to the midpoint of the week in which athlete was born (Brustio et al., 2018; Doyle and Bottomley, 2018).

Statistical Analyses

As recently suggested, the birthdate data were analyzed using Poisson regressions (Brustio et al., 2018; Doyle and Bottomley, 2018, 2019; Rada et al., 2018). Separate Poisson regressions were performed considering disciplines and gender. Using the formula $y = e^{(b0+b1x)}$ the Poisson regression enables the frequency count of an event (y) to be described by an explanatory variable x. Thus, in this study it has been calculated how the frequency of birth in a given week (y) was explained by the T_B (x). Additionally, the Index of Discrimination (ID), which provides the relative odds of being selected for an athlete born in the first vs. the last week of the competition year, was calculated as e^{-b1} (Doyle and Bottomley, 2018, 2019). Likelihood ratio R^2 was computed according to Cohen et al. (2013).

To allow comparisons with previous studies that did not adopt Poisson's regression analysis, all athletes were categorized in four groups based on their month of birth. Specifically, players born between January and March, April and June, July and September, and October and December were classified into the quartile 1 (Q1), quartile 2 (Q2), quartile 3 (Q3), and quartile 4 (Q4), respectively. Odds ratios (ORs) and 95% confidence intervals [95% CIs] were calculated for the first and the last quartile (i.e., Q1 vs. Q4). We compared the distribution of athletes' birthdates with an uniform distribution (i.e., 25% for each quartile) (Delorme and Champely, 2013).

All data were analyzed with custom-written software in MATLAB R2017b (Mathworks, Natick, Massachusetts). The level of significance was set at $p \leq 0.05$.

RESULTS

A total of 98,984 records were downloaded. After removal of missing data (about 9%) and duplicates (i.e., athletes that are present in top 100 official lists for over 1 year in the considered category) a total of 39,590 birthdates (51.6% females) were analyzed. The mean and standard deviation of W_B and T_B, as well as the results of Poisson regression equations, fit statistics and ID for each event are presented in **Table 1**. The scatterplots of RAE frequency by week of year both for male and female athletes in Under 18, Under 20, and Senior categories are provided in **Figure 1**.

When analyzing male athletes, the Poisson regressions were significant for Under 18 ($p < 0.001$; $R^2 = 0.91$), Under 20 ($p < 0.001$; $R^2 = 0.86$) and Senior categories ($p < 0.001$; $R^2 = 0.30$). Specifically, ID showed that in Under 18 and Under 20 categories the male athletes born right at the start of the year were 3.46 and 2.45 times, respectively, more likely to be included in top 100 rank than those born at the end of the year. In Senior category the ID score was lower (i.e., 1.29).

In general female athletes showed similar trends. Indeed, the Poisson regressions were significant for Under 18 ($p < 0.001$; $R^2 = 0.84$), Under 20 ($p < 0.0001$; $R^2 = 0.72$), and Senior categories ($p < 0.001$; $R^2 = 0.26$). Specifically, ID showed that in Under 18 and Under 20 categories the female athletes born in the first week of the year were 2.21 and 1.86 times, respectively, more likely to be included in the top 100 rank than those born at the end of the year. Again, in Senior category the ID was lower (i.e., 1.19).

When considering each event separately it is possible to highlight a few peculiarities among disciplines. For example, in males the Poisson regressions were significant in all disciplines for Under 18 (all $p < 0.001$; R^2 ranged = 0.12–0.70) and Under 20 (all $p < 0.0001$; R^2 ranged = 0.11–0.59), while in Senior category the Poisson regressions were significant only for 400-m hurdles and throwing events (all $p < 0.01$; R^2 ranged = 0.16–0.27), but not for the other disciplines (all $p > 0.05$; R^2 ranged = 0–0.05).

In females the trend was generally similar, but showed some differences. For example, the Poisson regressions were significant in all disciplines for Under 18 (all $p < 0.001$; R^2 ranged = 0.11-0.63). In Under 20 the Poisson regressions were significant in all disciplines (all $p < 0.001$; R^2 ranged = 0.06–0.34) with the exception of pole vault ($p = 0.112$; $R^2 = 0.06$). Similarly to males, in Senior category, two of the throwing events (shot put and discus throw) showed significant Poisson regressions. In addition, long jump showed significant Poisson regressions, while triple jump showed a trend close to significance ($p = 0.054$). In Senior category Poisson regressions were not significant for other disciplines ($p > 0.05$; R^2 ranged = 0–0.18).

Table 2 provides the odds ratios (ORs) and 95% confidence intervals [95% CIs] of Q1 vs. Q4. Regardless of the gender, ORs suggested that the likelihood of being included in the top 100 rank is higher for an athlete born in the Q1 rather than in Q4 both in Under 18 (OR ranged = 1.3–5.2) and Under 20 (OR ranged = 1.2–3.6) category, but not in Senior category (OR ranged = 0.8–1.5). Moreover, RAEs are likely stronger in males compared with females in all categories. Indeed, on average in Under 18, Under 20, and Senior categories male athletes were 2.5, 2.0, and 1.2 times, respectively, more likely to be born in Q1 than Q4, while female athletes were 1.8, 1.6, and 1.1 times, respectively, more likely to be born in Q1 than Q4. Of note, the ORs were generally smaller in middle distance events (e.g., 1,500-m and 5,000-m) and greater in throwing events in comparison with the other disciplines.

DISCUSSION

This study examined the birthdate of 39,590 track and field athletes, who were ranked in the world top-100 ranking at least once in the last 10 years. The results showed a large over-representation of athletes born close to the beginning of the calendar year in Under 18 and Under 20 categories. In some disciplines, this trend is maintained in the Senior category.

The Poisson regression analysis has recently been proposed to be the most reliable method to identify the presence of the RAE (Brustio et al., 2018; Doyle and Bottomley, 2018; Rada et al., 2018). The Poisson regression analysis quantifies the magnitude of the RAE through the Index of Discrimination (ID) which consists in the relative odds of being selected for an athlete born in the first vs. the last week of the competition year (**Table 1**). Under 18 and Under 20 athletes born in the first week of the year are about 2 to 3.5 times more likely to be included in the top-100 ranking than the athletes born in the last week of the year (see overall ID scores in **Table 1** and **Figure 1**). Similar trends can be observed adopting a more classical approach of subgrouping athletes based on their birthdate quartiles (**Table 2**). Indeed, the ORs between the athletes born in the first (i.e., between January and March) vs. the last (i.e., between October and December) quartile ranged from 1.5 to 2.5 in the Under 18 and Under 20 categories. Together these indices clearly indicate that being relatively older within a competition year confers a large effect on athletics performances up to 19 years of age. It is possible to suppose that differences in population distribution at Under 18 and Under 20 are not (highly unlikely to be) due to current maturational differences, but rather a relic of maturational differences that existed at a younger age, the effects of which were amplified by the actions of various social agents (Hancock et al., 2013). Indeed, according to the framework of

TABLE 1 | Relative Age Effect (RAE) according to the poisson regression for male and female athletes at each category of age group and event.

Category	Male								Female							
	N	W_B	T_B	b_0	b_1	ID	R^2	*P*	*N*	Wb	Tb	b_0	b_1	ID	R^2	*P*
OVERALL																
U18	5,950	21.26 ± 14.62	0.40 ± 0.28	5.297	−1.241	3.46	0.91	<0.001	8,342	23.10 ± 14.94	0.43 ± 0.29	5.449	−0.794	2.21	0.84	<0.001
U20	6,759	22.67 ± 14.55	0.43 ± 0.28	5.283	−0.897	2.45	0.86	<0.001	5,786	23.84 ± 14.98	0.45 ± 0.29	5.005	−0.618	1.86	0.72	<0.001
Senior	6,465	25.40 ± 15.00	0.48 ± 0.29	4.948	−0.255	1.29	0.30	<0.001	6,288	25.75 ± 15.22	0.49 ± 0.29	4.880	−0.172	1.19	0.26	<0.001
100-M																
U18	556	20.89 ± 14.49	0.39 ± 0.28	2.963	−1.332	3.79	0.56	<0.001	535	22.94 ± 15.19	0.43 ± 0.29	2.718	−0.831	2.3	0.38	<0.001
U20	352	23.14 ± 14.97	0.44 ± 0.29	2.278	−0.782	2.19	0.26	<0.001	302	23.80 ± 15.50	0.45 ± 0.30	2.056	−0.627	1.87	0.13	0.002
Senior	439	26.92 ± 14.69	0.51 ± 0.28	2.085	0.097	0.91	0.00	0.559	398	26.57 ± 15.55	0.50 ± 0.30	2.027	0.017	0.98	0.00	0.923
110-M HURDLES																
U18*	129	19.60 ± 14.83	0.37 ± 0.29	1.563	−1.181	3.26	0.30	<0.001	532	23.50 ± 14.57	0.44 ± 0.28	2.654	−0.699	2.01	0.32	<0.001
U20	402	22.13 ± 14.00	0.42 ± 0.27	2.493	−0.945	2.57	0.38	<0.001	385	23.75 ± 14.00	0.45 ± 0.27	2.304	−0.638	1.89	0.19	<0.001
Senior	356	25.76 ± 14.86	0.49 ± 0.29	2.008	−0.171	1.19	0.03	0.353	372	25.53 ± 15.39	0.48 ± 0.30	2.078	−0.225	1.25	0.04	0.211
200-M																
U18	563	21.32 ± 14.46	0.40 ± 0.28	2.933	−1.225	3.4	0.64	<0.001	555	23.13 ± 15.30	0.44 ± 0.29	2.735	−0.785	2.19	0.30	<0.001
U20	387	23.94 ± 14.73	0.45 ± 0.28	2.289	−0.594	1.81	0.15	<0.001	345	23.14 ± 15.52	0.44 ± 0.30	2.259	−0.784	2.19	0.19	<0.001
Senior	466	26.85 ± 14.37	0.51 ± 0.28	2.153	0.080	0.92	0.00	0.617	425	27.00 ± 15.64	0.44 ± 0.29	2.042	0.116	0.89	0.01	0.490
400-M																
U18	512	21.25 ± 14.79	0.40 ± 0.28	2.845	−1.242	3.46	0.51	<0.001	510	23.86 ± 15.00	0.45 ± 0.29	2.574	−0.614	1.85	0.21	<0.001
U20	372	24.56 ± 14.64	0.28 ± 2.18	2.184	−0.450	1.57	0.11	0.013	332	23.96 ± 15.13	0.45 ± 0.29	2.147	−0.576	1.78	0.19	0.002
Senior	443	26.70 ± 15.64	0.30 ± 2.12	2.120	0.045	0.96	0.00	0.784	414	25.52 ± 15.39	0.48 ± 0.30	2.186	−0.227	1.25	0.03	0.183
400-M HURDLES																
U18	340	18.53 ± 12.66	0.35 ± 0.24	2.639	−1.683	5.38	0.56	<0.001	550	24.03 ± 14.78	0.45 ± 0.28	2.631	−0.573	1.77	0.19	<0.001
U20	424	22.08 ± 14.06	0.27 ± 2.57	2.573	−1.037	2.82	0.38	<0.001	351	24.51 ± 14.91	0.46 ± 02.9	2.131	−0.461	1.59	0.1	0.013
Senior	399	23.71 ± 15.13	0.29 ± 2.34	2.345	−0.649	1.91	0.27	<0.001	376	27.58 ± 14.80	0.52 ± 0.28	1.851	0.250	0.78	0.03	0.163
800-M																
U18	573	21.31 ± 14.60	0.40 ± 0.28	2.952	−1.228	3.41	0.55	<0.001	550	24.60 ± 14.87	0.46 ± 0.29	2.571	−0.440	1.55	0.11	0.003
U20	435	22.94 ± 14.74	0.43 ± 0.28	2.511	−0.830	2.29	0.31	<0.001	310	24.62 ± 15.15	0.46 ± 0.29	1.995	−0.435	1.54	0.08	0.028
Senior	424	25.38 ± 15.46	0.48 ± 0.30	2.225	−0.258	1.29	0.05	0.125	408	25.98 ± 15.71	0.49 ± 0.30	2.119	−0.119	1.13	0.01	0.487
1,500-M																
U18	542	22.97 ± 15.20	0.43 ± 0.29	2.728	−0.824	2.28	0.32	<0.001	463	23.53 ± 15.15	0.44 ± 0.29	2.512	−0.691	2.00	0.20	<0.001
U20	432	23.89 ± 14.99	0.45 ± 0.29	2.405	−0.605	1.83	0.25	<0.001	331	23.36 ± 15.03	0.44 ± 0.29	2.194	−0.731	2.08	0.23	<0.001
Senior	409	25.59 ± 15.36	0.48 ± 0.30	2.166	−0.210	1.23	0.03	0.221	416	26.58 ± 15.21	0.50 ± 0.29	2.071	0.018	0.98	0.00	0.917
3,000-M STEEPLECHASE																
U18*	111	21.96 ± 16.08	0.41 ± 0.31	1.396	−1.031	2.80	0.23	0.002	226	23.67 ± 15.90	0.45 ± 0.31	1.780	−0.657	1.93	0.12	0.005
U20	416	23.26 ± 14.32	0.44 ± 0.28	2.411	−0.672	1.96	0.21	<0.001	402	24.23 ± 14.39	0.46 ± 0.28	2.297	−0.527	1.69	0.11	0.002
Senior	348	25.42 ± 14.94	0.48 ± 0.29	2.024	−0.250	1.28	0.04	0.178	375	25.22 ± 14.68	0.48 ± 0.28	2.120	−0.297	1.35	0.05	0.098

(Continued)

TABLE 1 | Continued

	Male								Female							
Category	***N***	**W_B**	**T_B**	**b_0**	**b_1**	**ID**	**R^2**	***P***	***N***	**Wb**	**Tb**	**b_0**	**b_1**	**ID**	**R^2**	***P***
5,000-m																
U18	183	23.16 ± 16.38	0.44 ± 0.32	1.656	−0.767	2.15	0.19	0.003	244	24.39 ± 15.30	0.46 ± 0.29	1.780	−0.488	1.63	0.11	0.029
U20	391	23.68 ± 15.30	0.45 ± 0.29	2.328	−0.656	1.93	0.23	<0.001	400	23.81 ± 15.75	0.45 ± 0.30	2.336	−0.624	1.87	0.19	<0.001
Senior	437	26.41 ± 15.79	0.50 ± 0.30	2.139	−0.021	1.02	0.00	0.899	475	26.66 ± 15.29	0.50 ± 0.29	2.193	0.038	0.96	0.00	0.813
HIGH JUMP																
U18	488	22.41 ± 14.52	0.42 ± 0.28	2.680	−0.958	2.61	0.42	<0.001	522	22.07 ± 14.41	0.41 ± 0.28	2.782	−1.042	2.83	0.52	<0.001
U20	383	21.69 ± 13.88	0.41 ± 0.27	2.511	−1.134	3.11	0.42	<0.001	275	24.52 ± 15.43	0.46 ± 0.30	1.887	−0.460	1.58	0.09	0.029
Senior	350	25.97 ± 14.65	0.49 ± 0.28	1.967	−0.123	1.13	0.01	0.508	362	25.85 ± 15.47	0.49 ± 0.30	2.015	−0.151	1.16	0.01	0.409
POLE VAULT																
U18	356	20.36 ± 14.37	0.38 ± 0.28	2.569	−1.468	4.34	0.56	<0.001	473	24.62 ± 15.22	0.46 ± 0.29	2.418	−0.436	1.55	0.12	0.007
U20	384	22.36 ± 14.86	0.42 ± 0.29	2.445	−0.970	2.64	0.37	<0.001	317	25.16 ± 15.06	0.47 ± 0.29	1.958	−0.310	1.36	0.06	0.112
Senior	344	25.41 ± 14.65	0.48 ± 0.28	2.013	−0.252	1.29	0.04	0.178	316	25.30 ± 14.34	0.48 ± 0.28	1.940	−0.278	1.32	0.04	0.155
LONG JUMP																
U18	547	20.63 ± 14.66	0.39 ± 0.28	2.972	−1.398	4.05	0.70	<0.001	549	22.34 ± 15.29	0.42 ± 0.29	2.805	−0.975	2.65	0.40	<0.001
U20	401	22.85 ± 15.07	0.43 ± 0.29	2.439	−0.853	2.35	0.31	<0.001	332	23.82 ± 14.73	0.45 ± 0.28	2.149	−0.623	1.86	0.24	0.001
Senior	420	25.88 ± 15.00	0.49 ± 0.29	2.160	−0.144	1.15	0.02	0.394	392	24.56 ± 15.03	0.46 ± 0.29	2.236	−0.450	1.57	0.09	0.011
TRIPLE JUMP																
U18	521	20.93 ± 14.40	0.39 ± 0.28	2.894	−1.323	3.75	0.49	<0.001	570	23.25 ± 15.03	0.44 ± 0.29	2.750	−0.758	2.13	0.33	<0.001
U20	374	23.21 ± 15.07	0.44 ± 0.29	2.332	−0.767	2.15	0.26	<0.001	322	24.76 ± 15.43	0.47 ± 0.30	2.018	−0.402	1.49	0.06	0.038
Senior	362	25.24 ± 14.71	0.48 ± 0.28	2.082	−0.291	1.34	0.05	0.111	336	24.92 ± 15.36	0.47 ± 0.30	2.043	−0.365	1.44	0.05	0.054
SHOT PUT																
U18*	95	21.35 ± 15.01	0.40 ± 0.29	1.209	−0.945	2.57	0.22	0.009	522	21.43 ± 14.04	0.40 ± 0.27	2.847	−1.199	3.32	0.63	<0.001
U20	405	20.40 ± 13.78	0.38 ± 0.26	2.677	−1.387	4.00	0.53	<0.001	354	22.36 ± 13.94	0.42 ± 0.27	2.340	−0.886	2.43	0.34	<0.001
Senior	346	23.27 ± 14.47	0.44 ± 0.28	2.248	−0.752	2.12	0.24	<0.001	318	24.00 ± 14.35	0.45 ± 0.28	2.087	−0.580	1.79	0.16	0.003
DISCUS THROW																
U18*	61	21.95 ± 13.45	0.41 ± 0.26	0.705	−0.476	1.61	0.06	0.310	473	20.99 ± 14.67	0.39 ± 0.28	2.792	−1.309	3.70	0.61	<0.001
U20	404	20.13 ± 13.71	0.38 ± 0.26	2.718	−1.527	4.60	0.59	<0.001	337	22.17 ± 14.55	0.42 ± 0.28	2.312	−0.934	2.54	0.30	<0.001
Senior	302	23.94 ± 14.71	0.45 ± 0.28	2.042	−0.595	1.81	0.16	0.003	304	24.00 ± 15.14	0.45 ± 0.29	2.042	−0.580	1.79	0.18	0.004
HAMMER THROW																
U18*	122	21.28 ± 14.89	0.40 ± 0.29	1.371	−0.713	2.04	0.12	0.031	514	22.00 ± 14.84	0.41 ± 0.29	2.774	−1.058	2.88	0.44	<0.001
U20	380	23.19 ± 13.95	0.44 ± 0.27	2.35	−0.772	2.16	0.24	<0.001	352	23.23 ± 15.25	0.44 ± 0.29	2.269	−0.761	2.14	0.22	<0.001
Senior	284	23.87 ± 14.75	0.45 ± 0.28	2.01	−0.616	1.85	0.17	0.003	290	25.25 ± 15.49	0.48 ± 0.30	1.860	−0.289	1.34	0.04	0.156
JAVELIN THROW																
U18*	251	21.82 ± 14.56	0.41 ± 0.28	2.059	−1.030	2.80	0.28	<0.001	554	23.19 ± 14.67	0.44 ± 0.28	2.727	−0.772	2.16	0.33	<0.001
U20	417	22.09 ± 14.65	0.42 ± 0.28	2.556	−1.037	2.82	0.34	<0.001	339	24.43 ± 15.12	0.46 ± 0.29	2.105	−0.480	1.62	0.12	0.011
Senior	336	23.48 ± 14.85	0.44 ± 0.29	2.197	−0.702	2.02	0.23	<0.001	311	25.99 ± 15.23	0.49 ± 0.29	1.846	−0.117	1.12	0.01	0.552

**In these disciplines the sample size was small because few U18 athletes competed with the Senior rules and tool weights. U18, Under 18; U20, Under 20.*

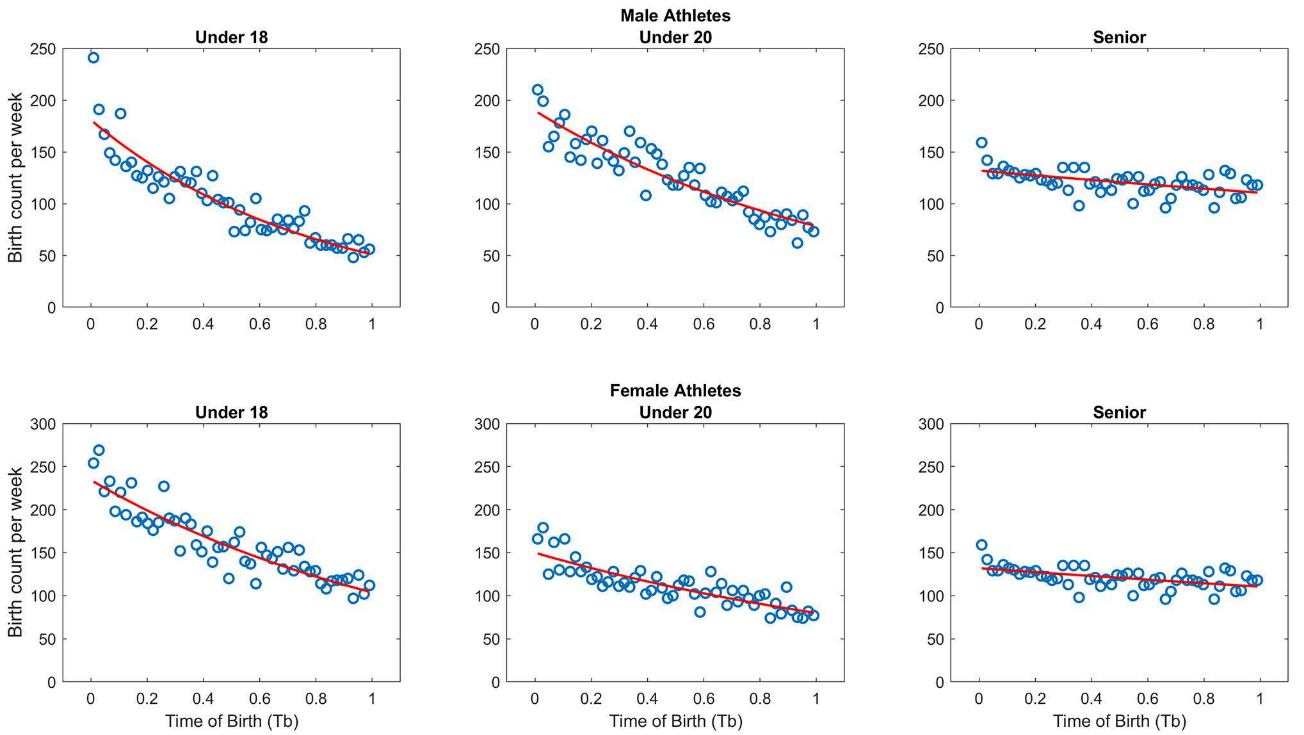

FIGURE 1 | Scatterplot of birthdate frequency by week for Under 18, Under 20, and Senior categories both for male (upper panel) and female athletes (bottom panel). The red line represents the best fit of the Poisson regression.

the Social Agent Model (Hancock et al., 2013) parents, coaches, or athletes may all amplify at a different level the RAE. Initially, parents may influence the RAE by enrolling more frequently relatively older than younger athletes. Furthermore, coaches might place greater expectations on relatively older athletes and consequently advantage them (e.g., more attention during the training sessions). Additionally, athletes themselves may affect the RAE through their self-expectations, influenced by coaches and parents, affording continued success (e.g., apply yourself in the training sessions). The IDs of Under 20 athletes was smaller than Under 18 ones (**Table 1**), highlighting that RAE decreases with the transition to the upper category. This is in line with the trends evident in national Spanish (Brazo-Sayavera et al., 2017, 2018) and UK athletes (Kearney et al., 2018) and in World Championship fields (Hollings et al., 2014). However, it interesting to note that in the study conducted by Hollings et al. (2014) in occasion of the Under 18 World Championship, the ORs were larger than those of the present study both for males (World Championship: OR = 3.7; world top-100 ranking: OR = 2.4) and females (World Championship OR = 2.1; world top-100 ranking: OR = 1.7). This difference may suggest that the selection in to compete at the World Championship may furthermore accentuate the RAE with respect to what can be expected from the athletes' performances. However, this difference in the effect size between the data of Hollings et al. (2014) and the present findings disappear in the Under 20 category.

The comparison between different disciplines may be of particular interest. In general, RAE in youth categories was generally weaker for the middle-distance events (e.g., 1,500-m and 5,000-m) with respect to the other disciplines. This may suggest that endurance capacity was less influenced by the relative age. The disciplines of 110 hurdles and 400 m hurdles were more affected by the RAE compared to the 100-m and 400-m races in line. This may suggest that the RAE may be of particular benefit in these disciplines where a more developed anthropometric profile (i.e., longer limbs) may confer an advantage in dealing with the distance between hurdles. Within the throwing events, the shot-put and discus throw were more influenced by the RAE than the hammer and javelin throw, both in males and females. These results at world class level reinforce the conclusion observed in national (Kearney et al., 2018) and World Athletics Championship (Hollings et al., 2014) where RAEs also are likely to be larger in events with a greater emphasis on speed and/or strength (Hollings et al., 2014; Kearney et al., 2018).

RAE was generally larger in males compared to female athletes. This finding was valid for all disciplines. Indeed, both IDs and ORs were overall higher in males (IDs ranged = 1.29–3.46; ORs ranged = 1.2–2.4) than in females (IDs ranged = 1.19–2.21; ORs ranged = 1.1–1.7) underlining that RAE has a smaller but consistent influence on female sports (Brazo-Sayavera et al., 2017, 2018; Kearney et al., 2018). Different speculative explanations may support these data. The inferior

TABLE 2 | Relative Age Effect (RAE) according Odds Ratio for male and female athletes at each category of age group and event.

	Male						Female					
	U18		U20		Senior		U18		U20		Senior	
Disciplines	**OR**	**[95% CI]**	**OR**	**[95% CI]**	**OR**	**[95% CI]**	**OR**	**[95% CI]**	**OR**	**[95% CI]**	**OR**	**[95% CI]**
Overall	2.4	[2.1–2.7]	2.0	[1.8–2.2]	1.2	[1.1–1.3]	1.7	[1.6–1.9]	1.6	[1.4–1.7]	1.1	[1.0–1.2]
100–m	2.7	[1.9–3.8]	1.8	[1.2–2.7]	0.9	[0.6–1.3]	1.8	[1.3–2.5]	1.4	[0.9–2.2]	0.9	[0.6–1.4]
110–m Hurdles	2.8	[1.4–5.9]	2.5	[1.6–3.8]	1.1	[0.7–1.7]	1.6	[1.1–2.3]	1.7	[1.1–2.6]	1.1	[0.8–1.7]
200–m	2.5	[1.8–3.6]	1.6	[1.0–2.3]	1.0	[0.7–1.4]	1.7	[1.2–2.4]	1.6	[1.0–2.4]	0.9	[0.6–1.3]
400–m	2.5	[1.7–3.6]	1.4	[0.9–2.1]	1.1	[0.7–1.6]	1.6	[1.1–2.2]	1.4	[0.9–2.2]	1.2	[0.8–1.7]
400–m Hurdles	5.2	[3.1–8.8]	2.4	[1.6–3.6]	1.5	[1.0–2.2]	1.5	[1.1–2.1]	1.5	[1.0–2.3]	0.8	[0.5–1.2]
800–m	2.3	[1.6–3.2]	1.9	[1.3–2.7]	1.2	[0.8–1.7]	1.4	[1.0–2.0]	1.6	[1.0–2.5]	1.1	[0.7–1.6]
1,500–m	1.6	[1.1–2.2]	1.4	[1.0–2.0]	1.1	[0.7–1.6]	1.6	[1.1–2.3]	1.8	[1.2–2.8]	1.0	[0.7–1.5]
5,000–m	1.7	[1.0–3.0]	1.6	[1.1–2.4]	1.0	[0.7–1.4]	1.5	[0.9–2.5]	1.5	[1.0–2.2]	1.0	[0.7–1.4]
3,000–m Steeplechase	2.2	[1.0–4.7]	1.8	[1.2–2.6]	1.1	[0.7–1.7]	1.5	[0.9–2.5]	1.6	[1.1–2.3]	1.2	[0.8–1.8]
High Jump	2.0	[1.4–2.8]	2.7	[1.7–4.1]	1.0	[0.7–1.6]	2.1	[1.5–3.0]	1.3	[0.8–2.0]	1.1	[0.7–1.6]
Pole Vault	2.8	[1.8–4.4]	1.9	[1.3–2.8]	1.1	[0.7–1.7]	1.3	[0.9–1.8]	1.2	[0.8–1.9]	1.2	[0.8–1.8]
Triple Jump	2.8	[1.9–4.0]	1.7	[1.2–2.6]	1.2	[0.8–1.8]	1.7	[1.2–2.4]	1.4	[0.9–2.2]	1.2	[0.8–1.8]
Long Jump	2.7	[1.9–3.8]	1.9	[1.3–2.9]	1.2	[0.8–1.7]	1.9	[1.4–2.6]	1.5	[1.0–2.3]	1.2	[0.8–1.8]
Shot Put	2.4	[1.0–5.6]	3.4	[2.2–5.2]	1.5	[1.0–2.4]	2.5	[1.7–3.6]	2.3	[1.5–3.6]	1.5	[1.0–2.4]
Discus Throw	2.5	[0.8–7.4]	3.6	[2.3–5.5]	1.4	[0.9–2.3]	2.6	[1.8–3.9]	2.2	[1.4–3.4]	1.5	[1.0–2.4]
Hummer Throw	2.4	[1.2–5.1]	1.7	[1.1–2.6]	1.5	[1.0–2.5]	2.2	[1.6–3.2]	1.7	[1.1–2.6]	1.3	[0.8–2.1]
Javelin Throw	2.1	[1.2–3.4]	1.9	[1.3–2.8]	1.5	[1.0–2.4]	1.7	[1.2–2.3]	1.4	[0.9–2.1]	1.1	[0.7–1.6]

odds ratios (ORs) and 95% confidence intervals (95% CI) first vs. last quartile. U18, Under 18; U20, Under 20.

popularity of the sports and the consequent more opportunities to be selected (Brazo-Sayavera et al., 2018), as well as the early maturation of females (Smith et al., 2018), may have minimized the RAE. The female pole vault was the only discipline at Under 20 that did not show a clear evidence of RAE. This may be linked to the fact that many female pole vaulters started their early sport career as gymnasts, a sport in which the typical RAE has not been found (Baker et al., 2014).

In the Senior category, the prevalence of RAE decreases but does not totally disappear (**Tables 1**, **2**). In fact, the chance of being in the world top-100 ranking was about 1.2–1.3 times greater for athletes born in the first compared to the last week of the year (**Table 1**). However, this effect was mainly driven by some specific disciplines. In males this effect was present only in 400-m Hurdles and throwing events (**Tables 1**, **2**). The throws in athletics are particularly influenced by the anthropometric and strength features of athletes, thus being relatively more mature may confer a great advantage in the early phase of an athlete's development (Hollings et al., 2014; Kearney et al., 2018). The fact that this effect was maintained at senior level suggests that the relatively older throwers had more chances of continuing their sport career up to the senior level. In females this effect was present in shot put and discus throw but not in javelin and hammer throw. In addition, it was present also in long and triple jump. For females, the senior trends are more difficult to explain and require further investigations. However, this data showed that at international level the large initial benefit observed in younger category has a long-lasting effect only for some disciplines. Minimizing the RAE in these disciplines is crucial to give the chance of accessing a world class career to athletes born late in the year. Furthermore, the finding that some disciplines showed RAE in youth but not in the Senior category may in part explain why previous studies showed that excelling at younger age grades is not a strong predictor of success in adulthood (Boccia et al., 2017a, 2018; Kearney and Hayes, 2018). Indeed, it is possible to speculate that some athletes born late in the year could reach the world class level only in the senior category, when the effect of relative age tends to disappear. However, this is not a prospective study, thus this is only a speculation that remains to be confirmed by future studies.

While increased coach and parent education has been proposed as a method for reducing RAEs (e.g., Musch and Grondin, 2001; Andronikos et al., 2016), Mann and van Ginneken (2017) illustrated that knowledge of the effect is insufficient to influence selection decisions. A number of structural solutions have been proposed to address RAEs, including systems for rotating cut off dates on a yearly basis (e.g., Hurley et al., 2001), classifying athletes by maturation status (e.g., Cumming et al., 2017), or applying a correction factor to performance results (e.g., Romann and Cobley, 2015; Cobley et al., 2019). However, there is a paucity of research investigating the long term effectiveness of these proposals (Haycraft et al., 2018).

Some limitations should be highlighted when interpreting the current data. In some countries (e.g., UK) the cut-off date for youth category is August 31st and this may have affected our results. However, according to IAAF rules we defined the cut-off for Under 18 and Under 20 date on the

31st December in the year of competition. Furthermore, it should be underlined that regarding Under 18 and Under 20 categories we analyzed each calendar year from 2010 to 2018. Thus, each young athlete had the chance of compare in the ranking both in the first or the second constituent year of each category. For this reason, we do not expect any bias caused by the fact that youth categories are constituted by two competitive years.

CONCLUSION

This is the first study examining the prevalence of RAE at world class level (i.e., athletes in the world top-100 ranking) in both youth and senior categories in all track and field disciplines. In conclusion, the present study underlined that relative age affected the performance of Under 18 and Under 20 world class athletes. The athletes born close to the cut-off date of selection had an increased chance of being included in the world top-100 ranking. This effect was larger in male compared to female athletes. The RAE may induce a bias in the talent identification process by decreasing the chance of selection for talented athletes born late in the year of consideration. This was evident in some peculiar disciplines, namely the 400-m Hurdles and throwing events for males, and shot put, discus throw, long and triple jump in females.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization: PB and GB. Investigation: PB and AU. Formal analysis: PB. Funding acquisition: AR and CL. Supervision: GB, AR, and CL. Writing—original draft: PB, GB, and PK. Writing—review and editing: PB, GB, PK, CL, AU, AM, and AR.

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REFERENCES

Andronikos, G., Elumaro, A. I., Westbury, T., and Martindale, R. J. (2016). Relative age effect: implications for effective practice. *J. Sports Sci.* 34, 1124–1131. doi: 10.1080/02640414.2015.1093647

Arrieta, H., Torres-Unda, J., Gil, S. M., and Irazusta, J. (2016). Relative age effect and performance in the U16, U18 and U20 European Basketball Championships. *J. Sports Sci.* 34, 1530–1534. doi: 10.1080/02640414.2015.1122204

Baker, J., Janning, C., Wong, H., Cobley, S., and Schorer, J. (2014). Variations in relative age effects in individual sports: skiing, figure skating and gymnastics. *Eur. J. Sport Sci.* 14(Suppl. 1), S183–S190. doi: 10.1080/17461391.2012.671369

Barnsley, R. H., Thompson, A. H., and Barnsley, P. E. (1985). Birthdate and performance: the relative age effect. *Can. J. Hist. Sport Phys. Educ.* 51, 23–28.

Bjerke, Ø., Pedersen, A. V., Aune, T. K., and Lorås, H. (2017). An inverse relative age effect in male alpine skiers at the absolute top level. *Front. Psychol.* 8:1210. doi: 10.3389/fpsyg.2017.01210

Boccia, G., Brustio, P. R., Moisè, P., Franceschi, A., La Torre, A., Schena, F., et al. (2018). Elite national athletes reach their peak performance later than non-elite in sprints and throwing events. *J. Sci. Med. Sport*. 22, 342–347. doi: 10.1016/j.jsams.2018.08.011

Boccia, G., Moise, P., Franceschi, A., Trova, F., Panero, D., La Torre, A., et al. (2017a). Career performance trajectories in track and field jumping events from youth to senior success: the importance of learning and development. *PLoS ONE* 12:e0170744. doi: 10.1371/journal.pone.0170744

Boccia, G., Rainoldi, A., and Brustio, P. R. (2017b). Relative age effect in males, but not females, undergraduate students of sport science. *Sport Sci. Health* 13, 349–353. doi: 10.1007/s11332-017-0364-7

Brazo-Sayavera, J., Martínez-Valencia, M. A., Müller, L., Andronikos, G., and Martindale, R. J. J. (2017). Identifying talented track and field athletes: the impact of relative age effect on selection to the Spanish National Athletics Federation training camps. *J. Sports Sci.* 35, 2172–2178. doi: 10.1080/02640414.2016.1260151

Brazo-Sayavera, J., Martínez-Valencia, M. A., Müller, L., Andronikos, G., and Martindale, R. J. J. (2018). Relative age effects in international age group championships: a study of Spanish track and field athletes. *PLoS ONE* 13:e0196386. doi: 10.1371/journal.pone.0196386

Brustio, P. R., Lupo, C., Ungureanu, A. N., Frati, R., Rainoldi, A., and Boccia, G. (2018). The relative age effect is larger in Italian soccer top-level youth categories and smaller in Serie A. *PLoS ONE* 13:e0196253. doi: 10.1371/journal.pone.0196253

Cobley, S., Abbott, S., Dogramaci, S., Kable, A., Salter, J., Hintermann, M., et al. (2018). Transient relative age effects across annual age groups in National level Australian Swimming. *J. Sci. Med. Sport* 21, 839–845. doi: 10.1016/j.jsams.2017.12.008

Cobley, S., Abbott, S., Eisenhuth, J., Salter, J., McGregor, D., and Romann, M. (2019). Removing relative age effects from youth swimming: the development and testing of corrective adjustment procedures. *J. Sci. Med. Sport* 22, 735–740. doi: 10.1016/j.jsams.2018.12.013

Cobley, S., Baker, J., Wattie, N., and McKenna, J. (2009). Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. *Sports Med.* 39, 235–256. doi: 10.2165/00007256-200939030-00005

Cohen, J., Cohen, P., West, S. G., and Aiken, L. S. (2013). *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences.* New York, NY: Routledge.

Cumming, S. P., Lloyd, R. S., Oliver, J. L., Eisenmann, J. C., and Malina, R. M. (2017). Bio-banding in sport: applications to competition, talent identification, and strength and conditioning of youth athletes. *Strength Cond. J.* 39, 34–47. doi: 10.1519/SSC.0000000000000281

Cumming, S. P., Searle, C., Hemsley, J. K., Haswell, F., Edwards, H., Scott, S., et al. (2018). Biological maturation, relative age and self-regulation in male professional academy soccer players: a test of the underdog hypothesis. *Psychol. Sport Exerc.* 39, 147–153. doi: 10.1016/j.psychsport.2018.08.007

Delorme, N., and Champely, S. (2013). Relative age effect and chi-squared statistics. *Int. Rev. Sociol. Sport* 50, 740–746. doi: 10.1177/1012690213493104

Doyle, J. R., and Bottomley, P. A. (2018). Relative age effect in elite soccer: more early-born players, but no better valued, and no paragon clubs or countries. *PLoS ONE* 13:e0192209. doi: 10.1371/journal.pone.0192209

Doyle, J. R., and Bottomley, P. A. (2019). The relative age effect in European elite soccer: a practical guide to Poisson regression modelling. *PLoS ONE* 14:e0213988. doi: 10.1371/journal.pone.0213988

Fukuda, D. H., Kelly, J. D., Albuquerque, M. R., Stout, J. R., and Hoffman, J. R. (2017). Relative age effects despite weight categories in elite junior male wrestlers. *Sport Sci. Health* 13, 99–106. doi: 10.1007/s11332-017-0351-z

Hancock, D. J., Adler, A. L., and Côté, J. (2013). A proposed theoretical model to explain relative age effects in sport. *Eur. J. Sport Sci.* 13, 630–637. doi: 10.1080/17461391.2013.775352

Haycraft, J. A. Z., Kovalchik, S., Pyne, D. B., Larkin, P., and Robertson, S. (2018). The influence of age-policy changes on the relative age effect across the Australian Rules football talent pathway. *J. Sci. Med. Sport* 21, 1106–1111. doi: 10.1016/j.jsams.2018.03.008

Hollings, S. C., Hume, P. A., and Hopkins, W. G. (2014). Relative-age effect on competition outcomes at the World Youth and World Junior Athletics Championships. *Eur. J. Sport Sci.* 14, S456–S461. doi: 10.1080/17461391.2012.713007

Hurley, W., Lior, D., and Tracze, S. (2001). A proposal to reduce the age discrimination in Canadian minor hockey. *Can. Public Policy/Analyse de Politiques* 27, 65–75. doi: 10.2307/3552374

Kearney, P. E., and Hayes, P. R. (2018). Excelling at youth level in competitive track and field athletics is not a prerequisite for later success. *J. Sports Sci.* 36, 2502–2509. doi: 10.1080/02640414.2018.1465724

Kearney, P. E., Hayes, P. R., and Nevill, A. (2018). Faster, higher, stronger, older: relative age effects are most influential during the youngest age grade of track and field athletics in the United Kingdom. *J. Sports Sci.* 36, 2282–2288. doi: 10.1080/02640414.2018.1449093

Lovell, R., Towlson, C., Parkin, G., Portas, M., Vaeyens, R., and Cobley, S. (2015). Soccer player characteristics in english lower-league development programmes: the relationships between relative age, maturation, anthropometry and physical fitness. *PLoS ONE* 10:e0137238. doi: 10.1371/journal.pone.0137238

Mann, D. L., and van Ginneken, P. J. (2017). Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. *J. Sports Sci.* 35, 784–790. doi: 10.1080/02640414.2016.1189588

Müller, L., Hildebrandt, C., Schnitzer, M., and Raschner, C. (2016). The role of a relative age effect in the 12th Winter European Youth Olympic Festival in 2015. *Percept. Mot. Skills* 122, 701–718. doi: 10.1177/00315125166 40390

Musch, J., and Grondin, S. (2001). Unequal competition as an impediment to personal development: a review of the relative age effect in sport. *Dev. Rev.* 21, 147–167. doi: 10.1006/drev.2000.0516

Peña-González, I., Fernández-Fernández, J., Moya-Ramón, M., and Cervelló, E. (2018). Relative age effect, biological maturation, and coaches' efficacy expectations in young male soccer players. *Res. Q. Exerc. Sport* 89, 373–379. doi: 10.1080/02701367.2018.1486003

Rada, A., Padulo, J., Jelaska, I., Ardigò, L. P., and Fumarco, L. (2018). Relative age effect and second-tiers: no second chance for later-born players. *PLoS ONE* 13:e0201795. doi: 10.1371/journal.pone.0201795

Romann, M., and Cobley, S. (2015). Relative age effects in athletic sprinting and corrective adjustments as a solution for their removal. *PLoS ONE* 10:e0122988. doi: 10.1371/journal.pone.0122988

Romann, M., Rössler, R., Javet, M., and Faude, O. (2018). Relative age effects in Swiss talent development - a nationwide analysis of all sports. *J. Sports Sci.* 36, 2025–2031. doi: 10.1080/02640414.2018.1432964

Smith, K. L., Weir, P. L., Till, K., Romann, M., and Cobley, S. (2018). Relative age effects across and within female sport contexts: a systematic review and meta-analysis. *Sports Med.* 48, 1451–1478. doi: 10.1007/s40279-018-0890-8

Steingröver, C., Wattie, N., Baker, J., Helsen, W. F., and Schorer, J. (2017). Geographical variations in the interaction of relative age effects in youth and adult elite soccer. *Front. Psychol.* 8:278. doi: 10.3389/fpsyg.2017.00278

Till, K., Cobley, S., Wattie, N., O'Hara, J., Cooke, C., and Chapman, C. (2010). The prevalence, influential factors and mechanisms of relative age effects in UK Rugby League. *Scand. J. Med. Sci. Sports* 20, 320–329. doi: 10.1111/j.1600-0838.2009.00884.x

Wattie, N., Schorer, J., and Baker, J. (2015). The relative age effect in sport: a developmental systems model. *Sports Med.* 45, 83–94. doi: 10.1007/s40279-014-0248-9

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Attacking Profiles of the Best Ranked Teams From Elite Futsal Leagues

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This study aimed to (i) explore the discriminatory power of the task-related variables and the context in establishing differences in the elite futsal leagues of Portugal, Spain, and Russia and (ii) understand how these variables vary according to the match outcome. Methodological issues concerning efficiency (goals and shots), offensive organisation (positional attack, counterattack, set pieces, or 5vs4+Goalkeeper), 1st goal scored during matches (home or away team), match type (balanced or unbalanced), and match outcome (winner, loser, or drawer) were discussed. Archival data were obtained from the 2017–2018 season of Portuguese, Spanish, and Russian professional futsal leagues for all play-off matches. Crosstabs analysis was conducted to establish the significance relationship between the elite futsal leagues and the situational variables. Afterward, discriminant analysis was used to identify the task-related variables that maximise mean differences between different league teams for defining offensive profile, and the variations found when the condition of the winner, loser, or drawer is taken into account. The results allowed to understand that the Portuguese and Russian teams used the positional attacks more, and less the counterattacks and set pieces than the Spaniards, who present a more balanced offensive profile. Overall, winners were better discriminated by goals scored, whereas 5vs4+Goalkeeper strategy discriminated loser teams. Coaches should be aware of these different offensive profiles in order to increase control over the match planning and decrease predictability against opposing teams.

Keywords: performance analysis, task-related variables, situational variables, match outcome, discriminant analysis

INTRODUCTION

Futsal is a team sport that involves quick actions and precise movements according to the required physical, technical, and tactical game demands (Castagna et al., 2009). As in other team sports, the constant variability in the contexts of performance in short spaces requires great tactical expertise on the part of the players (Amaral and Garganta, 2005). That is, players should constantly explore the game possibilities for action forged by the spatial–temporal relations with teammates and opponents in relation to the strategic plans defined by coaches, the context of the game, or even the game result (Corrêa et al., 2012; Travassos et al., 2016).

Besides game complexity, in order to identify some regularities that characterise game demands and dynamics, previous research from a performance analysis perspective revealed that there is a need to understand the influence of different types of attacking play (i.e., counterattack, positional attack, the set pieces, etc.) on team effectiveness (Lima-Duarte, 2008; Fukuda and Santana, 2012; Lapresa et al., 2013; Gómez et al., 2015; Sarmento et al., 2016). In line with that, previous research revealed that counterattack, positional attack, set pieces, and 5vs4+Goalkeeper (GK), in this order, are the most successful types of attacking play in futsal (Silva et al., 2004; Botelho and Coppi, 2010; Marchi et al., 2010; Fukuda and Santana, 2012; Poffo and Lima, 2012; Soares-Leite, 2012). Also, when ball possession effectiveness of 4vs4 and 5vs4+GK was analysed without considering the types of attacking play used, the 5vs4+GK revealed higher effectiveness than the 4vs4 (Vicente-Vila and Lago-Peñas, 2016). However, recent research showed that the use of the 5vs4+GK game strategy does not cause changes in the match status, and the teams that were losing and used the 5vs4+GK game strategy lost the game in 93% of cases and received more goals compared to those scored (Méndez, 2017). Regarding the number of shots obtained, without considering efficacy, it was observed that positional attack revealed higher values of shots than the counterattacks and set pieces (Orta et al., 2000; Soares-Leite, 2012; Coelho et al., 2013). The discrepancies observed could be related to the sample size, the level of the teams analysed, or even with the percentage of data in relation to the total number of goals or shots considering all possible types of offensive organisation.

In spite of previous results, team sports performance and effectiveness cannot be viewed in a general way but need to be contextualised to game dynamics according to the specific context of performance (Gómez et al., 2013). In this perspective, research has pointed to the importance of situational variables in team performance (Gómez et al., 2013). For instance, the first goal scored in the match (i.e., home or away team having scored before) is clearly linked to the match outcome (i.e., winner, loser, or drawer) (Armatas et al., 2009; Tenga, 2013). The scoring of the first goal in an elite futsal match determines the winner status of the game in 60–70% of the games evaluated (Sampedro and Prieto, 2012; Soares-Leite, 2013; Soares-Leite, 2014). Also, the match type (i.e., balanced or unbalanced matches were determined by the points or goals difference in the scoreboard. It was established based on previous research according to the opinion of expert coaches. That is, the match outcome exceeding the 10-point differences in basketball and two goals in futsal were considered unbalanced matches) has been investigated as a discriminating factor of the main performance indicators and to contextualise the factors associated with victory or defeat (Sampaio and Janeira, 2003; Csataljay et al., 2009). Therefore, the situational variables have to be controlled when analysing futsal performance (Eccles et al., 2009; Gómez et al., 2013).

Thus, it is clear that the environment of performance, the characteristics of the tournament, and the culture of the sport or even the level of the competition in different countries should be considered (Eccles et al., 2009; Gómez et al., 2013). However, the comparison of the performance of elite futsal teams from different countries has been neglected in research. To our best knowledge, few attempts have been made to identify the physical, technical, and tactical performance that characterise elite futsal teams from different countries. In one study the authors compared the physical and technical indicators that differentiated elite futsal teams from Brazil, Spain, and Australia (Dogramaci et al., 2015). It revealed that Australian players spent significantly more time engaged in high-intensity activity than Spanish players (sprinting: 0.36 vs. 0.06%; running: 5.89 vs. 3.33%, $p < 0.05$). The Brazilian team showed the best passing accuracy and shot accuracy (10.7 ± 1.06 vs. 8.68 ± 0.81 vs. 5.31 ± 0.60, respectively, $p < 0.01$) and longer duration in ball possession than Spanish and Australian teams (40.0 ± 10.4% vs. 23.5 ± 2.73% vs. 30.9 ± 2.54%, respectively, $p < 0.01$). The Brazilian team showed the best passing accuracy and shot accuracy and longer duration in ball possession than Spanish and Australian teams. These results were used for comparison purposes according to the levels of the leagues of each country, and it was concluded that higher-performing teams (Brazilian and Spanish) are more accurate on the moves and on the passing and shooting actions than sub-elite-performing teams (Australian) (Dogramaci et al., 2015). In the same line of reasoning, Travassos et al. (2016) evaluated the flexibility/stability tendencies of the offensive play behaviours in six matches from the national futsal teams of Spain and Portugal through social network analysis. The authors aimed to observe the coordination trends emerging in the tactical behaviours of the players when facing different defensive formations of the opponent. The results showed similar network properties between teams when they compete against riskier defensive formations, but a greater level of adaptability for the unfolding of tactical variants of the Spanish team against conservative defences was observed in comparison with the Portuguese team. It was argued that such results help on the characterisation of the level of adaptability of the different countries' teams to the futsal game variability and situational game environments (Travassos et al., 2016).

The available literature in futsal exploring team performance regarding task-related, situational, and contextual variables is limited (Moore et al., 2014). This is probably due to the lack of systematised information from futsal games and also due to the lack of researchers focusing on this sport in the past (Vicente-Vila and Lago-Peñas, 2016). The development of new studies in performance analysis of futsal that takes into account task-related, situational, and contextual variables is fundamental to understanding the game, identifying errors, and fundamentally perceiving its evolution (McGarry, 2009). Through these observations, coaches can identify the physical, technical, and tactical trends of the game that will allow a redefinition of game strategies to check and adapt the training routines to game demands (Niu et al., 2012; Morais et al., 2014).

Due to the unpredictable and complex nature of the sport of futsal (Vicente-Vila and Lago-Peñas, 2016), multivariate techniques for performance analysis are a useful tool when describing the normative profiles of the teams and their association with task-related, situational, and contextual variables. Accordingly, discriminant analysis has been suggested as a suitable statistical method for exploring and modelling such data in team sports (Sampaio and Janeira, 2003; Sampaio et al., 2006, 2018; Gómez et al., 2008; Ibáñez et al., 2009; Miloski et al., 2014) and examining differences between two or more groups with respect to several variables simultaneously (Klecka, 1980). For instance, previous research using this methodology in football revealed the following: the variables related to attacking play that best discriminate between winning and losing teams were goals scored, total shots, shots on goal, attacking moves, crosses, ball possession, match location, and quality of opposition. They emphasise the idea that coaches and players should be aware of these different attacking profiles in order to increase knowledge about game cognitive and motor solicitation and, therefore, to evaluate specificity in practise and game planning (Lago-Peñas et al., 2010, 2011; Lago-Peñas and Lago-Ballesteros, 2011; Castellano et al., 2012).

For the last two decades, Union of European Football Associations (UEFA) and Fédération Internationale de Football Association (FIFA) have promoted the implementation and development of futsal as a specific modality worldwide, although there are different levels of organisation and competitions at the amateur, semi-professional, and professional levels (Moore et al., 2014). The FIFA ranking recognises Brazil, Spain, Portugal, and Russia as the four best futsal national teams. Thus, their leagues, promoted by their national football federations, are presumed to represent the physical, technical, and tactical trends of the game (Göral, 2018). However, according to previous assumptions, task-related, situational, and contextual variables are fundamental for characterising such trends. Based on that, the aim of the present study was to identify the performance indicators that best discriminate the highest-ranked FIFA professional futsal leagues from three of the best four FIFA-ranked countries (Portuguese, Spanish, and Russian), as well as the variations that could be found when the condition of the winner, loser, or drawer is established. We expected to identify similarities between countries that help to characterise the trends of the game, but also to identify the characteristics that culturally define the national trends in the futsal game of Portuguese, Spanish, and Russian teams. Also, we expected to identify the variables that help to discriminate the winning, losing, or drawing teams in each country. Different results were expected to be observed among countries.

MATERIALS AND METHODS

Ethical Approval

The Ethics Committee of Research and Development activities of UPM (Technical University of Madrid) was responsible for the evaluation of ethical aspects in order that data collection and processing used in this study will not affect fundamental rights. The ethics committee confirmed that the study respects the European data protection law (General Data Protection Regulation) regarding the public data processing of team sports. Once informed of the activity described in this manuscript, it was reviewed and approved by the Ethics Committee of Research and Development activities of UPM in order to be published.

Since the study involved analysis of not publicly available data, the requirement for informed consent was necessary. Astrofutsal® and Instatscout® acted as statistical suppliers of the elite futsal leagues to offer scouting services. Payment licences are necessary to access their datasets, and requests should be addressed through registration at http://www.astro-sport.com and https://www.instatscout.com. In order to avoid conflict of interests, steps were completed to buy a licence and to have access and use such data for research purposes. The informed consent of both companies was obtained in order that this study could use their statistical reports data in research, as well as in subsequent publications, in exchange for the source of the data repository being named.

Data Sampling

A total of 56 matches corresponding to the playoffs from the 2017 to 2018 1st division of the Portuguese, Spanish, and Russian men's elite futsal leagues were examined. The playoff league stage is played by the eight best-ranked teams during the regular season (played in a balanced schedule of 16 teams), and then the playoff includes the quarter-final, semi-final, and final rounds in a best-of-three series (five in the final round) in the Portuguese and Spanish leagues and in a best-of-five series in the Russian league with a home court advantage predetermined by the regular season results. One hundred and twelve cases were recorded in which the differences between the three European leagues were analysed with respect to variables linked to offensive game organisation and some situational variables.

Data Processing

Regarding the data analysed in this study, the corresponding data on the Portuguese and Russian leagues were obtained through the Instat® platform, and the data on the Spanish league were provided by the Astrofutsal® platform. The data on the common variables in the match statistics of both platforms were observed, selected, and transferred to a unified matrix on an Excel spreadsheet. Astrofutsal® (Méndez and Méndez, 2005) and Instatscout® are common computer tools that provide data analysis of futsal competitions and are currently being used in sports research (Paz-Franco et al., 2014).

In the analysis of the reliability of the data, an expert observer from Astrofutsal® analysed a match from the Portuguese league, crossing the records with those previously obtained in that match by the expert observer from Instatscout®. To carry out the interobserver reliability, the expert observer (12 years of experience in the notational analysis of futsal events with the use of the Astrofutsal® tool) analysed the match between Sporting Club Portugal vs. Sport Lisboa e Benfica (1st match of the Playoff final series 2017–2018). The observer recorded the common events of the match for both teams, and the records were compared with those already established for that same game, using Cohen's *Kappa* index (k) (Robinson and O'Donoghue, 2007). The results of the Kappa values from the events of both teams revealed very good agreement between both independent observers ($k = 0.81$ and $k = 0.82$) (Viera and Garrett, 2005).

Data Notation

All the variables studied are defined in **Table 1**. The dependent variable was a categorical variable that determined the origin league of the best-ranked teams (eight best-ranked teams in

TABLE 1 | Distribution of descriptive statistics from the studied variables.

Variables	Portugal *n* = 30				Spain *n* = 36				Russia *n* = 46			
	%	*n*	$\bar{X}$	*SD*	%	*n*	$\bar{X}$	*SD*	%	*n*	$\bar{X}$	*SD*
Task related												
Efficiency												
Goals	–	88	2.9	1.8	–	102	2.8	1.3	–	140	3.0	1.9
Shots	–	1,161	38.7	14.8	–	1,243	34.5	8.8	–	2,127	46.2	8.9
Offensive organisation												
Counterattack	5.9	199	6.6	3.1	10.2	384	10.6	4.5	6.0	406	8.8	3.7
Positional attack	71.5	2,402	80.0	15.2	57.4	2,170	60.2	12.5	70.5	4,750	103.2	12.7
Set pieces	17.5	588	19.6	8.7	27.7	1,051	29.1	10.5	18.4	1,241	26.9	6.5
5vs4+Gk	5.1	170	5.6	6.4	4.7	178	4.9	6.6	5.1	339	7.3	9.2
Situational												
1st goal												
Home team	53.3	16	–	–	55.6	20	–	–	65.2	30	–	–
Away team	46.7	14	–	–	44.4	16	–	–	34.8	16	–	–
Match outcome												
Winner	50.0	15	–	–	44.4	16	–	–	47.8	22	–	–
Loser	50.0	15	–	–	44.4	16	–	–	47.8	22	–	–
Drawer	–	–	–	–	11.1	4	–	–	4.3	2	–	–
Match type												
Balanced	73.3	22	–	–	77.8	28	–	–	56.5	26	–	–
Unbalanced	26.7	8	–	–	22.2	8	–	–	43.5	20	–	–

each country, which were the ones that played the final playoff in the 2017–2018 season), being established in a polytomous contextual-dependent variable: Portugal, Spain, and Russia.

The independent or discriminating variables were presented as task-related variables and situational variables. The task-related variables (continuous) included variables related with efficiency of teams: (i) goals (number of goals scored by each team at the end of the match); (ii) shots (number of shots made by each team, without taking into account their final effects, although as the goal is almost always preceded by a shot, has been considered that the goals scored are included in the shots count); and variables related with the attacking teams' organisation; (iii) positional attack (number of times the team uses this type to end the attack), considered when the attacking players are ordered according to the ball and try to progress to the opposing goal with offensive means to unbalance a positioned opponent defence in front of the ball; (iv) counterattack (number of counterattacks carried out) considered at the attempt to exploit the free spaces caused by the absence of the adversary collective fallback, where speed and depth predominate in the game after ball recovery; (v) set pieces (total sum of actions to set pieces including throw-ins, corners, penalty free kick from the second penalty mark at 10 m, and free kick with opposition); and (vi) 5vs4+GK (number of times the team uses this strategy in the match). The situational variables (categorical) included (vii) the 1st goal scored in the match (that differentiates the teams that scores a goal before their opponent playing at home or away); (viii) match outcome (that differentiates winners, losers, and drawers, once the periods of play time have ended); and (ix) match type [that discriminates the balance between teams over the game (balanced game: with differences of up to two goals, and unbalanced games: more than a two-goal difference)].

Statistical Analysis

Firstly, the relationships of the dependent variable (teams from different leagues) with each of the independent categorical variables were analysed, taken one by one, using crosstabs. For each relationship, the Pearson chi-square test and its symmetric measurements were used in order to see significant effects between the teams of the different leagues and situational variables. The effect sizes (ESs) were calculated using Cramer's *V* test, and their interpretation was based on the following criteria: 0.10 = small effect, 0.30 = medium effect, and 0.50 = large effect (Volker, 2006).

Secondly, a discriminant analysis was used on the performance of the teams from the three different leagues considered to create a function that classifies the teams from each league as accurately as possible. The fact that the teams come from different leagues was used as a dependent variable, while the variables in which differences were assumed were used as independent variables. In each of the three groups (European futsal leagues), two discriminant functions were obtained and interpreted based on the examination of structure coefficients (SCs) greater than |0.30| (Tabachnick and Fidell, 2007). The current study basically consists of two discriminant analyses: First, a previous analysis tried to find out how the Portuguese, Spanish, and Russian teams differ with respect to their attacking game organisation and its effectiveness. After, a subsequent analysis tried to ascertain if there was any variable that could discriminate the teams when the condition of a winner or a non-winner was included.

The statistical specifications of the model included (i) an analysis of variance (ANOVA) test with *F* statistics that contrasts the equality of means hypothesis among the groups in each independent variable (it served as a preliminary test to detect if the groups differ significantly ($P < 0.05$) in the classification variables); (ii) the eigenvalues show the canonical correlation, whose value (between 0 and 1) indicates to what extent the discriminant variables make it possible to differentiate among the three groups; (iii) *Wilks' Lambda*, which expresses the total variability proportion not due to the differences among the groups, making it possible to contrast the null hypothesis that the means of the groups are equal and establish the discriminant functions of the model (1 and 2) associated with a critical level of significance ($P < 0.05$); (iv) group centroids show the location of the teams in each of the two discriminant functions, making it possible to see if they are located, on average, in the positive or negative scores of the function (the 1st function explains the maximum possible differences among groups, and the second function explains the maximum of the unexplained differences until reaching 100%); (v) the standardised coefficients determine the net contribution of each variable when predicting the group to which the teams belong; (vi) the SCs determine the correlation of the variables with the discriminant functions (1 and 2), those of the 1st function being the ones with the greatest discriminative capacity (the larger the magnitude of the coefficients, the greater the contribution of that variable to the discriminant function, showing the ones that contribute most to discriminating from the value $\geq |0.30|$); (vii) the classification statistics make it possible to assess the predictive capacity of the estimated model [previous or *a priori* probabilities indicate that the same relative importance has been given to all leagues (0.333) regardless of the sample size]; and (viii) the classification results indicate the % of cases correctly classified in relation to the 33% expected in a completely randomised classification. Statistical analyses were performed using IBM SPSS for Windows statistics, version 22.0 (IBM Corp., Armonk, NY, United States).

RESULTS

The distributions of relative frequencies from the studied variables are shown in **Table 1**. The results revealed (i) a goal average per match very similar among leagues (Portugal 2.9, Spain 2.8, and Russia 3.0); (ii) the highest frequency of offensive organisation is positional attack in all the leagues (Portugal 71.5%, Spain 57.4%, and Russia 70.5%); (iii) usually, the home team is the first to score in all the leagues (Portugal 53.3%, Spain 55.6%, and Russia 65.2%); and (iv) the majority of matches were characterised as balanced matches (Portugal 73.3%, Spain 77.8%, and Russia 56.5%).

Results from the crosstabs showed that the first goal scored by the home or away team did not significantly influence the team performance in the different leagues [**Table 2**: *p*-value = 0.520; ES (*V*) = 0.10], nor were significant differences found in the team performance in the different leagues in the case of the match type [**Table 3**: *p*-value = 0.093; ES (*V*) = 0.20].

Additionally, no significant relationship was observed between the winner–nonwinner condition of the teams from the different leagues and the team that scored the first goal of the match {**Table 4**: Portugal [*p*-value = 1.0; ES(*V*) = 0.00]; Spain [*p*-value = 0.060; ES(*V*) = 039]; and Russia [*p*-value = 0.141; ES(*V*) = 0.29]}.

The odds of scoring the first goal of the match were better in the home than in the away teams in all leagues. However, these differences do not make it possible to establish the final condition of the winner or loser, and therefore, no significant relationship was observed between both variables (**Figure 1**).

Secondly, the previous discriminant analysis revealed differences in the attacking game organisation of the Portuguese, Spanish, and Russian teams. The ANOVA revealed that teams from the different leagues differ significantly in four of

TABLE 2 | Dependence relationship between the 1st goal scored and the European leagues.

1st goal scored		Portugal	Spain	Russia	Total
Home team	Count	16	20	30	66
	% within league	53.3%	55.6%	65.2%	58.9%
	Corrected residue	−0.7	−0.5	1.1	–
Away team	Count	14	16	16	46
	% within league	46.7%	44.4%	34.8%	41.1%
	Corrected residue	0.7	0.5	−1.1	–
Total	Count	30	36	46	112
	% within league	100.0%	100.0%	100.0%	100.0%

Chi-square tests and symmetric measurements

χ^2	*df*	Sig	Mef	*V*
1.309	2	0.520	12.32	0.10

**P < 0.05; Sig, significance; df, degrees of freedom; Mef, minimum expected frequency; Cramer's V test, effect size.*

TABLE 3 | Dependence relationship between the match type and the European leagues.

Match type		Portugal	Spain	Russia	Total
Balanced	Count	22	28	26	76
	% within league	73.3%	78.8%	56.5%	67.9%
	Corrected residue	0.8	1.5	−2.1	–
Unbalanced	Count	8	8	20	36
	% within league	26.7%	22.2%	43.5%	32.1%
	Corrected residue	−0.8	−1.5	2.1	–
Total	Count	30	36	46	112
	% within league	100.0%	100.0%	100.0%	100.0%

Chi-square tests and symmetric measurements

χ^2	*df*	Sig	Mef	*V*
4.447	2	0.093	9.64	0.20

**P < 0.05; Sig, significance; df, degrees of freedom; Mef, minimum expected frequency; Cramer's V test, effect size.*

TABLE 4 | Dependence relationship between the winner–nonwinner condition and the 1st goal scored.

Match outcome		1st goal scored		Total
		Home team	Away team	
Winner	Count	33	20	53
	% within 1st goal	50.0%	43.5%	47.3%
	Corrected residue	0.7	−0.7	–
Loser	Count	33	20	53
	% within 1st goal	50.0%	43.5%	47.3%
	Corrected residue	0.7	−0.7	–
Drawer	Count	0	6	6
	% within 1st goal	0.0%	13.0%	5.4%
	Corrected residue	0.0	3.0	–
Total	Count	66	46	112
	% within 1st goal	100.0%	100.0%	100.0%

Chi-square tests and symmetric measurements

Country	χ^2	*df*	Sig	Mef	*V*
Portugal	0.000	1	1.0	7	0.00
Spain	5.625	2	0.060	1.78	0.39
Russia	3.920	2	0.141	0.70	0.29

**P < 0.05; Sig, significance; df, degrees of freedom; Mef, minimum expected frequency; Cramer's V test, effect size.*

TABLE 5 | ANOVA preliminary test with *F* statistics that contrasts the equality of means hypothesis among the groups in each independent variable.

Variables	Wilks' Lambda	*F*	df1	df2	Sig.
Goals	0.997	0.145	2	109	0.865
Shots	0.816	12.324	2	109	0.000*
Positional Attack	0.341	105.266	2	109	0.000*
Counterattack	0.862	8.753	2	109	0.000*
Set Pieces	0.831	11.059	2	109	0.000*
5vs4+Gk	0.981	1.050	2	109	0.353

**p < 0.01. **p < 0.05.*

the selected classification variables: shots, positional attack, counterattack, and set pieces (**Table 5**).

The summary of discriminant functions showed that the first function explained almost 90% of the data variability, while the second function 10.4%. Both functions make it possible to differentiate significantly among the teams of the three leagues. The first function fundamentally differentiates the Spanish teams from the Portuguese and Russian teams. The standardised coefficients showed that the first function discriminates between teams that played with more positional attacks and fewer counterattacks (Russian and Portuguese), and the second function between teams with more set pieces and fewer shots (Russian). The SCs corroborate the high correlation of the positional attack with the first function, and the set pieces and counterattacks with the second function (**Table 6**).

The explanatory capacity of the model indicates that 88.4% of the cases were correctly classified, with the highest percentage of correct classifications for the Spanish league teams, which are not to be confused with the Russian and Portuguese teams, which are more similar to each other (**Figure 2**).

The subsequent discriminant analysis compared the teams from the different leagues, trying to differentiate them by their status as winner, loser, or drawer. The results showed that the 5vs4+GK strategy and the goals are the variables that most contribute to discriminating the teams with respect to the condition of winner–nonwinner (**Table 7**).

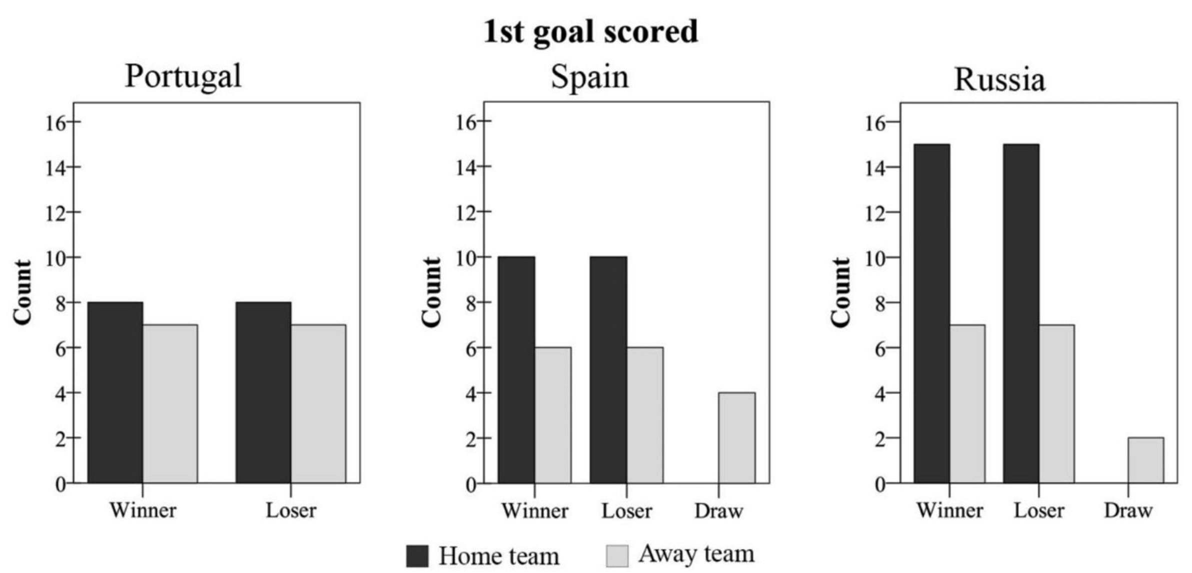

FIGURE 1 | Influence of the first goal scored in the winner–nonwinner condition in the Portuguese **(left)**, Spanish **(middle)**, and Russian **(right)** leagues.

TABLE 6 | Summary of discriminant functions.

Variables	Eigenvalues and *Wilks' Lambda*		Group centroids		Standardised coefficients		SCs	
	Function		Function		Function		Function	
	1	2	1	2	1	2	1	2
Portugal	–	–	0.438	– 1.061	–	–	–	–
Spain	–	–	−2.654	0.269	–	–	–	–
Russia	–	–	1.791	.481	–	–	–	–
Positional Attack	–	–	–	–	1.390	0.627	**0.698***†	0.511
Goals	–	–	–	–	−0.207	0.062	0.026*	0.018
Set Pieces	–	–	–	–	−0.340	1.262	−0.088	**0.634***†
Counterattack	–	–	–	–	−0.608	0.495	−0.129	**0.478***†
Shots	–	–	–	–	−0.271	−1.218	0.231	0.248*
5vs4+Gk	–	–	–	–	0.164	0.479	0.066	0.084*
Eigenvalue	3.733	0.432	–	–	–	–	–	–
% of Variance	89.6%	10.4%	–	–	–	–	–	–
Canonical correlation	0.888	0.549	–	–	–	–	–	–
Wilks' Lambda	0.148	0.698	–	–	–	–		
Chi-Square	201.870	37.867	–	–	–	–	–	–
Df	16	7	–	–	–	–	–	–
Significance	0.000	0.000	–	–	–	–	–	–

†*SC discriminant value* ≥ |*0.30*| . **The highest absolute correlation between each variable and any discriminant function.*

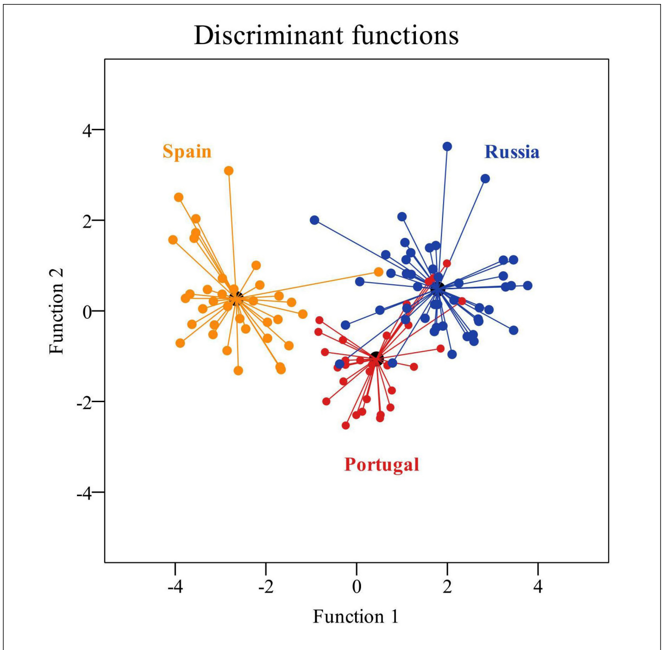

FIGURE 2 | Territorial map of the discriminant functions for the Portuguese, Spanish, and Russian leagues.

TABLE 7 | ANOVA preliminary test with *F* statistics that contrasts the equality of means hypothesis among the groups in each independent variable.

League	Variables	Wilks' Lambda	*F*	df1	df2	Sig.
Portugal	Goals	0.549	22.967	1	28	0.000*
	Shots	0.661	14.345	1	28	0.001*
	Positional attack	0.988	0.350	1	28	0.559
	Counterattack	0.959	1.199	1	28	0.283
	Set Pieces	0.747	9.503	1	28	0.005*
	5vs4+Gk	0.300	65.401	1	28	0.000*
Spain	Goals	0.442	20.791	2	33	0.000*
	Shots	0.898	1.867	2	33	0.171
	Positional attack	0.782	4.608	2	33	0.017**
	Counterattack	0.962	0.644	2	33	0.531
	Set Pieces	0.856	2.774	2	33	0.077
	5vs4+Gk	0.374	27.622	2	33	0.000*
Russia	Goals	0.560	16.926	2	43	0.000*
	Shots	0.964	0.797	2	43	0.457
	Positional attack	0.813	4.959	2	43	0.012**
	Counterattack	0.950	1.136	2	43	0.331
	Set Pieces	0.984	0.343	2	43	0.712
	5vs4+Gk	0.422	29.431	2	43	0.000*

*$p < 0.01$. **$p < 0.05$.

The summary of the discriminant functions (**Table 8**) showed that for Portugal, only the first discriminant function explains 100% of the variability, while Spain and Russia required both discriminant functions. Each and every one of the functions, with the exception of the second Russian discriminating function, shows significant differences between the winning and non-winning teams. In all leagues, the first function classifies winning teams from non-winning teams. The standardised coefficients showed that for Portugal and Spain, the first function essentially discriminates between the teams with

TABLE 8 | Summary of discriminant functions.

League	Variables	Eigenvalues and *Wilks' Lambda*		Group centroids		Standardised coefficients		SCs	
		Function		Function		Function		Function	
		1	2	1	2	1	2	1	2
Portugal	Winner	–	–	1.918	–	–	–	–	–
	Loser	–	–	−1.918	–	–	–	–	–
	Drawer	–	–	–	–	–	–	–	–
	5vs4+Gk	–	–	–	–	−0.617	–	**−0.770**†	–
	Goals	–	–	–	–	0.350	–	**0.456**†	–
	Shots	–	–	–	–	−2.150	–	**0.361**†	–
	Set Pieces	–	–	–	–	0.810	–	0.293	–
	Counterattack	–	–	–	–	0.366	–	0.104	–
	Positional attack	–	–	–	–	0.608	–	0.056	–
	Eigenvalue	3.941	–	–	–	–	–	–	–
	% of Variance	100%	–	–	–	–	–	–	–
	Canonical correlat.	0.893	–	–	–	–	–	–	–
	Wilks' Lambda	0.202	–	–	–	–	–	–	–
	Chi-Square	38.343	–	–	–	–	–	–	–
	Df	8	–	–	–	–	–	–	–
	Significance	0.000	–	–	–	–	–	–	–
Spain	Winner	–	–	2.258	0.283	–	–	–	–
	Loser	–	–	−2.141	0.462	–	–	–	–
	Drawer	–	–	−0.469	−2.980	–	–	–	–
	5vs4+GK	–	–	–	–	−0.439	0.193	**−0.566***†	0.367
	Goals	–	–	–	–	0.816	0.330	**0.504***†	0.225
	Counterattack	–	–	–	–	0.549	0.644	0.086*	−0.056
	Positional attack	–	–	–	–	1.277	−0.545	0.048	**−0.469***†
	Set Pieces	–	–	–	–	1.480	−0.419	−0.037	**−0.364***†
	Shots	–	–	–	–	−3.530	−1.469	0.071	−0.271*
	Eigenvalue	4.720	1.219	–	–	–	–	–	–
	% of Variance	79.5%	20.5%	–	–	–	–	–	–
	Canonical correlat.	0.908	0.741	–	–	–	–	–	–
	Wilks' Lambda	0.79	0.451	–	–	–	–	–	–
	Chi-Square	74.958	23.508	–	–	–	–	–	–
	Df	16	7	–	–	–	–	–	–
	Significance	0.000	0.001	–	–	–	–	–	–
Russia	Winner	–	–	1.619	0.102	–	–	–	–
	Loser	–	–	−1.631	0.086	–	–	–	–
	Drawer	–	–	0.134	−2.062	–	–	–	–
	5vs4+Gk	–	–	–	–	−0.671	0.583	**−0.708***†	0.258
	Goals	–	–	–	–	0.551	−0.036	**0.534***†	−0.270
	Counterattack	–	–	–	–	0.186	0.532	0.139*	0.052
	Positional attack	–	–	–	–	−0.098	−0.150	−0.188	**−0.808***†
	Shots	–	–	–	–	−0.583	−2.378	0.073	**−0.331***†
	Set Pieces	–	–	–	–	−0.076	0.554	0.031	−0.254*
	Eigenvalue	2.703	0.207	–	–	–	–	–	–
	% of Variance	92.9%	7.1%	–	–	–	–	–	–
	Canonical correlat.	0.854	0.414	–	–	–	–	–	–
	Wilks' Lambda	0.224	0.829	–	–	–	–	–	–
	Chi-Square	59.140	7.425	–	–	–	–	–	–
	Df	16	7	–	–	–	–	–	–
	Significance	0.000	0.386	–	–	–	–	–	–

†*SC discriminant value* $\geq |0.30|$ *. *The highest absolute correlation between each variable and any discriminant function.*

most shots and playing more with 5vs4+GK and less with set pieces and positional attack (losers). Similarly, in Russia, the first function discriminates between the teams playing more with 5vs4+GK but less with counterattacks (losers). The SCs showed in all leagues the highest absolute correlation of the 5vs4+GK strategy and goals with the main discriminant function and were also the variables that most contribute to discriminating between winning and non-winning teams. In addition, the Spanish league established the highest correlation of positional attacks and set pieces with the second discriminant function (**Table 8**).

The explanatory capacity of the model indicates that Portugal correctly classifies 100% of cases, Spain 97.2%, and Russia 89.1%. Dispersion diagrams showed that it is easier to differentiate winning from non-winning teams in Spain than in Russia (**Figure 3**).

DISCUSSION

The aim of this study was to identify the performance indicators that best discriminate the best-ranked FIFA professional futsal leagues from three of the best four FIFA-ranking countries (Portugal, Spain, and Russia), as well as the variations that could be found when the condition of the winner, loser, or drawer is established. According to our expectations, despite considering three of the best leagues, it was possible to identify characteristics that culturally define the national trends in futsal of Portuguese, Spanish, and Russian teams. The crosstab results do not establish dependency between the leagues and any of the situational variables. The discriminant analysis results indicated that the Portuguese and Russian teams used more positional attacks and less counterattacks and set pieces in relation to the Spanish teams. However, the same was not observed in the analysis of winners, losers, or drawers among leagues. Generally, the results revealed that the 5vs4+GK strategy and the number of goals obtained were the most powerful match variables for discriminating losing and winning teams in the three leagues.

The analysis of the situational variables did not reveal differences between the three leagues analysed. That is, for the Portuguese, Spanish, and Russian leagues, the home teams revealed a greater frequency in scoring the first goal than the away teams, and balanced matches were recorded more often than unbalanced matches. In fact, the differences observed do not reflect a trend that makes it possible to establish a relationship between first goal, match type, and match outcome for all the leagues considered. However, these results do not agree with previous investigations, where the match location had an influence and the effect of scoring the first goal showed a significant relationship with the victory in the final result of the match in teams from the Spanish futsal league (Sampedro and Prieto, 2012). Further research is required considering teams of different levels and from different moments of game competition (regular phase or play-off).

The results of the discriminant analysis indicated that the Portuguese and Russian teams used more positional attacks and less counterattacks and set pieces than the Spanish teams. The contribution of the so-called organised game or positional attack to the end of the offensive phase in elite futsal matches is well documented (Alvarez et al., 2004; Silva et al., 2004; Soares-Leite, 2012; Ribeiro et al., 2014; Sarmento et al., 2016). The results revealed that positional attack is the type of attack most used by the teams and, together

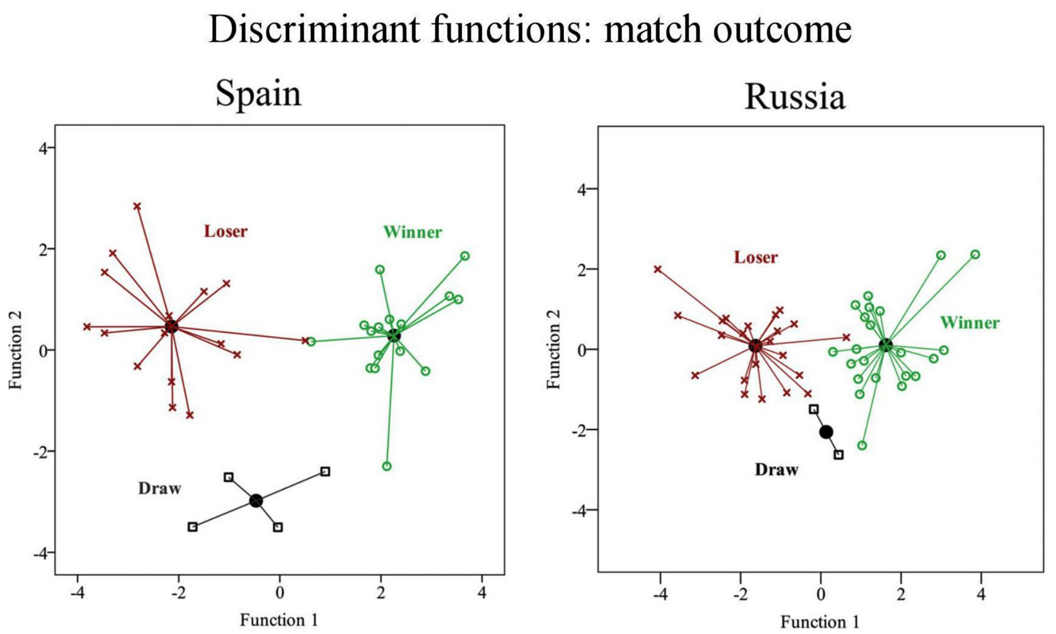

FIGURE 3 | Territorial map of the discriminant functions according to match outcome for the Spanish and Russian leagues.

with counterattack and the set pieces, provides the greatest number of goals (Alvarez et al., 2004; Silva et al., 2004; Soares-Leite, 2012; Ribeiro et al., 2014; Sarmento et al., 2016). Trying to establish similarities with previous results from Travassos et al. (2016), which observe that the Spanish national futsal team had higher variability in the positional attack than the Portuguese national team, our results also seem to reveal that Spanish teams used positional attacks, counterattacks, and set pieces with more variability according to the contextual match dynamics than Portuguese and Russian teams. In agreement, the findings may be suggesting that Spanish teams employ a greater variety of tactical resources, promoting higher adaptability in collective behaviour.

The variations found in the discriminant analysis, when the winning, losing, or drawing condition is established, showed that the 5vs4+GK strategy was the variable that reaches the greatest magnitude and weighting in the SCs to discriminate the losing teams in all the leagues. As was expected, goals scored discriminate winning teams, in accordance with a previous study by Lago-Peñas and Lago-Ballesteros (2011). From the findings observed, the Portuguese, Spanish, and Russian losing teams used the 5vs4+GK strategy much more than the winning teams. It is a conventional strategy used by futsal coaches when losing the game in order to promote numerical superiority, with the aim of recovering the balance on the scoreboard (Travassos et al., 2011). However, usually, this type of strategy cannot help teams to change the match outcome and possibly means finishing the game with more goals received than scored. Recent research reinforces the idea that teams that use the 5vs4+GK do not alter the match outcome with respect to match status. Although it is a risk strategy that can provide superiority and profitability, the likelihood of changing the final match status is scarce, and the teams that were losing and used the 5vs4+GK game strategy lost the game in 93% of cases and received more goals compared to those scored (Méndez, 2017). Thus, according to such results, it cannot be considered an effective strategy for winning matches (Göral, 2018).

Additionally, previous research has considered that the 5vs4+GK game strategy does not make it possible to achieve the same number of goals when compared to the counterattack, positional attack, and set pieces (Silva et al., 2004; Botelho and Coppi, 2010; Marchi et al., 2010; Fukuda and Santana, 2012; Poffo and Lima, 2012; Soares-Leite, 2012). In agreement, other authors found a similar percentage of goals scored and received with the 5vs4+GK strategy (Alvarez et al., 2004; Barbosa, 2011).

In the end, losing teams are well discriminated in all leagues through the use of the 5vs4+GK game strategy. That is, this game strategy was almost always used by the teams that were losing the game and did not allow them to change the final game status. Previous research revealed that this game strategy is more profitable when it is used during the game when the attacking team is winning or drawing than at the end of the game when the attacking team is losing (Méndez, 2017). Thus, coaches should use this information to prepare the training sessions and the use of different game strategies according to variations in task-related and situational game variables (Ganef et al., 2009; Newton-Ribeiro, 2011).

The discriminatory power of the attacking game profiles of teams from elite futsal leagues made it possible to understand that the Spanish teams have a more balanced profile than the Portuguese and Russian teams when facing the end of the offensive phase. This means that Spanish players are better able to adapt to the variability of the competition, allowing them greater heterogeneity not only to take the initiative but also to wait and see what the other team does in attacking situations and take the most suitable action depending on the trend of the game. These results suggest that regarding winning, drawing, and losing, the national futsal teams may be discriminated from one another on the basis of variables such as ball possession and the effectiveness of their attacking play.

The present study has the limitation of only considering games from the play-off of the three elite futsal leagues analysed. Consequently, the characterisation of each futsal league may be biassed due to only considering the best eight ranked teams playing play-off games. Further research should consider the analysis of the entire leagues to improve the comparison. Also, further research should be developed considering other task-related variables and situational variables that help to improve the tactical characterisation of the teams' behaviour. For instance, the aspects that discriminate the teams from the different leagues between winners and non-winners should be expanded to recognise the importance of the match type, so it would be interesting to create subcategories that indicate if that final condition was achieved within a match balanced (up to 2 goals) or unbalanced (above 2 goals difference). It will help to not only to describe but also to explain the main differences obtained (Travassos et al., 2013). In the same way, it would be interesting to note which tactical systems were used in organised attack (1:3:1 or 1:4:0), whether the counterattack was in superiority (1vs0+GK, 2vs1+GK)..., or in numerical equality (1vs1+GK or 2vs2+GK...), which were the set pieces that resulted in more goals or the offensive or defensive spatial–temporal relations that characterise each pattern of play (space covered, distances between players, zones of the court used...).

AUTHOR CONTRIBUTIONS

CM and BT contributed to the conception and design of the study. CM, JS, and BG collected the data and performed the statistical analysis. CM, BT, and JR wrote the manuscript. JS, JR, and BT revised and finalised the manuscript. CM organised the database. All the authors contributed to the manuscript revision and read and approved the submitted version.

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REFERENCES

Alvarez, J., Puente, J., Manero, J., and Manonelles, P. (2004). Análisis de las acciones ofensivas que acaban en gol de la liga profesional de fútbol sala española. *Red Rev. Entrenamiento Deportivo* 18, 27–32.

Amaral, R., and Garganta, J. (2005). A modelação do jogo em futsal: análise sequencial do 1x1 no processo ofensivo. *Rev. Port. Ciênc. Desporto* 5, 298–310. doi: 10.5628/rpcd.05.03.298

Armatas, V., Yiannakos, A., Papadopoulou, S., and Skoufas, D. (2009). Evaluation of goals scored in top ranking soccer matches: greek "super league" 2006–07. *Serbian J. Sports Sci.* 3, 39–43.

Barbosa, A. (2011). Variação tática de goleiro linha não altera o resultado das partidas de futsal na taça são paulo 2009. *RBFF* 3, 101–107.

Botelho, M., and Coppi, A. (2010). Análise dos gols da copa do mundo de futsal FIFA 2008. *RBFF* 2, 33–37.

Castagna, C., D'ottavio, S., Vera, J., and Alvarez, J. (2009). Match demands of professional futsal: a case study. *J. Sci. Med. Sport* 12, 490–494. doi: 10.1016/j.jsams.2008.02.001

Castellano, J., Casamichana, D., and Lago-Peñas, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *J. Hum. Kinet.* 31, 137–147. doi: 10.2478/v10078-012-0015-7

Coelho, P., Migliardi, R., Marciano, R., Mata, B., and Camargo, E. (2013). Análise das finalizações como indicadores de rendimento em jogos de futsal. *Rev. Mackenzie Educação Fís. Esporte* 12, 89–99.

Corrêa, U., Alegre, F., Freudenheim, A., Dos Santos, S., and Tani, G. (2012). The game of futsal as an adaptive process. *Nonlinear Dyn. Psychol. Life Sci.* 16:185.

Csataljay, G., O'donoghue, P., Hughes, M., and Dancs, H. (2009). Performance indicators that distinguish winning and losing teams in basketball. *Int. J. Perform. Anal. Sport* 9, 60–66. doi: 10.1080/24748668.2009.11868464

Dogramaci, S., Watsford, M., and Murphy, A. (2015). Activity profile differences between sub-elite futsal teams. *Int. J. Exerc. Sci.* 8:2.

Eccles, D., Ward, P., and Woodman, T. (2009). Competition-specific preparation and expert performance. *Psychol. Sport Exerc.* 10, 96–107. doi: 10.1016/j.psychsport.2008.01.006

Fukuda, J., and Santana, W. (2012). Análises dos gols em jogos da liga futsal 2011. *RBFF* 4, 62–66.

Ganef, E., Pereira, F., De Almeida, E., and Coppi, A. (2009). Influência do goleiro-linha no resultado do jogo de futsal. *RBFF* 1, 186–192.

Gómez, M., Lago-Peñas, C., and Pollard, R. (2013). "Situational variables," in *The Routledge Handbook of Sports Performance Analysis*, eds T. Mcgarry, P. O'donoghue, and J. Sampaio (London: Routledge International Handbooks), 259–269.

Gómez, M., Lorenzo, A., Sampaio, J., Ibáñez, S., and Ortega, E. (2008). Game-related statistics that discriminated winning and losing teams from the spanish men's professional basketball teams. *Coll. Antropol.* 32, 451–456.

Gómez, M., Moral, J., and Lago-Peñas, C. (2015). Multivariate analysis of ball possessions effectiveness in elite futsal. *J. Sports Sci.* 33, 2173–2181. doi: 10.1080/02640414.2015.1075168

Göral, K. (2018). Analysis of serbia UEFA futsal euro 2016 competitions in terms of some variables. *J. Educ. Train Stud.* 6, 1–6.

Ibáñez, S., García, J., Feu, S., Lorenzo, A., and Sampaio, J. (2009). Effects of consecutive basketball games on the game-related statistics that discriminate winner and losing teams. *J. Sport Sci. Med.* 8:458.

Klecka, W. (1980). *Discriminant Analysis*. Thousand Oaks, CA: Sage.

Lago-Peñas, C., and Lago-Ballesteros, J. (2011). Game location and team quality effects on performance profiles in professional soccer. *J. Sport Sci. Med.* 10:465.

Lago-Peñas, C., Lago-Ballesteros, J., Dellal, A., and Gómez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the spanish soccer league. *J. Sport Sci. Med.* 9:288.

Lago-Peñas, C., Lago-Ballesteros, J., and Rey, E. (2011). Differences in performance indicators between winning and losing teams in the UEFA champions league. *J. Hum. Kinet.* 27, 135–146.

Lapresa, D., Álvarez, L., Arana, J., Garzón, B., and Caballero, V. (2013). Observational analysis of the offensive sequences that ended in a shot by the winning team of the 2010 UEFA futsal championship. *J. Sports Sci.* 31, 1731–1739. doi: 10.1080/02640414.2013.803584

Lima-Duarte, R. (2008). Análise da utilização da posse de bola durante o processo ofensivo no futsal. Contributo para a determinação da eficiência colectiva. *Motricidade* 4, 77–82.

Liu, H., Hopkins, W., and Gómez, M. (2016). Modelling relationships between match events and match outcome in elite football. *Eur. J. Sport Sci.* 16, 516–525. doi: 10.1080/17461391.2015.1042527

Marchi, R., Silva, C., Scramin, L., Teixeira, A., and Chiminazzo, J. (2010). Incidência de gols resultantes de contra-ataques de equipes de futsal. *Conexões* 8, 16–22. doi: 10.20396/conex.v8i3.8637724

McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in sport: scientific issues and challenges. *Int. J. Perf. Anal. Sport* 9, 128–140. doi: 10.1080/24748668.2009.11868469

Méndez, C. (2017). *Análisis de la Eficacia del Portero Jugador en los Momentos Críticos de las Competiciones de Futsal a Través del Software Astrofutsal*®. Doctoral thesis. Facultad de Ciencias de la Actividad Física y el Deporte Universidad Politécnica, Madrid.

Méndez, C., and Méndez, V. (2005). *Astrofutsal*®. Madrid patent application.

Miloski, B., Pinho, J., Gobo, C., Rebouças, P., and Schultz, A. (2014). Quais ações técnico-táticas realizadas durante as partidas de futsal podem discriminar o resultado de vitória ou derrota? *Rev. Bras. Educ Fís. Esporte* 28, 203–209. doi: 10.1590/1807-55092014000200203

Moore, R., Bullough, S., Goldsmith, S., and Edmondson, L. (2014). A systematic review of futsal literature. *Am. J. Sports Sci. Med.* 2, 108–116. doi: 10.12691/ajssm-2-3-8

Morais, E., Ferreira, A., Cunha, S. A., Barros, R. M., Rocha, A., and Goldenstein, S. (2014). A multiple camera methodology for automatic localization and tracking of futsal players. *Pattern Recognit. Lett.* 39, 21–30. doi: 10.1016/j.patrec.2013.09.007

Newton-Ribeiro, F. (2011). A influência do goleiro linha no resultado do jogo de futsal. *RBFF* 3, 187–198.

Niu, Z., Gao, X., and Tian, Q. (2012). Tactic analysis based on real-world ball trajectory in soccer video. *Pattern Recognit.* 45, 1937–1947. doi: 10.1016/j.patcog.2011.10.023

Orta, A., Pino, J., and Moreno, I. (2000). Propuesta de un método de entrenamiento universal para deportes de equipo basándose en el análisis observacional de la competición. *Lect. Educ. Fís. Deportes. Rev. Digit.* 5:27.

Paz-Franco, A., Bores-Cerezal, A., Barcala-Furelos, R., and Mecias-Calvo, M. (2014). Analysis of the conducts of elite futsal goalkeeper in the different situations of the game. *Am. J. Sports Sci. Med.* 2, 71–76. doi: 10.12691/ajssm-2-3-1

Poffo, I., and Lima, E. (2012). Análise dos gols na primeira fase da liga de futsal 2012. *RBFF* 4, 118–123.

Ribeiro, R., Coelho, P., Marciano, R., Mata Fernandes, B., and Camargo Moreira, E. (2014). Análise das finalizações como indicadores de rendimento em jogos de futsal. *Rev. Mackenzie Educação Fís. Esporte* 12:2.

Robinson, G., and O'Donoghue, P. (2007). A weighted kappa statistic for reliability testing in performance analysis of sport. *Int. J. Perf. Anal. Sport* 7, 12–19. doi: 10.1080/24748668.2007.11868383

Sampaio, J., Gonçalves, B., Mateus, N., Shaoliang, Z., and Leite, N. (2018). "Team sports and the modelling of playing processes and tactical behaviour: basketball," in *Modelling and Simulation in Sport and Exercise*, eds A. Baca and J. Perl (Oxon, NY: Routledge), 108–126.

Sampaio, J., Ibáñez, S., Lorenzo, A., and Gómez, M. (2006). Discriminative game-related statistics between basketball starters and nonstarters when related to team quality and game outcome. *Percept. Mot. Skills* 103, 486–494. doi: 10.2466/pms.103.2.486-494

Sampaio, J., and Janeira, M. (2003). Statistical analyses of basketball team performance: understanding teams' wins and losses according to a different index of ball possessions. *Int. J. Perf. Anal. Sport* 3, 40–49. doi: 10.1080/24748668.2003.11868273

Sampedro, J., and Prieto, J. (2012). El efecto de marcar primero y la ventaja de jugar en casa en la liga de fútbol y en la liga de fútbol sala de España. *Rev. de psicología del deporte* 21, 301–308.

Sarmento, H., Bradley, P., Anguera, M., Polido, T., Resende, R., and Campaniço, J. (2016). Quantifying the offensive sequences that result in goals in elite futsal matches. *J. Sports Sci.* 34, 621–629. doi: 10.1080/02640414.2015.1066024

Silva, M., Costa, F., Souza, P., and Greco, P. (2004). Ações ofensivas no futsal: uma comparação entre as situações de jogo organizado, de contra-ataque e de bola parada. *Rev. Port. Ciênc. Desporto* 4, 199–204.

Soares-Leite, W. (2012). Analysis of the offensive process of the portuguese futsal team: a comparison between the actions of finalization. *Pamukkale J. Sport Sci.* 3, 78–89.

Soares-Leite, W. (2013). The impact of the first goal in the final result of the futsal match. *Ann. Appl. Sport Sci.* 1, 1–8.

Soares-Leite, W. (2014). Relação entre o primeiro gol eo resultado final do jogo de futsal na copa do mundo de 2012. *RBFF* 6, 32–36.

Tabachnick, B., and Fidell, L. (2007). *Using Multivariate Statistics*. Boston, MA: Allyn & Bacon.

Tenga, A. (2013). "First goal and home advantage at different levels of play in professional soccer," in *Performance Analysis of Sport IX*, eds D. Peters and P. O'donoghue (London: Routledge), 45–49.

Travassos, B., Araújo, D., Vilar, L., and Mcgarry, T. (2011). Interpersonal coordination and ball dynamics in futsal (indoor football). *Hum. Mov. Sci.* 30, 1245–1259. doi: 10.1016/j.humov.2011.04.003

Travassos, B., Bourbousson, J., Esteves, P., Marcelino, R., Pacheco, M., and Davids, K. (2016). Adaptive behaviours of attacking futsal teams to opposition defensive formations. *Hum. Mov. Sci.* 47, 98–105. doi: 10.1016/j.humov.2016.02.004

Travassos, B., Davids, K., Araujo, D., and Esteves, P. (2013). Performance analysis in team sports: advances from an ecological dynamics approach. *Int. J. Perf. Anal. Sport* 13, 83–95. doi: 10.1080/24748668.2013.11868633

Vicente-Vila, P., and Lago-Peñas, C. (2016). The goalkeeper influence on ball possession effectiveness in futsal. *J. Hum. Kinet.* 51, 217–224. doi: 10.1515/hukin-2015-0185

Viera, A., and Garrett, J. (2005). Understanding interobserver agreement: the kappa statistic. *Fam. Med.* 37, 360–363.

Volker, M. (2006). Reporting effect size estimates in school psychology research. *Psychol. Sch.* 43, 653–672. doi: 10.1002/pits.20176

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REVIEW
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Relationship Between Sport Expertise and Postural Skills

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The review addresses the relationship between sport expertise (i.e., sport competition level), postural performance (amount of motion of the center of mass/of pressure of foot or ability to preserve body balance), and postural strategy (geometric organization of different body segments as well as neurobiological involvement of organism). Since the conditions of postural evaluation are likely to influence results, the aim is to compare athletes at different competition levels in ecological postural conditions (specific postural conditions related to the sport practiced) and non-ecological postural conditions (decontextualized postural conditions in relation to the sport practiced). Evidence suggests that the most successful athletes in terms of sport competition level have the best postural performance both in ecological and non-ecological postural conditions. However, in non-ecological conditions, the postural tasks should be preferentially challenging or relatively close to the sport practice stance. Moreover, the most successful athletes also have more elaborate postural strategies compared with athletes at lower competition level. Mechanistic explanations as well as conceptual models are proposed to explain the role of different factors influencing the relationship between sport expertise and postural performance and strategy.

Keywords: balance, posture, postural control, sport, expertise, postural performance

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INTRODUCTION

An expert athlete can be defined as a specialist in a particular sport who is able to achieve high levels of motor skills related to the sport practiced. His/her expertise requires the expression of physical qualities related to biomechanical (e.g., muscle strength, power, and segmental mobility), bioenergetic (energy supply), and/or bio-informational (information taking, reaction time, and response accuracy) aspects that are skillfully exploited in order to accomplish efficient motor command and control. In fact, his/her motor expression achieves maximal efficiency for minimal effort. The motor expression is based on phases of movement and balance whatever the sport practiced (i.e., any kind of sport technique carried out), however complex it may be. Indeed, a motor activity as basic as walking includes phases of monopedal and bipedal balance as well as phases of movement (swing) at the lower limb level (Bessou et al., 1988).

When movement is described in terms of efficiency or aestheticism in the sports community (by athletes, trainers, and the media), balance is rarely taken into account in the commentary/analysis of performance (Masseglia, 2011). However, movement and balance are intimately linked and inseparable when analyzing performance for most sport activities since no sport technique movement is (efficiently) achievable without an efficient body balance (Paillard, 2017a). Indeed, the slightest segmental movement engenders the displacement of the center of mass (COM), which means that movement potentially generates body imbalance which needs to be restored to avoid falling (Paillard, 2017b). Hence, during the sport practice, movement is continuous which compels the athlete to continually restore his/her balance through compensatory postural adjustments. In expert athletes, postural regulation is even anticipated before the onset of movement by anticipatory postural adjustments (Paillard, 2017a).

Before running, jumping, throwing, or any kind of motor action, each athlete must be able to maintain his/her balance (i.e., maintenance of the vertical projection of his/her center of mass above the base of support) and his/her posture (i.e., position of different body segments) in static condition (the base of support does not deform or move) or dynamic condition (the base of support is deformed and/or displaced) in order to not only resist falling but also to act efficiently (Paillard and Noe, 2015). An expert athlete showing high motor skills (e.g., in terms of accuracy, precision, agility, and velocity) in the expression of his/her motricity necessarily needs high postural skills (i.e., high ability to maintain balance in different postures when stationary or moving in the most economical way possible), particularly in the specific positions related to his/her sport (Asseman et al., 2008). Hence, evidence suggests that the skill level related to movement should be associated to the skill level related to balance in athletes. More precisely, there should be a relationship between sport expertise and postural skills for a given attainment level in a particular sport.

However, even if postural skills are fundamental to the use of motor skills, no proof of a direct relationship (i.e., the greater the sport competition level, the better postural skills; or better athletes also have better postural skills) has been established to date (Paillard, 2014, 2017a). It is not yet established that there is a close relationship between the motor expertise level (often analyzed through the sport competition level, e.g., amateur, local, regional, national, sub-elite, professional, international, and elite) and the postural skill level within the same sport, excluding comparison between different sports since each sport develops specific postural abilities (Paillard, 2014). Although a number of observational studies have analyzed this relationship, the resulting data are still subject to question. Hrysomallis (2011) carried out a significant review dealing with balance ability and athletic performance on the basis of quantitative analysis of postural skills (i.e., displacement of the center of foot of pressure – COP). However, the comparison of postural conditions related, or not related, to the sport practiced, i.e., ecological (specific postural condition) versus non-ecological (decontextualized postural condition) conditions, was not considered, although this seem likely to influence the relationship between the motor expertise level and the postural skills level. Indeed, in ecological condition, such as gymnasts executing handstands or rifle shooters accomplishing shooting while measuring the displacements of their COP, the possible relationship between motor (sport) expertise and postural skills could be strong since the amplitude of body sway (in stationary situations) is a criterion of performance in gymnastics (depending on the evaluation of judges) and the body segmental movements can be transmitted to the rifle barrel at the moment of shooting which are likely to affect performance (accuracy of shot) in rifle shooting. By comparison, in non-ecological or decontextualized postural conditions, such as for instance, bipedal quiet stance, for all kinds of athletes, this relationship between motor expertise and postural skills could be weaker or nonexistent, since there would not necessarily be any interaction between them. Moreover, qualitative data of postural skills could also deepen the knowledge relating to the relationship between the motor expertise level and the postural skills level by analyzing and describing how postural skills are organized in relation to the mechanical (geometric organization of different body segments) and neurophysiological (neurobiological involvement of organism) aspects.

The refinement of the method of analysis of the relationship between sport expertise and postural skills, based on the postural conditions in the sports studied supplemented by qualitative data of postural skills, could improve the analysis of sport performance and the elaboration of sport training. The present work therefore aims to provide an overview of the relationship between sports expertise and postural skills by identifying new mechanistic explanations.

METHODS FOR STUDYING THE RELATIONSHIP BETWEEN MOTOR EXPERTISE AND POSTURAL SKILLS

Postural regulation is considered in the present manuscript as a motor action that involves taking information (sensory functions), processing this information, and command of action (central integration and command) as well as motor execution (motor function). It relies on neurophysiological components (the neural loops involved as well as their sensory receptors), cognitive function relative to body representation in space (cortical regulation), and motor function (muscle command). In this context, posture and balance are regulated on the basis of reference values (position and orientation of the segments that serve as a reference frame for perception and action with respect to the environment) and internal representation of the body (also named body representation in space or postural body scheme) (**Figure 1**). Actions require matching multisensory inputs regulating orientation and stabilization of body segments with anticipated and compensated postural adjustments (postural responses and motor programs) (Massion, 1994). In order to analyze the influence of these different components in the regulation of posture and balance, quantitative and qualitative measures are required.

Quantitative and Qualitative Analyses

In each postural condition, postural skills can be quantified to assess postural performance not only by measuring the movement of the COM, the COP, and body segments but also by measuring electromyographic activities and evaluations of the contribution of different sensory information (i.e., visual, vestibular, proprioceptive, and cutaneous) in the participation of postural regulation. Postural skills can also be considered

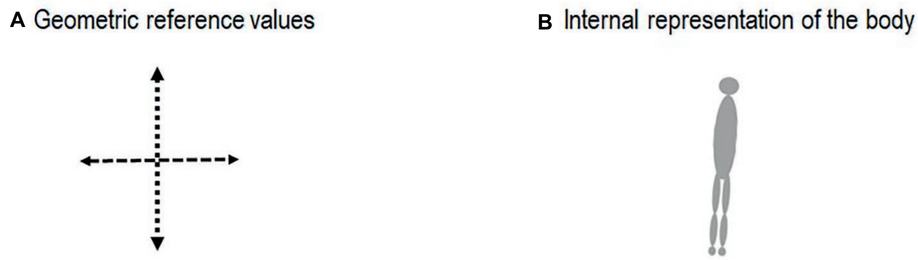

FIGURE 1 | Posture and balance are regulated on the basis of reference values [**(A)**: geometric position and orientation of the segments that serve as a reference frame for perception and action with respect to the environment, i.e., knowledge of the orientation of the body axis and verticality] and internal representation of the body [**(B)**: also named body representation in space or postural body scheme].

qualitatively to assess postural strategy by analyzing and describing how postural balance is organized in relation to the mechanical and neurophysiological aspects (Paillard and Noe, 2015). Postural performance combined with postural strategy is the main component of postural skills.

Postural Performance and Strategy

In static condition, postural performance can be equated to the ability to minimize body sway (i.e., displacements of the COM – or displacements of the whole body – and/or displacements of the COP – or variation of the moment around the ankle) in conventional postural conditions (e.g., bipedal quiet stance). It can also refer to the ability to maintain body balance in challenging postural conditions with small bases of support (e.g., a stance classed as a handstand, monopedal stance) to avoid falling or/and postural imbalance (Paillard and Noe, 2015). In dynamic condition, postural performance can be equated to the ability to maintain body balance in changing postural conditions (e.g., displacement of pedal supports and displacement of the base of support), as well as in external mechanical changes (e.g., fast horizontal accelerations of the ground surface, unexpected percussion, or pushing a large body segment requiring postural reactions) in order to avoid falling (Paillard and Noe, 2015). Postural strategy can be defined on the basis of the spatial and temporal organization of different body segments as well as the extent and order of recruitment of different muscles activated. The different sensory inputs involved in postural regulation as well as the relative importance of different sensory information and/or the preferential involvement of different neuronal loops can also contribute to postural strategy.

Methodological Caution

Movement can be characterized by whole body displacements or body segmental displacements in space. These displacements involve large and small accelerations and decelerations over large and small amplitudes. Body segments can alternate phases of long displacements with phases more or less stationary. During phases of long displacements, postural skills are used particularly in dynamic condition while during stationary phases postural skills are mainly used in static conditions but both phases follow each other continually. Hence, the separate analysis of movement and balance is mechanically very complex. As mentioned above, movement and balance are intimately linked and inseparable when analyzing motor expertise (e.g., performance) for many sports.

Evaluation Conditions

For a given sport, motor expertise could greatly depend on postural skills while postural skills could also depend on motor expertise. Both skills can be reciprocally influenced but it is difficult to determine precisely the influence of each one, particularly in a very mobile sport (constant and long displacements). As part of mobile sports, the analysis of the relationship between motor expertise (e.g., performance) and postural skills cannot be directly quantified since balance and dynamic movement are almost inextricable. Hence, one can only attempt to correlate/associate postural skills with motor skills through separate tests evaluating each of the two skills. In this case, the evaluation of postural skills can only be undertaken in non-ecological conditions, i.e., in a decontextualized environment in relation to the sport practice. However, for a static or low mobility sport activity (no significant displacements), the postural skills and motor expertise can be simultaneously quantified. In this case, the evaluation of postural skills can be made in ecological conditions, i.e., during the sport practice (contextualized environment).

Knowing that each sport develops specific postural skills (Paillard, 2014), the study of the relationship between sport expertise and postural skills should only include young adult athletes (in order to avoid the effects related to age, i.e., development in children and involution in aged subjects) who practice the same sport. Sport experts are elite athletes compared to sub-elite, amateur, or recreational athletes, who are not considered as sport experts but as non-elite athletes.

POSTURAL PERFORMANCE AND SPORT PERFORMANCE

The quantitative analysis of postural skills helps to define the postural performance of athletes while their sport performance is established through their sport competition level. Since postural performance can be studied in ecological and non-ecological postural conditions (specific condition versus non-specific or decontextualized condition) in relation to the considered sport, it is worth studying the relationship between postural performance and sport performance in these two postural conditions.

Ecological Postural Conditions

In ecological conditions, athlete's postural skills are evaluated during their practice of the sport (e.g., rifle shooting, recurve archery) or during the execution of specific motor skills (e.g., handstand posture in gymnasts, juggling in jugglers). With sports such as rifle shooting and recurve archery, one could naturally think that body sway at the moment of shooting would affect its accuracy. Hence, it seems relevant to evaluate the relationship between sport performance and postural performance during shooting. It was observed that the best elite rifle shooters and archers also had the best postural performance (Ball et al., 2003; Musa et al., 2018). By holding their rifles with their arms, rifle shooters create a trunk-head-arms block that must be well interlocked to limit the movements of the rifle and to enable the best possible shooting score (Bermejo et al., 2015). Hence, Ball et al.'s result is not surprising since body sway (evaluated through displacement of COP) is likely to be transmitted to the motion of the gun and aim point and is thus likely to affect shooting performance. The average magnitude of displacement of COP would be smaller before high shooting scores than before low shooting scores (Konttinen et al., 1999). Obviously, shooting accuracy depends on body sway while the ability to keep the gun stable is a sine qua none condition for high shooting performance (Mononen et al., 2007). Indeed, the reduction of body sway alone is not a guarantee for improving shooting performance if it is not (necessarily) associated to minimal movement of the gun barrel (Konttinen et al., 1999). This explains why postural performance would have a limited direct influence on shooting score (in terms of variance of shooting score) but would have a real but indirect influence on shooting score through the ability to hold more stably (Ihalainen et al., 2016, 2018). This principle was corroborated by Ko et al. (2018) who showed that the amount of the COP and pistol motion was lower for skilled pistol shooters than novice shooters. Postural regulation was better coordinated with arm movements to minimize the motion of the pistol in skilled shooters than in novice shooters (Ko et al., 2017).

Moreover, the postural performance level would reflect the sport performance level of rifle shooters since international level rifle shooters were more stable than national level shooters who were more stable than amateur shooters (Era et al., 1996). These authors specified that elite shooters were able to reduce their body sway in the last few seconds just before shooting while amateur shooters kept their body sway pattern during the same time. Moreover, expert shooters limit/control movement in the medio-lateral direction more than shooters without experience (Niinimaa and McAvoy, 1983). In fact, international shooters were able to reduce medio-lateral movements more throughout the test period and antero-posterior movements more during the last few seconds before shooting than national shooters (Ihalainen et al., 2016). COP measurements carried out 1 s prior to arrow release and 0.5 s post-arrow release with elite archery shooters confirmed that reduced postural sway was a predictor of higher scoring shots (Spratford and Campbell, 2017).

Ecological postural tasks performed in dynamic condition (i.e., in movement) such as ball juggling tasks are also of use to study the relationship between motor performance and postural performance using simultaneous measures. Expert jugglers showed better postural performance than intermediate jugglers which corroborated the idea that juggling skills are associated with body sway (Rodrigues et al., 2016). In addition, these authors observed that expert jugglers were less affected by the reduction of the basis of support during juggling tasks than intermediate jugglers. Moreover, the execution of gymnastic tasks by expert and non-expert gymnasts while measuring body sway with force platform can increase our understanding of this subject. The handstand and monopedal stance (but not the bipedal quiet stance) differentiates postural performance between expert gymnasts and non-expert gymnasts (Asseman et al., 2005, 2008; Marcolin et al., 2019). These authors reported that the more the postural tasks are specific and difficult, the more the athletes' postural performance can be related to their competition level. Other works corroborate this principle since dance-like postural tasks have made it possible to discriminate expert dancers from intermediate dancers while this was not possible though static postural tasks (Munzert et al., 2018). Paillard et al. (2011) observed that surfers at national and international competition levels were distinguished from surfers at local competition level when using dynamic postural tasks carried out on an unstable support (very close to the postural condition implied by surfing) but not when using static postural tasks completed on a stable support.

Evidence suggests that in ecological postural condition there is a relationship between postural performance and sport performance.

Non-ecological Postural Conditions

For non-ecological postural tasks such as bipedal quiet stance or any other postural stance decontextualized in relation to the sport considered, the relationship considered was largely studied through a number of sport activities whether mobile or immobile. In an immobile sport activity, without holding a rifle and without specific clothing (i.e., non-ecological condition), elite shooters (competition shooters) had better postural performance than non-elite (military) shooters in visual and nonvisual conditions (Aalto et al., 1990). In mobile sports, there would be also a relationship between sport performance and postural performance in athletes practicing different activities such as soccer, gymnastics, golf, baseball, and stand-up paddle board (Paillard et al., 2006, 2007b, 2011; Paillard and Noe, 2006; Sell et al., 2007; Asseman et al., 2008; Butler et al., 2016; Schram et al., 2016; Jadczak et al., 2018; Pau et al., 2018). However, for a given sport, it is not always possible to distinguish the athletes' postural performance according to their competition levels in the standard postural conditions (e.g., bipedal quiet stance) often used by experimenters (Paillard et al., 2002; Asseman et al., 2004). Similarly, in static and non-specific conditions (i.e., non-ecological conditions), expert judokas and surfers did not exhibit better postural performance than non-expert judokas and surfers (Paillard et al., 2002; Chapman et al., 2008). In fact, postural tasks too simple and easy make it difficult to discriminate between the competition levels of athletes in terms of postural performance.

Nevertheless, in response to unexpected external disturbances, elite female ice hockey players showed shorter recovery period of COM and smaller body sway than non-athletes (Kim et al., 2018). Golfers and runners demonstrated faster onset of trunk muscle activation and higher muscle activation amplitudes in response to sudden trunk loading disturbances when compared to control subjects (Glofcheskie and Brown, 2017). Young soccer players at national level displayed faster and more efficient postural stabilization after a forward jump than young soccer players at regional level (Pau et al., 2018). On the basis of specific and difficult postural tasks, one can wonder whether the relationship between sport performance and postural performance is found in postural disturbance conditions particularly when activating, naturally or artificially, the sensory functions of athletes. As part of vestibular stimulation induced by several and successive body rotations related to dance figures, the COP displacements of elite dancers were smaller than those of amateur dancers and control subjects (Hopper et al., 2014). As part of artificial sensory manipulations at the level of plantar cutaneous (cooling the feet) and myotatic proprioceptive (electrically stimulating the lower limb musculature and blockage of cervical segment) information, professional soccer players who initially exhibited better postural performance (non-manipulated postural condition) than amateur soccer players also showed smaller COP displacements in the manipulated condition (Paillard et al., 2007b). Evidence suggests that whatever the postural condition – i.e., with or without disturbance – the most successful athletes (competition level) also display better postural performance.

Moreover, the conditions of practice of some sports are likely to impact negatively postural performance when they are intensively practiced (i.e., frequent practices). Indeed, at the end of a sports season, skiers competing at a national level showed worse postural performance than skiers competing at a regional level (Noé and Paillard, 2005). On the basis of data mentioned above, this result is contradictory since Noé and Paillard (2005) postulated that this phenomenon occurred because of the effects of wearing ski boots during frequent training sessions. Ski boots of Alpine skiing are rigid and limit/reduce ankle movement, so in the long run the frequent wearing of such ski boots would adversely affect proprioception and postural performance. Since national skiers spent more time at training than regional skiers, this would explain why their postural performance was worse than regional skiers at the end of sport season (Noé and Paillard, 2005).

In non-ecological postural conditions, the relationship between sport performance and postural performance is not systematically observed in athletes and requires caution in the methods of analysis.

Summary

According to the current literature, the ecological postural condition turns out to be more appropriate to investigate the relationship between sport performance and postural performance. In non-ecological postural conditions, this relationship would assuredly be preserved only in two conditions. First, the postural tasks used for the evaluation should be sufficiently specific and difficult in relation to the sport considered, and second, material conditions of sport practice should not affect proprioception.

POSTURAL STRATEGY AND SPORT PERFORMANCE

By describing postural strategy, i.e., how postural regulation is organized in relation to the mechanical and neurophysiological aspects (cf. the sub-section "Postural Performance and Strategy"), it turns out to be possible to compare expert or elite athletes with non-expert or non-elite athletes and to specify the differences between them from a postural view point.

Ecological Postural Conditions

Postural strategy between expert athletes and non-expert athletes can be differentiated through biomechanical and neurophysiological analyses which focus on input of information (sensory functions), processing this information, and commanding action (central integration) as well as motor action (motor function).

Shooting and juggling tasks are well suited to our study framework since it is relatively easy to simultaneously evaluated motor performance and postural performance. Elite shooters gave less importance to visual cues and more importance to proprioceptive and vestibular cues than non-elite shooters (Aalto et al., 1990). In shooting conditions, the vision is devoted only to targeting and does not contribute to control of posture (Aalto et al., 1990). In this case, the reduction of the contribution of visual information in postural regulation is compensated for by greater contributions of proprioceptive and vestibular information (Aalto et al., 1990) which enables elite shooters to dedicate more resources to the main motor task (i.e., shooting) especially for controlling the rifle movement and pressing its trigger (Konttinen et al., 1999). Moreover, expert jugglers were less dependent on foveal vision than intermediate jugglers who moved their gaze around a larger visual area. This suggests that intermediate jugglers were searching spatially for the balls which would be associated with an increase of body sway (Rodrigues et al., 2016).

Konttinen et al. (1999) found that non-elite rifle shooters more actively controlled their posture (cerebral and muscle activities) during shooting than elite rifle shooters. Intermediate jugglers displayed a higher level of attention and prioritized the manipulation task rather than postural regulation, increasing body sway differently from expert jugglers, who were able to deal better with both the manipulation task and postural regulation (Rodrigues et al., 2016). A lower cognitive load for expert jugglers would use their resources less which could explain why they were less affected than intermediate jugglers since their adaptation capacities remained greater (Rodrigues et al., 2016). Moreover, high level biathletes would present better central integration of sensory cues and/or better filtering of erroneous cues than lower level biathletes (Simoneau et al., 1996). According to these authors, higher level biathletes would also detect the discrepancy between the actual posture and the desired posture more quickly while they would demonstrate better motor coordination and motor responses earlier than lower level biathletes.

In ecological postural conditions, on the basis of the data above, elite and non-elite shooters, biathletes, and jugglers would implement different postural strategies to regulate their posture.

Non-ecological Postural Conditions

Biomechanical and neurophysiological analyses also highlighted differences in terms of postural strategies between elite and non-elite athletes in non-ecological postural conditions.

With decontextualized postural tasks in relation to the sports considered (e.g., bipedal stance), biomechanical data obtained with accelerometric measures showed that the number of mobilized body segments decreased as the sport level increased in judokas (Mesure and Crémieux, 1996). Moreover, with greater gymnastic skills, acceleration time series were less variable and more stable (Lamoth et al., 2009). This suggests that the best athletes in terms of sport level could proceed by slight (local) postural adjustments while the other athletes would undertake more global postural strategies as part of pure postural tasks. However, as part of more complex locomotor tasks (e.g., narrow and wide beam-walking) rather than pure postural tasks, Sawers et al. (2015) observed that expert ballet dancers used multiple motor modules for executing a biomechanical function whereas novice dancers executed such functions with a single motor module. Taken together, these results emphasize that the postural adjustment strategy between experts and non-experts could depend on the context of the motor task. Experts would have more flexibility in achieving motor goals thanks to a larger motor repertoire which would be useful under challenging conditions (Sawers et al., 2015). In turn, as part of easy or reflex postural conditions experts could operate through slight postural adjustments. Moreover, postural strategies could be more automatic in expert athletes (Lamoth et al., 2009; Sawers et al., 2015; Michalska et al., 2018) while they would be more actively controlled in non-expert athletes.

Neurophysiological data indicate that gymnast and soccer player experts made better use of vestibular inputs, probably through a better central integration, than gymnast and soccer player non-experts (Bringoux et al., 2000; Paillard et al., 2006). In expert athletes, a greater contribution of vestibular information would reduce the contribution of proprioception especially as part of easy and simple postural tasks. In this case, the proprioceptive function would be saved and would offer supplementary resources for carrying out more challenging postural tasks. Hence, expert athletes would have additional abilities to cope with destabilizing motor tasks (Paillard et al., 2006). By comparison, in non-expert athletes, as part of easy and simple postural tasks, the lower contribution of vestibular information would result in a greater contribution of proprioception which would already be fully exploited. Thus, the contribution of proprioception in postural regulation could not increase as the difficulty of the postural task increased and would not make it possible to cope with particularly challenging and destabilizing postural tasks (Paillard et al., 2006). Evidence suggests that the contribution of vestibular and proprioceptive inputs increases in postural regulation as the competition level is raised. In this context, it would be logical that the contribution of visual cues diminishes.

Indeed, the contribution of visual information is reduced as the sport competition level increased in surfers and soccer players (Paillard et al., 2006, 2011; Paillard and Noé, 2006; Chapman et al., 2008). The lower visual dependence in elite soccer players in comparison with sub-elite soccer players enables elite soccer players to devote their gaze more to processing the information that stems from the game (Paillard and Noé, 2006; Paillard et al., 2006; Zouita Ben Moussa et al., 2012). Sub-elite soccer players being more visually-dependent than elite soccer players would have less resources to devote to the game actions. Indeed, the analysis of movements of the ball and the team partners and opponents is essential in soccer in order to implement cooperative or opposition strategies. For a given soccer player, the time required to take in visual information needed to perform his/her own motor actions (i.e., balance, movement, displacement, control of the ball) reduces the time available for analyzing the game (Paillard and Noé, 2006). For instance, the control of the ball with the feet involves looking down which limits the observation time of the environment.

Moreover, it turns out that the less the visual contribution, the more the proprioception contribution in postural regulation by athletes. This phenomenon is particularly observed as part of the sport expertise (e.g., Paillard and Noé, 2006). Expert surfers shifted sensorimotor dominance from vision to proprioception (Chapman et al., 2008). Postural regulation achieved on the basis of low visual dependence would facilitate the technical expression and motor skills. This would explain why the visual dependence is lower in expert surfers than in non-expert surfers. Expert surfers would divert their visual contribution from postural regulation mainly to processing the relevant information about environmental factors such as height and shape of waves. As observed previously by Asseman et al. (2005) with elite and sub-elite gymnasts, Paillard et al. (2011) indicated that the difference in visual dependence between elite surfers and sub-elite surfers increased as the difficulty of the postural task increased (e.g., bipedal vs. monopedal, stable support vs. unstable support; upright vs. handstand postures).

It is however important to note that certain physical activities such as dancing develop postural and motor strategies which are more visually-dependent (related to the fact that the environment is stable) than most other activities such team sports or sliding sports as mentioned above (Michalska et al., 2018). This is why the contribution of visual information does not decrease as the expertise level is increased in dancers. The suppression of visual cues would penalize expert dancers more than non-expert dancers (Paillard, 2017a). The physical activities practiced in a stable environment and an unmoving space, such as dance sports, remain exceptions since generally in an unstable environment and/or space, the contribution of visual information decreases as the expert level is increased. Overall, sport skill-specific expertise impacts sensory integration for spatial referencing and postural skills (Thalassinos et al., 2018).

Moreover, the expertise level would also influence the motor command of the postural function. Kim et al. (2018) observed that non-athletes displayed more co-activation of the ankle plantar flexors and dorsiflexors while elite female ice hockey players showed low co-activation strategy of agonist and antagonist in ankle and neck extensors. Sawers et al. (2015) also found less muscle co-activation and greater efficiency in muscle output in expert ballet dancers than in novice dancers (no dance or gymnastic training).

In non-ecological postural conditions, the different sensory and motor resources are exploited differently in expert and non-expert athletes for regulating posture.

Summary

Overall, for both ecological and non-ecological postural tasks, expert and non-expert athletes deploy different postural strategies whether for basic or challenging postural tasks.

POSTURAL SKILLS AND INDIVIDUAL NATURAL PREDISPOSITIONS

It is known that motor performance depends on training (quantitative and qualitative aspects) as well as individual natural predispositions (psychological and physiological qualities adapted to the specific aspects of a given sport). While it is also known that training influences postural skills of athletes (Paillard, 2017a), little is known about the influence of individual natural predispositions on postural skills and this deserves to be studied.

If the individual natural predispositions can affect postural skills, they could act on the sensory, central and/or motor components of the postural function. At the sensory level, the proprioception emanating from lower and upper limbs would be more accurate in elite athletes than in sub-elite athletes independent of the amount of training (i.e., the number of years of practice) for different sports such as badminton, soccer, swimming (Han et al., 2015a). According to these authors, this result illustrates that the amount of training would not impact proprioception but individual predispositions would determine its accuracy. Even if caution is due, one can postulate that the amount of training would not be fundamental to the proprioception output.

At the level of the central component of the postural function, Paillard et al. (2006) inferred that elite soccer players had a better knowledge of the orientation of body axis and verticality than sub-elite soccer players (**Figure 2**). This could mean more accurate internal body representation and subjective verticality in elite soccer players than in sub-elite soccer players. In addition, the reaction time (total reaction time and premotor reaction time) to sport-specific visual stimuli was shorter in elite taekwondo practitioners than in sub-elite taekwondo practitioners (Chung and Ng, 2012). Hence, these authors highlighted that the speed of perception would be faster to discriminate relevant cues in motor actions of opponents (especially sport-specific postures) in the elites taekwondo practitioners than in sub-elite practitioners.

FIGURE 2 | Comparison of abilities to regulate posture and balance between sportive non-experts and sportive experts. Experts would have a better knowledge of the orientation of the body axis and verticality as well as a more accuracy internal body representation than non-experts.

At the level of motor output of the postural function, Barbado et al. (2016) reported higher trunk extensor muscle strength in elite judokas than in sub-elite judokas. On the basis of postural data, Paillard and Noé (2006) concluded that the tone of the posterior leg muscles would be greater in elite soccer players than in sub-elite soccer players. Moreover, the neuromuscular excitability threshold of the quadriceps muscles was lower in the elite taekwondo practitioners than in sub-elite taekwondo practitioners (Chung and Ng, 2012). As it is accepted that the higher the muscle excitability, the better the muscle contractility, these authors stated that the motor output of the postural function would be naturally better in elite taekwondo practitioners than in sub-elite taekwondo practitioners.

On the basis of the data above, it can be assumed that individual predispositions influence postural skills. Hence, one can wonder whether the individual postural potential can be improved thanks to sport training.

INDIVIDUAL POSTURAL TRAINABILITY

The athlete's potential to increase his/her postural skills following training can be defined by the term "postural trainability". The postural skills can initially (naturally) be low or high in athletes but with increased experience whatever their initial level (low or high), some athletes continue to progress while others stagnate. Hence, the postural trainability differs between athletes. On the basis of these practical observations that emanate from coaches (unpublished data) regardless of the initial natural predispositions, the individual trainability is more or less great and it is difficult to identify the subjects who can make great progress and those who cannot. According to current knowledge, whether for trainers (coaches) or scientists, individual trainability is difficult to estimate prospectively (predict) for a sports career. Future research works should explore individual postural trainability on the basis of interventional studies since the current literature is relatively devoid of useful data likely to advance the training and selection plans of young athletes.

TRANSFER BETWEEN POSTURAL SKILLS AND MOTOR SKILLS

Another problem that presents itself to trainers is that the influence of postural skills on sport performance is currently still unknown. One can observe that the most successful athletes (in relation to the competition level) have the best postural skills but one does not know if those with the best postural skills are always the most successful athletes. Although there are relationships between postural skills and technical skills (dribbles, passes, shots) as well as running speeds (including accelerating, stopping) in small-sided soccer games (Edis et al., 2016, 2017), currently, the transfer of postural skills toward motor skills remains to be explored through sport training. As far as is known, there is no evidence that improvement in postural skills would enhance motor skills.

In turn, particular training leads to specific postural regulation induced by the acquisition of specific new motor skills due to the practice of the specific movements (Paillard et al., 2007a). This would support the idea that each learned new technique is associated with new postural adaptation/skills. However, if a transfer of motor skills toward postural skills occurs, it would be limited to very close movements in terms of posture/position compared to those practiced in training and competition (Paillard et al., 2017a). If it is not a skills transfer, the acquisition of new postural skills would be integrated into new motor skills which would mean that motor skills and postural skills are indissociable.

The state of the current literature suggests that studies should be undertaken in order to unravel the possible reciprocal influences between postural skills and motor (sport) skills. These works could also show that there is not any dependence between these two skills which would be surprising from a theoretical point of view, on the basis of current knowledges.

CONCLUSION

Evidence suggests that the most successful athletes in term of sport competition level have the best postural performance both in ecological and non-ecological postural conditions. However, in non-ecological condition, postural tasks should be preferentially challenging or relatively close to the sport practice stance. The relationship between sport performance and postural performance is not systematic when the postural conditions are remote from those of the sport practice. Moreover, the most successful athletes also have more elaborate postural strategies compared with athletes at lower competition levels. Sports experts would also show better natural postural predispositions than sports non-experts. Currently, it is known that motor skills could greatly depend on postural skills while postural skills could also depend on motor skills. Both skills influence each other but it is difficult to determine precisely the influence of one over the other either for ecological and non-ecological postural tasks, even if the current assumption is that the influence of motor skills toward postural skills would probably be stronger than the reverse influence. Future studies should unravel the concepts involved thus enabling sports trainers (coaches) to improve their intervention and to refine their training programs for athletes as well as enabling physicians to enhance their preventive and therapeutic strategies.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

REFERENCES

Aalto, H., Pyykkö, I., Ilmarinen, R., Kähkönen, E., and Starck, J. (1990). Postural stability in shooters. *ORL J. Otorhinolaryngol Relat. Spec.* 52, 232–238.

Asseman, F., Caron, O., and Crémieux, J. (2004). Is there a transfer of postural ability from specific to unspecific postures in elite gymnasts? *Neurosci. Lett.* 358, 83–86.

Asseman, F., Caron, O., and Crémieux, J. (2005). Effects of the removal of vision on body sway during different postures in elite gymnasts. *Int. J. Sports Med.* 26, 116–119.

Asseman, F. B., Caron, O., and Crémieux, J. (2008). Are there specific conditions for which expertise in gymnastics could have an effect on postural control and performance? *Gait Posture* 27, 76–81.

Ball, K. A., Best, R. J., and Wrigley, T. V. (2003). Body sway, aim point fluctuation and performance in rifle shooters: inter- and intra-individual analysis. *J. Sports Sci.* 21, 559–566.

Barbado, D., Lopez-Valenciano, A., Juan-Recio, C., Montero-Carretero, C., van Dieën, J. H., and Vera-Garcia, F. J. (2016). Trunk stability, trunk strength and sport performance level in judo. *PLoS One* 11:e0156267. doi: 10.1371/journal.pone.0156267

Bermejo, J. L., García-Massó, X., Gomis, M., Noé, F., Huertas, F., Pablos, C., et al. (2015). The difficulty of postural tasks amplifies the effects of fatigue on postural stability. *Eur. J. Appl. Physiol.* 115, 489–495.

Bessou, P., Dupui, P., Montoya, R., and Pagès, B. (1988). Simultaneous recording of longitudinal displacements of both feet during human walking. *J. Physiol.* 83, 102–110.

Bringoux, L., Marin, L., Nougier, V., Barraud, P. A., and Raphel, C. (2000). Effects of gymnastics expertise on the perception of body orientation in the pitch dimension. *J. Vestib. Res.* 10, 251–258.

Butler, R. J., Bullock, G., Arnold, T., Plisky, P., and Queen, R. (2016). Competition-level differences on the lower quarter Y-balance test in baseball players. *J. Athl. Train.* 51, 997–1002.

Chapman, D. W., Needham, K. J., Allison, G., Lay, B., and Edwards, D. J. (2008). Effects of experience within a dynamic environment on postural control. *Br. J. Sports Med.* 42, 16–21.

Chung, P., and Ng, G. (2012). Taekwondo training improves the neuromotor excitability and reaction of large and small muscles. *Phys. Ther. Sport* 13, 163–169.

Edis, Ç., Vural, F., and Vurgun, H. (2016). The importance of postural control in relation to technical abilities in small-sided soccer games. *J. Hum. Kinet.* 53, 51–61.

Edis, C., Vural, F., and Vurgun, H. (2017). Does running performance in small-sided games have a relation with postural control in youth soccer players. *Turk. J. Sport Exerc.* 19, 83–91.

Era, P., Konttinen, N., Mehto, P., Saarela, P., and Lyytinen, H. (1996). Postural stability and skilled performance – a study on top-level and naive rifle shooters. *J. Biomech.* 29, 301–306.

Glofcheskie, G. O., and Brown, S. H. (2017). Athletic background is related to superior trunk proprioceptive ability, postural control, and neuromuscular responses to sudden perturbations. *Hum. Mov. Sci.* 52, 74–83.

Han, J., Waddington, G., Anson, J., and Adams, R. (2015a). Level of competitive success achieved by elite athletes and multi-joint proprioceptive ability. *J. Sci. Med. Sport* 18, 77–81. doi: 10.1016/j.jsams.2013.11.013

Hopper, D. M., Grisbrook, T. L., Newnham, P. J., and Edwards, D. J. (2014). The effects of vestibular stimulation and fatigue on postural control in classical ballet dancers. *J. Dance Med. Sci.* 18, 67–73.

Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports Med.* 41, 221–232.

Ihalainen, S., Kuitunen, S., Mononen, K., and Linnamo, V. (2016). Determinants of elite-level air rifle shooting performance. *Scand. J. Med. Sci. Sports* 26, 266–274.

Ihalainen, S., Laaksonen, M. S., Kuitunen, S., Leppävuori, A., Mikkola, J., Lindinger, S. J., et al. (2018). Technical determinants of biathlon standing shooting performance before and after race simulation. *Scand. J. Med. Sci. Sports* 28, 1700–1707.

Jadczak, L., Grygorowicz, M., Dzudziński, W., and Śliwowski, R. (2018). Comparison of static and dynamic balance at different levels of sport competition in professional and junior elite soccer players. *J. Strength Cond. Res.* doi: 10.1519/JSC.0000000000002476 [Epub ahead of print].

Kim, M., Kim, Y., Kim, H., and Yoon, B. (2018). Specific muscle synergies in national elite female ice hockey players in response to unexpected external perturbation. *J. Sports Sci.* 36, 319–325. doi: 10.1080/02640414.2017.1306090

Ko, J. H., Han, D. W., and Newell, K. M. (2017). Skill level constrains the coordination of posture and upper-limb movement in a pistol-aiming task. *Hum. Mov. Sci.* 55, 255–263.

Ko, J. H., Han, D. W., and Newell, K. M. (2018). Skill level changes the coordination and variability of standing posture and movement in a pistol-aiming task. *J. Sports Sci.* 36, 809–816. doi: 10.1080/02640414.2017.1343490

Konttinen, N., Lyytinen, H., and Era, P. (1999). Brain slow potentials and postural sway behavior during sharpshooting performance. *J. Mot. Behav.* 31, 11–20.

Lamoth, C. J., van Lummel, R. C., and Beek, P. J. (2009). Athletic skill level is reflected in body sway: a test case for accelometry in combination with stochastic dynamics. *Gait Posture* 29, 546–551.

Marcolin, G., Rizzato, A., Zuanon, J., Bosco, G., and Paoli, A. (2019). Expertise level influences postural balance control in young gymnasts. *J. Sports Med. Phys. Fitness.* 59, 593–599. doi: 10.23736/S0022-4707.18.08014-3

Masseglia, D. (2011). "Technologie et performance sportive" *La chimie et le sport* eds. M.-T. Dinh-Audouin, R. A. Jacquesy, D. Olivier, and P. Frankish (Les Ulis, France: EDP Sciences), 99–110.

Massion, J. (1994). Postural control system. *Curr. Opin. Neurobiol.* 4, 877–887.

Mesure, S., and Crémieux, J. (1996). "L'entraînement de judo se traduit-il par l'utilisation de nouvelles stratégies sensori-motrices dans le contrôle postural?" in *Arts martiaux et sports de combats*. eds. Y. Kerlirzin, and G. Fouquet (Paris: Cahiers de l'INSEP 12-13), 77–83.

Michalska, J., Kamieniarz, A., Fredyk, A., Bacik, B., Juras, G., and Słomka, K. J. (2018). Effect of expertise in ballet dance on static and functional balance. *Gait Posture* 64, 68–74.

Mononen, K., Konttinen, N., Viitasalo, J., and Era, P. (2007). Relationship between postural balance, rifle stability and shooting accuracy among novice rifle shooters. *Scand. J. Med. Sci. Sports* 17, 180–185.

Munzert, J., Müller, J., Joch, M., and Reiser, M. (2018). Specificity of postural control: comparing expert and intermediate dancers. *J. Mot. Behav.* 23, 1–13. doi: 10.1080/00222895.2018.1468310 [Epub ahead of print].

Musa, R. M., Abdulla, M. R., Juahir, H., Maliki, A. B. H. M., Mat-Rasid, S. M., Kosni, N. A., et al. (2018). A multidimensional analysis of physiological and mechanical variables among archers of different levels of expertise. *J. Fund. Appl. Sci.* 10, 18–32. doi: 10.4314/jfas.v10i1s.2

Niinimaa, V., and McAvoy, T. (1983). Influence of exercise on body sway in the standing rifle shooting position. *Can. J. Appl. Sport Sci.* 8, 30–33.

Noé, F., and Paillard, T. (2005). Is postural control affected by expertise in alpine skiing? *Br. J. Sports Med.* 39, 835–837.

Paillard, T. (2014). Sport-specific balance develops specific postural skills. *Sports Med.* 44, 1019–1020.

Paillard, T. (2017a). Plasticity of the postural function to sport and/or motor experience. *Neurosci. Biobehav. Rev.* 72, 129–152. doi: 10.1016/j.neubiorev.2016.11.015

Paillard, T. (2017b). Relationship between muscle function, muscle typology and postural performance according to different postural conditions in young and older adults. *Front. Physiol.* 8:585. doi: 10.3389/fphys.2017.00585. eCollection 2017

Paillard, T., Bizid, R., and Dupui, P. (2007b). Do sensorial manipulations affect subjects differently depending on their postural abilities? *Br. J. Sports Med.* 41, 435–438. doi: 10.1136/bjsm.2006.032904

Paillard, T., Costes-Salon, C., Lafont, C., and Dupui, P. (2002). Are there differences in postural regulation according to the level of competition in judoists? *Br. J. Sports Med.* 36, 304–305.

Paillard, T., Margnes, E., Portet, M., and Breucq, A. (2011). Postural ability reflects the athletic skill level of surfers. *Eur. J. Appl. Physiol.* 111, 1619–1623.

Paillard, T., Montoya, R., and Dupui, P. (2007a). Postural adaptations specific to preferred throwing techniques practiced by competition-level judoists. *J. Electromyogr. Kinesiol.* 17, 241–244. doi: 10.1016/j.jelekin.2006.01.006

Paillard, T., and Noé, F. (2006). Effect of expertise and visual contribution on postural control in soccer. *Scand. J. Med. Sci. Sports* 16, 345–348.

Paillard, T., and Noe, F. (2015). Techniques and methods for testing the postural function in healthy and pathological subjects. *Biomed. Res. Int.* 2015:891390. doi: 10.1155/2015/891390

Paillard, T., Noé, F., Rivière, T., Marion, V., Montoya, R., and Dupui, P. (2006). Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *J. Athl. Train.* 41, 172–176.

Pau, M., Porta, M., Arippa, F., Pilloni, G., Sorrentino, M., Carta, M., et al. (2018). Dynamic postural stability, is associated with competitive level, in youth league soccer players. *Phys. Ther. Sports* 35, 36–41. doi: 10.1016/j.ptsp.2018.11.002

Rodrigues, S. T., Polastri, P. F., Gotardi, G. C., Aguiar, S. A., Mesaros, M. R., Pestana, M. B., et al. (2016). Postural control during cascade ball juggling: effects of expertise and base of support. *Percept. Mot. Skills* 123, 279–294.

Sawers, A., Allen, J. L., and Ting, L. H. (2015). Long-term training modifies the modular structure and organization of walking balance control. *J. Neurophysiol.* 114, 3359–3373.

Schram, B., Hing, W., and Climstein, M. (2016). Profiling the sport of stand-up paddle boarding. *J. Sports Sci.* 34, 937–944. doi: 10.1080/02640414.2015.1079331

Sell, T. C., Tsai, Y. S., Smoliga, J. M., Myers, J. B., and Lephart, S. M. (2007). Strength, flexibility, and balance characteristics of highly proficient golfers. *J. Strength Cond. Res.* 21, 1166–1171.

Simoneau, M., Bard, C., Fleury, M., Teasdale, N., and Boulay, M. R. (1996). Les effets de l'activation métabolique sur la stabilité posturale et la précision de tir chez les biathlètes de niveau élite et intermédiaires. *Sci. Mot.* 29, 22–29.

Spratford, W., and Campbell, R. (2017). Postural stability, clicker reaction time and bow draw force predict performance in elite recurve archery. *Eur. J. Sport Sci.* 17, 539–545.

Thalassinos, M., Fotiadis, G., Arabatzi, F., Isableu, B., and Hatzitaki, V. (2018). Sport skill-specific expertise biases sensory integration for spatial referencing and postural control. *J. Mot. Behav.* 50, 426–435. doi: 10.1080/00222895.2017.1363704

Zouita Ben Moussa, A., Zouita, S., Dziri, C., and Ben Salah, F. Z. (2012). Postural control in Tunisian soccer players. *Sci. Sports* 27, 54–56.

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Comparing the Pathway to Success in European Countries Competing in the Swimming World Championships

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Purpose: This study aimed to compare the performance progression model of the European countries that participated in the World Championships (WCs) from 2006 to 2017. Data from all championships were compared between the top five (1–5) and the next five (6–10) countries on the medal table. The study also identifies the ages of peak performance in senior swimmers, the annual ratio of progression and the effect of junior performance on senior success by these groups of countries. We hypothesized that: (1) countries with swimmers achieving better performances at the Junior WCs would also be higher in the medal ranking at the Senior WCs and (2) a higher annual performance progression in their swimmers increases the chances of countries being ranked in the top 5 at the Senior World Championships.

Methods: Participant's data from all Junior and Senior WCs between 2006 and 2017 were obtained from FINA. The final, filtered database included 629 swimmers after removing those participating only in the Junior WCs and selecting swimmers from the top 10 countries. One-way ANOVA, F test, and decision tree methods were used to examine differences between the top (1–5) and the next best (6–10) countries on the medal table for first participation age, annual progress, and best-time in junior and senior championships.

Results: There was no difference ($p = 0.492$ and $p = 0.97$) between 1–5 and 6–10 ranked countries for best senior time and annual progression, respectively. Countries ranked in the top 5 at the Senior WCs had swimmers with faster times at the Junior WCs ($p > 0.001$). Decision tree analysis found that best-time at the Junior WC had the greatest explanatory capacity (94%).

Conclusion: European countries with swimmers who perform best at the Junior WCs are also likely to be in the top 5 countries that win medals at the Senior WCs.

Keywords: talent, swimming, progression model, youth, junior

INTRODUCTION

The short (25 m pool) and long course (50 m pool) swimming World Championships (Cs) are run by FINA. Since 2001, the long course Championships have been held every 2 years in the odd years, while the long course after the Summer Olympics every 4 years. Since 2006, European (as a whole), American, and Australian swimmers are regularly the top nations ranked by number of medals won. Although the USA and Australia have been studied in a number of investigations (Trewin et al., 2004; Allen et al., 2014), little is known about the performances of the European countries. As nationality seems to play a key role in achieving the top positions at the WCs, a more detailed analysis of the performance of European countries is warranted.

Due to the increasing competition between nations for medals at major international events such as the World Championships and Olympic Games (Bosscher et al., 2006), many national sporting organizations have invested their available resources more effectively by identifying talented athletes well in advance (Vaeyens et al., 2009; Allen et al., 2015). Talent identification programs aim to identify athletes with high potential for success in senior elite sport (Allen et al., 2014). As a result, the best young athletes are routinely selected into talent development programs (Boccia et al., 2017) based primarily on their age-related competition performance (Lloyd et al., 2015). The concept of developing talent in youth is the goal of many coaches and sports systems. Developing talent at youth level to improve senior performance is the goal of many coaches and sporting organizations. Consequently, an increasing number of national governing bodies have adopted long-term development models in an attempt to provide a structured approach to the training of youth athletes (Svendsen et al., 2018).

Well-designed training plans can enhance performance by improving physiological parameters and enhancing technique (Morais et al., 2014). Details of these plans and their effects on performance are scarce. Many different factors contribute to performance in swimming (Morais et al., 2014) and other sports (Morais et al., 2017), although very little is known about their relative contribution, their progression as athletes develop and the interaction of these factors.

Longitudinal performance assessment is important to help coaches to define realistic goals and monitor training methods (Pyne et al., 2004). One way to achieve this is by tracking the swimmers' performance for a given period of time and analyzing the progression between competitions and seasons. This information can be used to: (1) describe and estimate the progression and the variability of performance during and between seasons; (2) estimate chronological points that predict swimmer's performances throughout their career or a given time frame; and (3) determine a swimmer's probability to reach finals or win medals in important competitions (Costa et al., 2010).

If early sporting success is a pre-requisite for senior elite success (Neeru et al., 2013; Green, 2015), it is clear that maximizing sporting talent is an important goal of long-term development models. Some studies have described athlete development as an ascending scale and depicted improvements using a pyramid or linear model (Barreiros et al., 2014; Green, 2015). However, this assumption appears contentious given the low conversion rates of junior to senior athletes when focusing on specific groups (Durand-Bush and Salmela, 2002; Barreiros et al., 2014).

Consequently, the lack of studies that have focused on the general paths to success followed by international elite swimmers suggests there is a need to track the improvement and development of junior elite athletes. Performance models that provide useful information and minimize the drop out from junior to senior swimming would be extremely valuable (Costa et al., 2011; Allen et al., 2014). In addition, such predictive models can ensure that elite youth athletes are provided with a strategic plan to develop their maximal potential, thereby maximizing participation rates between junior and senior ages and improve long-term sports performance.

No studies have investigated trends in participation, age, and performance in European swimmers at the swimming WCs. In addition, the differences between the more successful and less successful teams have not been studied. The aim of the present study therefore was to compare the general performance progression model of the European countries that participate in the World Championships (WCs) from 2006 to 2017. Data compare the five best (1–5) and the next five best (6–10) European countries from a general medal ranking created with data from all the years analyzed. In addition, we identify the ages of peak performance in senior swimmers, the annual ratio of progression, and the effect of junior performance on senior success in these two groups of European countries.

MATERIALS AND METHODS

Subjects and Design

Authors have no conflicts of interest to disclose. The Castilla-La Mancha University Ethical Committee approved this research dated November 30th 2016. This retrospective study was conducted with public data, and hence no informed consent was obtained. Results and birth dates were obtained from http://www.fina.org/ and http://www.omegatiming.com/ and processed by the authors. All historical data were retrieved from official results websites for the 2007, 2009, 2011, 2013, 2015, and 2017 Senior WCs and 2006, 2008, 2011, 2013, 2015, and 2017 Junior WCs. The age of the swimmers participating in Junior WCs must be between 14–17 and 15–18 years for women and men, respectively.

The final, filtered database (628 swimmers) included swimmers who swam in the Senior WCs (C3) and both Junior and Senior WCs (C1). The analysis was accomplished from top to bottom, trying to analyze where the swimmers who participate in the Absolute World Championship come from.

Mean ± standard deviations were identified by swim strokes, distances, and gender for a more appropriate standardization of the times. Each entry contains the full name, race time, position, age, country, gender, distance, swimming stroke, and year of competition. The distances analyzed were 50, 100, 200, 400, 800, and 1,500 m freestyle; 50, 100, and 200 m backstroke/breaststroke/butterfly, and 200 and 400 m individual medleys.

Procedure

The times have been standardized by means of Ztime scores in order to compare swimmers' times without influencing the variables gender, swim stroke, and distance. The, Ztime score was created by using the annual best performance of each swimmer.

$$Z_{ij} = \frac{X_{ij} - \overline{X}_i}{\sigma_i}$$

where j = individual i = group by gender, swim stroke, and distance.

The following variables have been defined within the model: the top five countries (1) European countries that have had the best results in medal rankings at the WCs (1–5: France, Italy, United Kingdom, Russia, and Sweden); and the next five (0) in the medal rankings (6–10: Hungary, Netherlands, Germany, Denmark, and Poland).

The criteria followed to subdivide the countries between the five best and 6th to 10th has been to develop a general ranking medal with the whole amount of European countries participating in the World Championships. For this purpose, we searched on internet the information about the ranking medal for each World Championship, and a general ranking was created integrating all this information. A total of 10 European countries had participated in all the World Championships analyzed in this study. Therefore, noticing the differences between the positions obtained by the five best and 6th to 10th countries, authors decided to subdivide the countries in that way.

The following variables were analyzed for statistical significance: (1) best-time Senior or peak performance at Senior level (BS): best-standardized performance in its senior stage; (2) minimum age (MA): age in years in which swimmers made their first World Championship; (3) best-time Junior (BJ): the best-standardized performance at the Junior competition; and (4) progress (P): an annual average of the interannual variations of standardized performances. As swimmers can participate in many events in a championship, the z scores of each of their performances were calculated and their minimum scores identified at Junior and Senior level. Both scores were then subtracted and divided by the number of championships.

Statistical Analysis

Mean ± standard deviation was used to characterize swimmers from both groups (1–5 vs. 6–10 countries). Graphical and analytical descriptive statistical measures were used to identify differences between groups of countries in BS, BJ, and P. One-way ANOVA and F test were used to determine the differences and relationships between performances at the Junior and Senior WCs.

Non-parametric tests were also used to estimate the previous patterns with a classification methodology based on decision trees which enabled the identification of the significant aspects in order to achieve the best performances at the swimming WCs. The total sample was divided into a learning sample that was used to estimate both models and a test sample that allowed the estimated models to be validated. All analyses were performed with the software R.

RESULTS

Descriptive average values between the top five (1–5) and the next five (6–10) countries are shown in **Table 1**.

TABLE 1 | Descriptive average values between top and non-top countries.

	N = 628	
	Top countries	**Non-top countries**
% Swimmers	40.13	59.87
% Males	46.28	53.72
% Females	45.24	54.76
Mean age of best performance in senior	22.70 ± 3.50	22.15 ± 3.70
MA	21.11 ± 3.72	20.83 ± 3.81

"MA" minimum age: age in years in which swimmers involved in this study competed their first world championship competition.

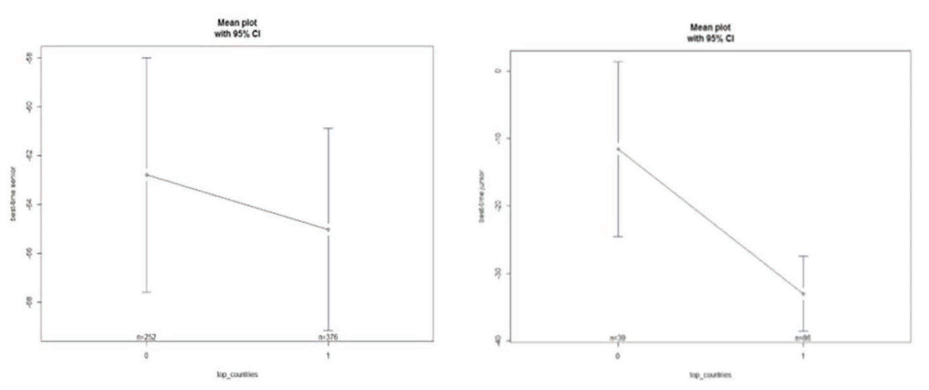

FIGURE 1 | Differences between top and non-top countries in best-time senior and best-time junior.

No significant differences were found ($p = 0.492$) between the 1–5 and 6–10 countries (**Figure 1**).

As best time at senior level (BS) was not a discriminant factor in achieving 1–5 country status, further analyses were carried out to answer the hypothesis of the study.

We accept hypothesis (1) countries with swimmers achieving better performances at the Junior WCs would also be higher in the medal ranking at the Senior WCs as BJ was significantly higher in 1–5 vs. 6–10 countries ($p < 0.001$; $F = 12.86$, **Figure 1**).

Despite this, we reject hypothesis (2) a higher annual performance progression in their swimmers increases the chances of countries being ranked in the top 5 at the Senior World Championships as no differences ($p = 0.97$; $F = 0.001$) were found (**Figure 2**).

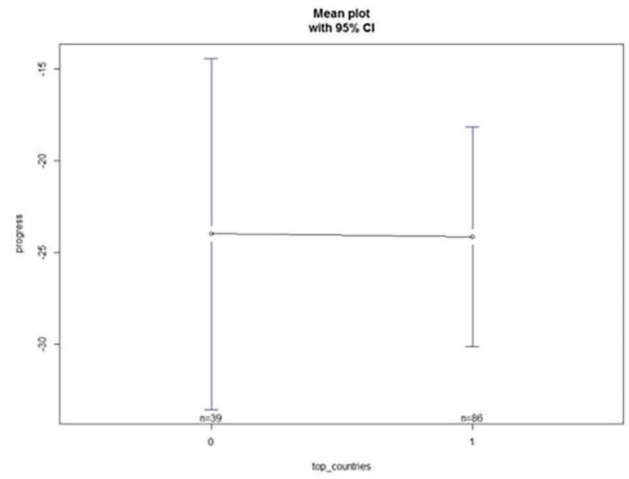

FIGURE 2 | Differences between top and non-top countries in annual progression performance.

The deviation analysis carried out by the decision tree model found that BJ had the greatest explanatory capacity (94%). In addition, both P and MA (3%) carry much less importance.

Therefore, the first relevant classification variable according to the estimated tree is BJ. If the score is below −0.025, there is a high probability (63%) of becoming one of the top (1–5) countries (**Figure 3**).

The confusion matrix, validation sample, and accuracy of the conditional inference tree are shown in **Table 2**.

DISCUSSION

The main objective of the study was to compare the performance progression model of the top 10 European countries that participate in all World Championships (WCs) from 2006 to 2017. The swimmers' performance in Junior WCs was significantly better in European countries ranked 1–5 than those ranked between 6 and 10 in the Senior WCs.

Previous studies have also suggested that Senior competitive level prediction increases markedly from the age of 16 (Costa et al., 2011; Neeru et al., 2013; Green, 2015). Svendsen et al. (2018) found that race performance at Junior level was found to be a strong predictor of subsequent success in senior elite cyclists. In swimming, Yustres et al. (2017) showed that 45.0%

TABLE 2 | Confusion matrix with the validation sample.

	Predicted	
Actual	**No**	**Yes**
No	1	10
Yes	4	23
Accuracy	0.63	

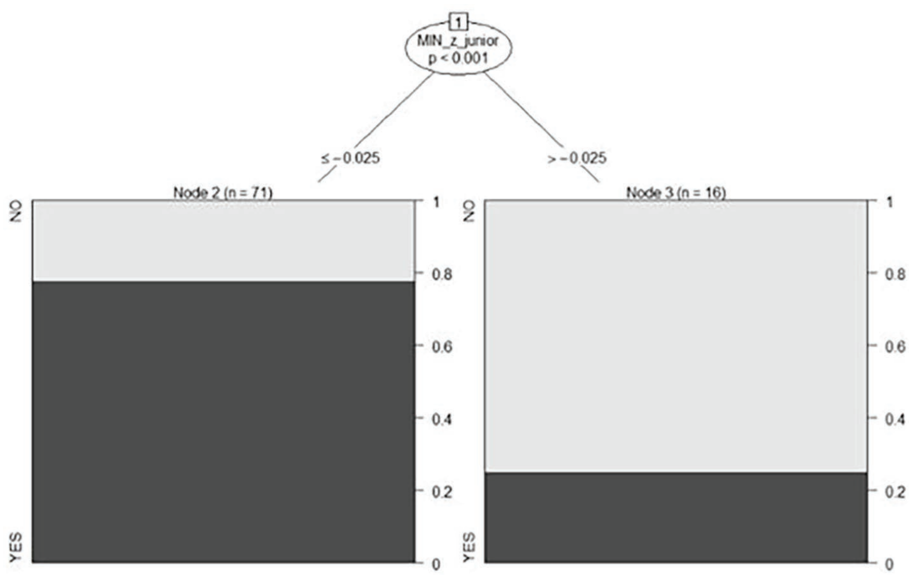

FIGURE 3 | Conditional inference tree.

of Russian and 53.9% of Australian swimmers who achieved medals at the Junior WCs qualified for the finals in Senior WCs. Consequently, it seems that recruiting and developing swimmers from an early age will be advantageous in maximizing performance in Senior swimmers.

While this strategy appears logical, contradictory evidence from the German elite sport system showed that athletes recruited to talent-development squads at young ages exited the system the earliest, and the use of athlete support services was not substantially related to greater attainment of senior success. These observations were corroborated by Sokolovas et al. (2006), who found that most of the top American swimmers at the age of 17–18 were not ranked in the country's top-100 at younger ages.

Allen et al. (2014) indicated that national swimming federations might improve the performance success by targeting resources towards larger groups of swimmers several years out from an international event. Concentrating on training processes and creating independence may help swimmers create an intrinsic motivation to succeed rather than an early specialized program that offers the benefit of early access to Sports Science and other resources.

Longitudinal performance prediction in National federations is increasingly popular to identify the characteristics necessary for winning medals at major events such as the World Championships or Olympic Games. Results from this study showed that an optimal annual progression in performance from Junior to Senior does not improve the chances of becoming a top-ranked country in the medal table at the Senior WCs. This indicates that on average, swimmers from all countries improve at a similar rate and the ones who start from a higher level at the Junior WCs are still in the top 5 at the Senior WCs. This supports the study by Trewin et al. (2004) who found no differences in mean progression rates between nations when analyzing the variability of competitive performance between FINA world-rankings and Olympic performances. This appears to be a conflicting area for research.

In contrast to our results, Pyne et al. (2001) found that lower ranked athletes with greater rates of performance improvement will increased their chances of winning a medal more than highly ranked athletes in future International competitions. Hopkins et al. (1999) also observed that an athlete in contention for a medal has to improve their performance by approximately one-half of the typical race to-race variation in performance (expressed as a standard deviation) to substantially increase their chances of success. In addition, improvements of this magnitude (~1% per year) should be considered when estimating performance times for future competitions (Pyne et al., 2004).

Longitudinal monitoring of performance progress must be able to differentiate between "normal" increases in performance caused by maturation and training, and "unnatural" improvement caused by doping (Hopker et al., 2018). Seasonal performance variability could become a useful indicator in targeting possible offenders. Previous studies suggested a coefficient of variation ranging from 1 to 1.5% in track and field athletics (Malcata and Hopkins, 2014) and 1% for elite rowing athletes (Smith and Hopkins, 2011). This confounding variable could be one reason why the annual rate of progression is not critical in becoming a top 5 country in the medal table at the Senior WCs.

In this study, there were no differences in minimum age (MA) between the top 5 countries and the next 5 on the WCs medal table. This suggests that national governing bodies would be advised to focus on maximizing swimmer's performance at the Junior level over early exposure to Senior International competition.

Yustres et al. (2017) found a close relationship ($p < 0.001$) between the position obtained at Senior level and the number of years remaining competing in World Championships. Swimmers tend to be older when they achieve their best performance. It would appear that a greater number of experiences at international level will increase the chances of achieving better performances at the Senior WCs. It is likely that a better Junior performance level and competing for longer at Senior international level will increase the chances of success for counties aiming to be ranked in the top 5 at the Senior WCs.

In this study, we support the hypothesis that European countries with swimmers achieving an optimal performance at the Junior WCs have a better chance of success at the Senior WCs. We rejected the hypothesis that the swimmer's annual performance progression is critical to Nations being a top-ranked European country in the medal table at the Senior WC. Future studies might analyze the evolution of the best junior swimmers competing the Junior World Championships to really determine how many will reach the World Championships of absolute category, identifying further contributory factors in helping countries to develop athletes and predict success at the Senior WCs. Besides, some other variables that could explain our main aim can be analyzed. However, it was not possible in our study due to the limited relevant information that we have about some other explicative variables.

CONCLUSION

Countries with swimmers achieving an optimal performance in the Junior WCs will have a better chance of reaching the top 5 position in the medal ranking at the Senior WCs.

Average best time at the Senior WCs and an optimal annual progression performance from Junior to Senior do not affect the chances of becoming a top-ranked (1–5) country in the medal table at the Senior WCs.

This comparison between the performance progression model of European countries shows that countries aiming to reach the top positions in the medal should not focus on annual progression rates, the age of first performance, or the age of peak performance at Senior level. However, there is a 63% chance of swimmers who succeed at the Junior WCs that will also help their countries to achieve a top 5 medal ranking at the Senior WCs.

DATA AVAILABILITY

Publicly available datasets were analyzed in this study. This data can be found here: http://www.omegatiming.com/index.htm.

AUTHOR CONTRIBUTIONS

IY, JG-R, and JS conceptualized, designed and performed the experiments. IY, JG-R, JS, and FG-M analyzed and interpreted the data. IY, JG-R, MP, and FG-M edited and critically reviewed the manuscript. IY, JG-R, MP, and JS wrote the manuscript.

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REFERENCES

Allen, S., Vandenbogaerde, T., and Hopkins, W. (2014). Career performance trajectories of Olympic swimmers: benchmarks for talent development. *Eur. J. Sport Sci.* 14, 643–651. doi: 10.1080/17461391.2014.893020

Allen, S., Vandenbogaerde, T., Pyne, D., and Hopkins, W. (2015). Predicting a nation's Olympic-qualifying swimmers. *Int. J. Sports Physiol. Perform.* 10, 431–435. doi: 10.1123/ijspp.2014-0314

Barreiros, A., Côté, J., and Fonseca, A. M. (2014). From early to adult sport success: analysing athletes' progression in national squads. *Eur. J. Sport Sci.* 14(Supp. 1), S178–S182. doi: 10.1080/17461391.2012.671368

Boccia, G., Moisè, P., Franceschi, A., Trova, F., Panero, D., La Torre, A., et al. (2017). Career performance trajectories in track and field jumping events from youth to senior success: the importance of learning and development. *PLoS One* 12:1. doi: 10.1371/journal.pone.0170744

Bosscher, V., de Knop, P., van Bottenburg, M., and Shibli, S. (2006). A conceptual framework for analysing sports policy factors leading to international sporting success. *Eur. Sport Manag. Q.* 6, 185–215. doi: 10.1080/16184740600955087

Costa, M., Marinho, D., Bragada, J., Silva, A., and Barbosa, T. (2011). Stability of elite freestyle performance from childhood to adulthood. *J. Sports Sci.* 29, 1183–1189. doi: 10.1080/02640414.2011.587196

Costa, M., Silva, A. J., Marqués, M., Bragada, J. A., and Barbosa, T. (2010). Tracking the Performance of World-Ranked Swimmers. *J. Sports Sci. Med.* 9, 411–417.

Durand-Bush, N., and Salmela, J. (2002). The development and maintenance of expert Athletic performance: perceptions of World and Olympic champions. *J. Appl. Sport Psychol.* 14, 154–171. doi: 10.1080/10413200290103473

Green, B. (2015). Building sport programs to optimize athlete recruitment, retention and transition: toward a normative theory of sport development. *J. Sport Manag.* 19, 233–253. doi: 10.1123/jsm.19.3.233

Hopker, J., Schumacher, Y. O., Fedoruk, M., Mørkeberg, J., Bermon, S., Iljukov, S., et al. (2018). Athlete performance monitoring in anti-doping. *Front. Physiol.* 9:232. doi: 10.3389/fphys.2018.00232

Hopkins, W. G., Hawley, J. A., and Burke, L. M. (1999). Design and analysis of research on sport performance enhancement. *Med. Sci. Sports Exerc.* 31, 472–485. doi: 10.1097/00005768-199903000-00018

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Howard, R., De Ste Croix, M. B. A., Williams, C. A., et al. (2015). Long-term athletic development: part 1: a pathway for all youth. *J. Strength Cond. Res.* 29, 1439–1450. doi: 10.1519/JSC.0000000000000756

Malcata, R. M., and Hopkins, W. G. (2014). Variability of competitive performance of elite athletes: a systematic review. *Sports Med.* 44, 1763–1774. doi: 10.1007/s40279-014-0239-x

Morais, J. E., Marques, M. C., Marinho, D. S., Silva, A. J., and Barbosa, T. M. (2014). Longitudinal modeling in sports: young swimmers' performance and biomechanics profile. *Hum. Mov. Sci.* 37, 111–122. doi: 10.1016/j.humov.2014.07.005

Morais, J. E., Silva, A. J., Marinho, D. A., Lopes, V. P., and Barbosa, T. M. (2017). Determinant factors of long-term performance development in young swimmers. *Int. J. Sports Physiol. Perform.* 12, 198–205. doi: 10.1123/ijspp.2015-0420

Neeru, J., Dugas, L., and LaBella, C. (2013). Sports specialization in young athletes: evidence-based recommendations. *Sports Health* 5, 251–257. doi: 10.1177/1941738112464626

Pyne, D. B., Lee, H., and Swanwick, K. (2001). Monitoring the lactate threshold in world-ranked swimmers. *Med. Sci. Sports Exerc.* 33, 291–297. doi: 10.1097/00005768-200102000-00019

Pyne, D., Trewin, C., and Hopkins, W. (2004). Progression and variability of competitive performance of Olympic swimmers. *J. Sports Sci.* 22, 613–620. doi: 10.1080/02640410310001655822

Smith, T. B., and Hopkins, W. G. (2011). Variability and predictability of finals times of elite rowers. *Med. Sci. Sports Exerc.* 43, 2155–2160. doi: 10.1249/MSS.0b013e31821d3f8e

Sokolovas, G., Vilas-Boas, J. P., Alves, F., and Marques, A. (2006). Analysis of USA swimming's all-time top 100 times. Biomechanics and Medicine in Swimming X. *Rev. Port. Cien. Desp.* 11, 315–317. https://bibliotecadigital.ipb.pt/bitstream/10198/3571/3/BMS2010_BMS_XI_final_lowres-co%CC%81pia.pdf

Svendsen, I. S., Tønnesen, E., Tjelta, L. I., and Orn, S. (2018). Training, performance and physiological predictors of a successful elite senior career in junior competitive road cyclists. *Int. J. Sports Physiol. Perform.* 20, 1–6. doi: 10.1123/ijspp.2017-0824

Trewin, C. B., Hopkins, W. G., and Pyne, D. B. (2004). Relationship between world-ranking and Olympic performance of swimmers. *J. Sports Sci.* 22, 339–345. doi: 10.1080/02640410310001641610

Vaeyens, R., Lenoir, M., Williams, A. M., and Philippaerts, R. M. (2009). Talent identification and promotion programmes of Olympic athletes. *J. Sports Sci.* 27, 1367–1380. doi: 10.1080/02640410903110974

Yustres, I., Martín, R., Fernández, L., and González-Ravé, J. M. (2017). Swimming championship finalist positions on success in international swimming competitions. *PLoS One* 12:11. doi: 10.1371/journal.pone.0187462

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The Beginning of Senior Career in Team Sport Is Affected by Relative Age Effect

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Many previous studies in national team sports did not report evidence about relative age effect (RAE) in senior categories. This study aimed for the first time to determine if the RAE may specifically affect the early, but not the late, phase of senior career in elite team sports. A total of 3,319 birthdates (basketball: n = 642; rugby: n = 572; soccer: n = 1318; volleyball: n = 337; water polo: n = 450) of elite senior players were analyzed. Senior players with an age lower or equal to the 25° percentile of age were considered as *early phase* players while the others as *late phase* players. Separate Poisson regression models were applied to investigate the RAE in each sport (overall, and for *early phase* and *late phase* subgroups). Considering the overall sample, players born close to the beginning of the year were 1.57, 1.34, 2.69, 1.48, and 1.45 times more likely to reach first and second Italian division of basketball, rugby, soccer, volleyball, and water polo respectively, than those born in the last part of the year. RAE was present in all *early phase* subgroups. Differently, in the *late phase* subgroups the RAE was present only in soccer. Data highlighted a bias in the selection of senior teams, which may limit the chance to identify talented players born late in the second part of the year. Italian sport federations should promote the talent development of relatively younger players by equally promoting the joining of young players to senior teams.

Keywords: talent identification, biological age, team sports, physical maturation, RAE

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INTRODUCTION

In sport context, birthdates are usually chosen to gather sport categories of adolescents and young athletes. Literature reported that in youth teams' relatively older players (i.e., athletes born close to cut-off date of selection) and relatively younger players (i.e., athletes born far away to cut-off date of selection) may present large differences in physical and psychological maturation (Cobley et al., 2009; Lovell et al., 2015). As consequence, relatively older players are advantaged in sport performance if compared with relatively younger players (Cobley et al., 2009) and have more probabilities to be selected by coaches and talent scouts (Lovell et al., 2015; Furley and Memmert, 2016; Sarmento et al., 2018). This leads to an over-representation of athletes born close to selection date. This phenomenon is recognized with the name of Relative Age Effect (RAE) (Barnsley et al., 1985; Musch and Grondin, 2001; Boccia et al., 2017).

The RAE has been successively observed in several individual (Cobley et al., 2018; Kearney et al., 2018; Brustio et al., 2019) and team sports. In the latter sport area, this phenomenon has been especially investigated in soccer (Fumarco and Rossi, 2015; Gonzalez-Villora et al., 2015; Sierra-Diaz et al., 2017; Brustio et al., 2018; Rađa et al., 2018), basketball (Arrieta et al., 2016;

Rubajczyk et al., 2017; Steingrover et al., 2017; Ibanez et al., 2018), and rugby union (Till et al., 2010; McCarthy et al., 2016; Jones et al., 2018), but also in other team sports such as volleyball (Campos et al., 2016) and water polo (Barrenetxea-Garcia et al., 2018). Despite the pervasiveness of RAE in youth sport teams, controversial results were found at senior professional level (Delorme et al., 2009; Romann et al., 2018). For example, large RAE was found in soccer (Gonzalez-Villora et al., 2015; Brustio et al., 2018), while small or negligible RAE was observed in other sport teams such rugby league (Delorme et al., 2009; Till et al., 2010; Jones et al., 2018), basketball (Delorme et al., 2009; Werneck et al., 2016; López de Subijana and Lorenzo, 2018), volleyball (Campos et al., 2016) and water polo (Barrenetxea-Garcia et al., 2018). A discrepancy in RAE at senior professional level may also emerge in relation to the countrywide. For example, in a nationwide analysis of most popular sports in Switzerland (Romann et al., 2018), despite authors found an overall RAE in male athletes, RAE associated to single sports reported substantial differences. Similarly, Delorme et al. (2009) showed in French male professional players a different pattern in RAE according to the sport teams considered. Specifically, a significant RAE was observed only in ice-hockey while only a trend was detected in handball and rugby union but not in basketball, soccer or volleyball. Interesting, a different trend was observed in female professional players, where RAE was found to be small or not present at all (for an extensive review and meta-analysis see Smith et al., 2018). Indeed, the social context, the level of competition, the popularity, and number of active participants may affect the presence of RAE (Musch and Grondin, 2001). The paucity of studies focused on RAE of different team sports in the same countrywide is evident, and further studies are strongly needed.

New evidences underlined a reversal RAE at senior professional level, where relative younger players may have the greatest potentiality for a later success (McCarthy et al., 2016; Till et al., 2016). In other words, it is possible that relative younger players may have the chance to be identified and selected at senior professional level at late stage of their career. Accordingly, as previously suggested, it is possible that RAE magnitude may differ in the early and late phase of professional senior career (Brustio et al., 2018). Indeed, it is likely to hypothesize that only the first years of senior career may be affected by the RAE. This would mean that the relatively older athletes (i.e., those born close to the selection date) may be advantaged in entering the senior teams. Despite this sensible hypothesis, previous studies, focusing on RAE at senior level, investigated the senior teams without differentiating between the athletes in the first years of senior career and the others (Delorme et al., 2009; Till et al., 2010; Werneck et al., 2016; Jones et al., 2018; López de Subijana and Lorenzo, 2018).

Thus, the aim of this study was to quantify the prevalence and magnitude of RAE in male Italian context at professional senior level (i.e., first and second division), focusing on basketball, rugby (i.e., rugby union, 15 players each team), soccer, volleyball, and water polo, which are the most popular team sports in Italy[1]. In addition, RAE was separately quantified for players competing in the early (*early phase* players) and later (*late phase* players) stage of their senior career in order to determine if the RAE in senior team may be influenced over time.

[1]https://www.coni.it

MATERIALS AND METHODS

Design

Birthdates of 3,319 male athletes were collected from the first and second Italian division of basketball, rugby, soccer, volleyball and water polo for the 2017–2018 seasons. Date of birth was obtained from different sources such as TransferMarkt database for soccer players and web sites of clubs for the other sports. Data collection has been performed at the end of the season, when the teams' rosters are consolidated after eventual players moving among different clubs. All players included in the rosters of senior teams were considered in this analysis regardless of the age.

Procedure

A total of 642 (mean age = 25.6 ± 5.6 years), 572 (mean age = 24.2 ± 4.5 years), 1318 (mean age = 25.0 ± 5.0 years), 337 (mean age = 25.6 ± 5.5 years), and 450 (mean age = 25.6 ± 6.3 years) male elite players were analyzed in basketball, rugby, soccer, volleyball, and water polo, respectively. The 18, 7, 9 4, and 24 % of the subjects in basketball, rugby, soccer, volleyball, and water polo, respectively aged less than 18 years. Players' names were removed from the data set. Since our data are based on anonymous resources, no informed consent was requested. This study was approved by the local ethics committee of the University of Turin (Italy) and conducted in accordance with the declaration of Helsinki.

Statistical Analyses

To explore the possible differences in RAE between *early phase* and *late phase* players, the whole sample of each sport was split in two subgroups on the basis of their age. Those senior players with an age lower or equal to the 25° percentile of age of the considered sport (i.e., the first quartile of players in terms of age) were considered as *early phase* players; the rest of sample was considered as *late phase* players. It is likely that *early phase* players (i.e., the younger players in the senior sample) were those in their first years of their adult career. In absence of the actual year of entering the senior team, the age of the player has been considered as the most sensible index to determine if a player is in the early or late phase of his adult career.

In Italy, the youth categories are based on calendar years, for which all young players born from 1st January to 31st December of a calendar year are grouped together. Thus, the birth week (W_B) and the time of birth (T_B) of each player were computed according to previous studies (Brustio et al., 2018, 2019; Doyle and Bottomley, 2018, 2019). W_B indicates the week of the year of player's birth while T_B indicates how far from the beginning of the year a player was born (range score between 0 and 1).

In line with recent studies on RAE (Brustio et al., 2018, 2019; Doyle and Bottomley, 2018, 2019; Rađa et al., 2018), a separate Poisson regression was applied to investigate the RAE in each team sport following the formula $y = e^{(b0 + b1x)}$. Specifically, y represents the frequency of birth in a given week while x represents the T_B. Moreover, the Index of Discrimination (ID), which provided the relative odds of being selected for a player born in the first versus last week of the competition year (Doyle and Bottomley, 2018, 2019), was calculated as e^{-b1}. Finally, likelihood ratio R^2 was computed (Cohen et al., 2013). All data were analyzed in MATLAB R2017b (Mathworks, Natick, MA, United States).

RESULTS

Figure 1 reports the scatter-plots of relative birth frequency by week, the red line in the **Figure 1** represents the best fit of the Poisson regression modeling the frequency of birth in a given week the T_B. **Table 1** shows the descriptive statistic of W_B and T_B, and the output of Poisson regression for each subgroup and sport. The **Table 1** shows that the players of each considered sport were born at beginning of the year (mean T_B range: 0.42–0.48). Moreover, players born close to the beginning of the year (i.e., in the first week of the year) were 1.57, 1.34, 2.69, 1.48, and 1.45 times more likely to reach first and second Italian division of basketball, rugby, soccer, volleyball, and water polo than those born in the last part (i.e., last week) of the year (see ID values).

The cut-off ages for discriminating *early phase* and *late phase* subgroups were: 19 years, for basketball and water polo; 21 years, for rugby and soccer; and 22 years, for volleyball. According to these scenarios, the results suggested that the amount of RAE was greater in the *early phase* than *late phase* subgroup of players in each sport. In fact, the Poisson regressions were significant for *early phase* players in basketball ($p < 0.0001$; $R^2 = 0.19$), rugby ($p = 0.01$; $R^2 = 0.14$), soccer ($p < 0.0001$; $R^2 = 0.47$), volleyball ($p < 0.03$; $R^2 = 0.16$), and water polo ($p < 0.04$; $R^2 = 0.12$). Differently, Poisson regression was significant for *late phase* subgroups, only in soccer ($p < 0.0001$; $R^2 = 0.47$), but not in the other sports. The T_B indexes in all sports were lower in *early phase* compared to *late phase* subgroups (see **Figure 1**). In addition, coherently to the above-mentioned results, IDs indexes in all sports were greater in *early phase* compared to *late phase* subgroups (see **Table 1**).

DISCUSSION

The aim of this study was to examine the prevalence and magnitude of RAE at senior professional level in Italian team sports, discriminating male players in relation to *early* or *late phase* of career. For this purpose, the birthdates distribution of basketball, rugby, soccer, volleyball, and water polo players competing in the first and second Italian Championships was recorded. The main finding consisted of a large over-representation of players born close to the beginning of the calendar year in early, but not in late, phase of senior career. Soccer was an exception, showing that even *late phase* players presented evidence of RAE, despite smaller than *early phase*.

Considering the overall sample, evidence of RAE was found in each considered team sport. To quantify the RAE, we adopted the ID which consists in the relative odds of being selected

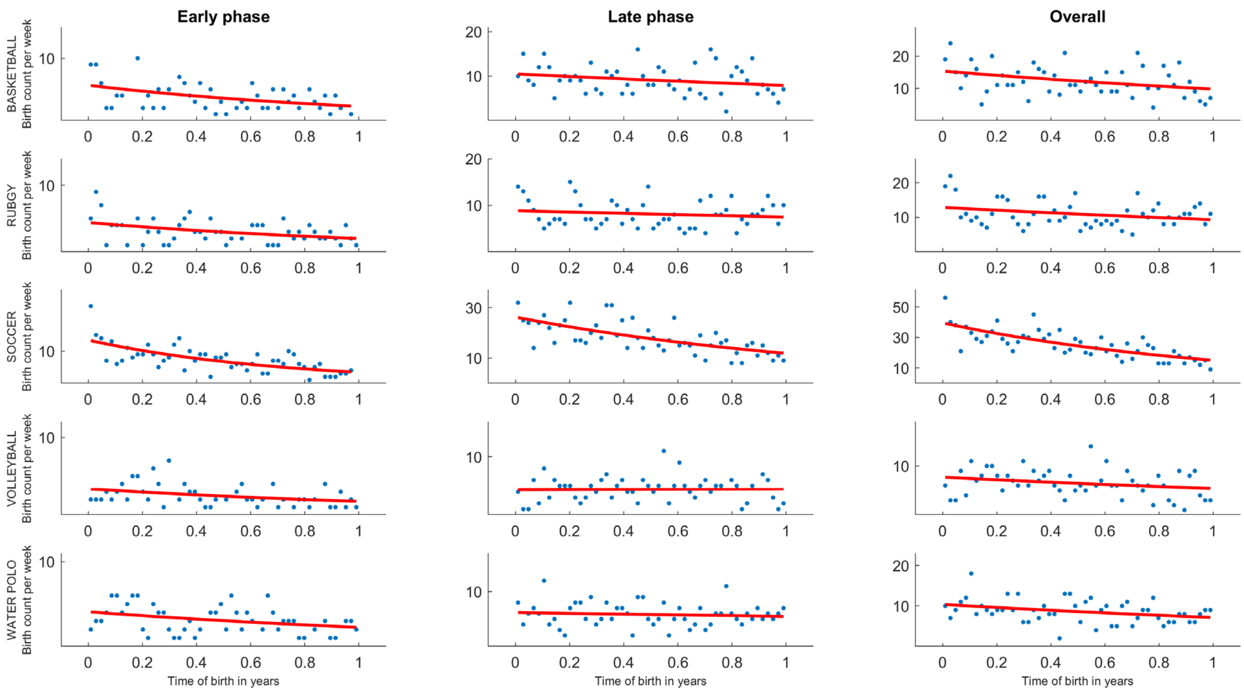

FIGURE 1 | Scatter-plots of birthdates reported for each team sport (i.e., basketball, rugby, soccer, volleyball, and water polo) in relation to the entire samples, and to the *early phase* and *late phase* career subgroups. The red line represents the best fit of the Poisson regression.

TABLE 1 | Poisson regression results in basketball, rugby, soccer, volleyball, and water polo.

		Basketball	Rugby	Soccer	Volleyball	Water polo
Overall	N	642	572	1318	337	450
	W_B	25 ± 15	25 ± 16	22 ± 14	25 ± 14	25 ± 15
	T_B	0.46 ± 0.29	0.48 ± 0.3	0.42 ± 0.28	0.47 ± 0.27	0.45 ± 0.29
	b_0	2.732	2.541	3.687	2.058	2.337
	b_1	−0.454	−0.294	−1.000	−0.392	−0.370
	ID	**1.57**	**1.34**	**2.69**	**1.48**	**1.45**
	R^2	0.12	0.07	0.6	0.07	0.11
	p value	<0.0001	0.04	<0.0001	0.04	0.02
Early phase	N	168	149	376	115	147
	W_B	23 ± 15	24 ± 16	21 ± 14	23 ± 15	23 ± 15
	T_B	0.42 ± 0.28	0.44 ± 0.30	0.39 ± 0.27	0.42 ± 0.28	0.43 ± 0.28
	b_0	1.714	1.457	2.581	1.243	1.415
	b_1	−0.866	−0.729	−1.333	−0.716	−0.611
	ID	**2.38**	**2.07**	**3.79**	**2.05**	**1.84**
	R^2	0.19	0.14	0.47	0.16	0.12
	p value	<0.0001	0.01	<0.0001	0.03	0.04
Late phase	N	474	423	942	222	303
	W_B	25 ± 15	26 ± 16	23 ± 14	26 ± 14	26 ± 15
	T_B	0.48 ± 0.29	0.49 ± 0.3	0.43 ± 0.28	0.49 ± 0.27	0.49 ± 0.29
	b_0	2.351	2.171	3.283	1.472	1.820
	b_1	−0.288	−0.152	−0.829	0.037	−0.145
	ID	**1.33**	**1.16**	**2.29**	**0.96**	**1.12**
	R^2	0.06	0.02	0.47	0	0.01
	p value	0.07	0.37	<0.0001	0.87	0.56

W_B, week in which players born; T_B, time of birth; ID, Index of Discrimination.

for an athlete born in the first versus the last week of the calendar year (Doyle and Bottomley, 2018, 2019). In this study, the IDs ranged from 1.34 to 2.69 underlined the presence of RAE in all considered team sports. Thus, the present results showed a different pattern in senior Italian context compared to International ones, where RAE was small or negligible as observed in basketball (Delorme et al., 2009; Werneck et al., 2016; López de Subijana and Lorenzo, 2018), rugby league (Till et al., 2010), volleyball (Campos et al., 2016) and water polo at senior level (Barrenetxea-Garcia et al., 2018). On the other hand, it possible that the proportion of players with less than 18 years (overall mean = 12%) in analyzed teams may partially influence the results contradicting previous results in senior teams and in accordance with other studies which describe RAE in European National Teams (Arrieta et al., 2016). However, as outlined before, controversial results may arise in relation to the countrywide, because the social context, the level of competitiveness, the popularity, and number of active participants affect the magnitude of RAE (Musch and Grondin, 2001; Cobley et al., 2009; Wattie et al., 2015). Thus, this finding should be considered specific to Italian context and cannot be generalized to other countries. Some speculations could be provided to more deeply interpret the results of the present study. The team sports of our study may be considered as highly physical demanding sports, where strength and power represent a substantial role. Since physical maturation is related to muscular strength, endurance, and speed, and is important to obtain successful performances (Musch and Grondin, 2001; Cobley et al., 2009), relatively older players could be more favored than younger counterparts. Moreover, soccer, basket, rugby, and water polo are invasion sports and characterized by physical contacts, where higher muscular strength and body dimensions are directly favorable. Differently, despite volleyball is not an invasion sport, greater body dimension and physical capabilities can be favorable as well. This can explain the fact that also volleyball presented RAE values in line with the other sports, even if it is not an invasion sport. Beyond the physical aspect, the influence of social agents such as parents, coaches or the athletes themselves, especially at the beginning of the careers, may amplify RAE (e.g., best coaches, facilities, equipment, higher self-expectations) (Hancock et al., 2013). Furthermore, also environmental factors, such as birthplace, may positively impact on athletes' development and increase the opportunity to obtain success in sport (Côté et al., 2006).

Soccer is the sport more affected by RAE (**Table 1**). Players born near the cut-off date of selection are nearly three times more likely to play in the first or second division. The larger RAE in soccer may be related to the fact that soccer is the most popular sport in Italy. In fact, the high professionalism of the first and second division can be associated to a more severe player selection in comparison with other team sports. Moreover, the greater attractiveness of soccer compared to other sports in term of media presence and higher funding (Romann et al., 2018) might explain the larger RAE in soccer. In other words, we may speculate that the relative inferior popularity and number of active participants of basketball, rugby, volleyball, and water polo in Italy, and consequent more opportunities to be selected in elite teams may have minimized the RAE. As consequence, even though soccer can benefit from a huge number of players, its talent selection seems to risk more than other team sports to lose valuable elite players only because of a late physical maturation occurring during the youth phase of career. Therefore, it could be hypothesized a paradoxical phenomenon, where an effective and trivial talent selection is developed in minor team sports and soccer, respectively.

The most interesting result of this study was that in basketball, rugby, volleyball, and water polo, the RAE was present only in *early phase* subgroup (IDs ranged = 1.84–2.38) but not in the *late phase* subgroup (IDs ranged = 0.96–1.33). This finding highlights that, in these sports, relatively younger players may still suffer the initial disadvantage undergone in youth career (Cobley et al., 2009) during their *early phase* of adult career (McCarthy et al., 2016; Till et al., 2016). In soccer, the results presented the same trend but with even more pronounced RAE. Indeed, the ID was extraordinarily large in *early phase* subgroup (ID = 3.8) and lower, but still large, in *late phase* subgroup (ID = 2.3). Taken together, the present findings show that the relatively older soccer players (i.e., those born close the beginning of the year) are facilitated in entering the senior professional teams. Moving from youth to senior team is a delicate passage in players' careers. However, it seems that the relatively older players have early chances to join the senior teams compared to the relatively younger players. Anyway, for relatively younger players, further opportunities to play with senior team should be offered to optimize the process of talent development. However, it is known that the excessive research of immediate successes in youth categories could prevent the promotion of long-term talent development, leading coaches to select youth players with more mature physical characteristics (Lovell et al., 2015; Furley and Memmert, 2016; Sarmento et al., 2018).

This study presents some limitations. The study considered the whole roster of the selected teams. Hence, it included also foreign players as well as players with less than 18 years. These aspects could potentially influence the observed RAE and the cut-off age used to categorize *early phase* and *late phase* players. Moreover, the present study did not investigate the possible causal factors of RAE, such individual performance during a season (e.g., total minutes and number of the match played) or individual characteristics (e.g., physical fitness performance, physical maturation, and anthropometrical measures) which may better describe the phenomenon. Additionally, the present study focused on male competitions only. Due to the possible small effect of RAE in female sport contexts (Smith et al., 2018), future studies are needed to investigate this phenomenon in the *early* and *late* phase of female players' career. Finally, the present study considered only one year of completion (e.g., 2017–2018 season). Furthermore, studies are needed to investigate the RAE considering the starting age of the players in elite teams as well as the phenomenon longitudinally.

CONCLUSION

At senior professional level, a large over-representation of players born close to the beginning of the year is evident in all popular Italian team sports. However, this trend significantly emerged for the *early phase* of players' career, whereas it was weaker for the *late phase*, which was significant only in soccer. Therefore, these data suggested that relatively older players have more chances to join senior teams especially at the beginning of their adult career.

To limit the negative RAE consequence, Italian sport federations should provide different solutions to advantage all athletes with different time points of development (Hurley et al., 2001; Romann and Cobley, 2015; Mann and van Ginneken, 2017; Haycraft et al., 2018). Since results of present study showed that the RAE is more evident in the early phase of players' career, practitioners should try to find solutions to support athletes in the transition from youth to senior teams. Taking in mind that even relatively younger players can reach top-level senior competition, team sports coaches should consider the later development trajectories of youth athletes. Thus, they should promote the talent development of the relatively younger players by equally promoting the joining of young players to senior teams.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

CL, GB, and PRB conceptualized and supervised the study and wrote the original draft of the manuscript. All authors investigated the study, wrote, reviewed, and edited the manuscript. PRB carried out the formal analysis. CL acquired the funding.

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REFERENCES

Arrieta, H., Torres-Unda, J., Gil, S. M., and Irazusta, J. (2016). Relative age effect and performance in the U16, U18 and U20 european basketball championships. *J. Sports Sci.* 34, 1530–1534. doi: 10.1080/02640414.2015.1122204

Barnsley, R. H., Thompson, A. H., and Barnsley, P. E. (1985). Birthdate and performance: the relative age effect. *Can. J. Hist. Sport Phys. Educ.* 51, 23–28.

Barrenetxea-Garcia, J., Torres-Unda, J., Esain, I., and Gil, S. M. (2018). Relative age effect and left-handedness in world class water polo male and female players. *Laterality* 24, 259–273. doi: 10.1080/1357650X.2018.1482906

Boccia, G., Rainoldi, A., and Brustio, P. R. (2017). Relative age effect in males, but not females, undergraduate students of sport science. *Sport Sci. Health* 13, 349–353. doi: 10.1007/s11332-017-0364-7

Brustio, P. R., Kearney, P. E., Lupo, C., Ungureanu, A. N., Mulasso, A., Rainoldi, A., et al. (2019). Relative age influences performance of world-class track and field athletes even in the adulthood. *Front. Psychol.* 10:1395. doi: 10.3389/fpsyg.2019.01395

Brustio, P. R., Lupo, C., Ungureanu, A. N., Frati, R., Rainoldi, A., and Boccia, G. (2018). The relative age effect is larger in Italian soccer top-level youth categories and smaller in Serie A. *PLoS One* 13:e0196253. doi: 10.1371/journal.pone.0196253

Campos, F. A. D., Stanganelli, L. C. R., Rabelo, F. N., Campos, L. C. B., and Pellegrinotti, Í. L. (2016). The relative age effect in male volleyball championships. *Int. J. Sports Sci.* 6, 116–120.

Cobley, S., Abbott, S., Dogramaci, S., Kable, A., Salter, J., Hintermann, M., et al. (2018). Transient relative age effects across annual age groups in national level australian swimming. *J. Sci. Med. Sport* 21, 839–845. doi: 10.1016/j.jsams.2017.12.008

Cobley, S., Baker, J., Wattie, N., and McKenna, J. (2009). Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. *Sports Med.* 39, 235–256. doi: 10.2165/00007256-200939030-00005

Cohen, J., Cohen, P., West, S. G., and Aiken, L. S. (2013). *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*. New York, NY: Routledge.

Côté, J., Macdonald, D. J., Baker, J., and Abernethy, B. (2006). When "where" is more important than "when": birthplace and birthdate effects on the achievement of sporting expertise. *J. Sports Sci.* 24, 1065–1073. doi: 10.1080/02640410500432490

Delorme, N., Boiche, J., and Raspaud, M. (2009). The relative age effect in elite sport: the French case. *Res. Q. Exerc. Sport* 80, 336–344. doi: 10.1080/02701367.2009.10599568

Doyle, J. R., and Bottomley, P. A. (2018). Relative age effect in elite soccer: more early-born players, but no better valued, and no paragon clubs or countries. *PLoS One* 13:e0192209. doi: 10.1371/journal.pone.0192209

Doyle, J. R., and Bottomley, P. A. (2019). The relative age effect in european elite soccer: a practical guide to poisson regression modelling. *PLoS One* 14:e0213988. doi: 10.1371/journal.pone.0213988

Fumarco, L., and Rossi, G. (2015). *Relative Age Effect on Labor Market Outcomes for High Skilled Workers–Evidence from Soccer*. Available at: http://www.bbk.ac.uk/management/docs/workingpapers/WP9.pdf (accessed January 18, 2019).

Furley, P., and Memmert, D. (2016). Coaches' implicit associations between size and giftedness: implications for the relative age effect. *J. Sports Sci.* 34, 459–466. doi: 10.1080/02640414.2015.1061198

Gonzalez-Villora, S., Pastor-Vicedo, J. C., and Cordente, D. (2015). Relative age effect in UEFA championship soccer players. *J. Hum. Kinet.* 47, 237–248. doi: 10.1515/hukin-2015-0079

Hancock, D. J., Adler, A. L., and Cote, J. (2013). A proposed theoretical model to explain relative age effects in sport. *Eur. J. Sport Sci.* 13, 630–637. doi: 10.1080/17461391.2013.775352

Haycraft, J. A. Z., Kovalchik, S., Pyne, D. B., Larkin, P., and Robertson, S. (2018). The influence of age-policy changes on the relative age effect across the Australian rules football talent pathway. *J. Sci. Med. Sport* 21, 1106–1111. doi: 10.1016/j.jsams.2018.03.008

Hurley, W., Lior, D., and Tracze, S. (2001). A proposal to reduce the age discrimination in Canadian minor hockey. *Can. Public Policy* 27, 65–75.

Ibanez, S. J., Mazo, A., Nascimento, J., and Garcia-Rubio, J. (2018). The relative age effect in under-18 basketball: effects on performance according to playing position. *PLoS One* 13:e0200408. doi: 10.1371/journal.pone.0200408

Jones, B. D., Lawrence, G. P., and Hardy, L. (2018). New evidence of relative age effects in "super-elite" sportsmen: a case for the survival and evolution of the fittest. *J. Sports Sci.* 36, 697–703. doi: 10.1080/02640414.2017.1332420

Kearney, P. E., Hayes, P. R., and Nevill, A. (2018). Faster, higher, stronger, older: relative age effects are most influential during the youngest age grade of track and field athletics in the United Kingdom. *J. Sports Sci.* 36, 2282–2288. doi: 10.1080/02640414.2018.1449093

López de Subijana, C., and Lorenzo, J. (2018). Relative age effect and long-term success in the Spanish soccer and basketball national teams. *J. Hum. Kinet.* 65, 197–204. doi: 10.2478/hukin-2018-0027

Lovell, R., Towlson, C., Parkin, G., Portas, M., Vaeyens, R., and Cobley, S. (2015). Soccer player characteristics in english lower-league development programmes: the relationships between relative age, maturation, anthropometry and physical fitness. *PLoS One* 10:e0137238. doi: 10.1371/journal.pone.0137238

Mann, D. L., and van Ginneken, P. J. (2017). Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. *J. Sports Sci.* 35, 784–790. doi: 10.1080/02640414.2016.1189588

McCarthy, N., Collins, D., and Court, D. (2016). Start hard, finish better: further evidence for the reversal of the RAE advantage. *J. Sports Sci.* 34, 1461–1465. doi: 10.1080/02640414.2015.1119297

Musch, J., and Grondin, S. (2001). Unequal competition as an impediment to personal development: a review of the relative age effect in sport. *Dev. Rev.* 21, 147–167. doi: 10.1006/drev.2000.0516

Rađa, A., Padulo, J., Jelaska, I., Ardigò, L. P., and Fumarco, L. (2018). Relative age effect and second-tiers: no second chance for later-born players. *PLoS One* 13:e0201795. doi: 10.1371/journal.pone.0201795

Romann, M., and Cobley, S. (2015). Relative age effects in athletic sprinting and corrective adjustments as a solution for their removal. *PLoS One* 10:e0122988. doi: 10.1371/journal.pone.0122988

Romann, M., Rossler, R., Javet, M., and Faude, O. (2018). Relative age effects in Swiss talent development - a nationwide analysis of all sports. *J. Sports Sci.* 36, 2025–2031. doi: 10.1080/02640414.2018.1432964

Rubajczyk, K., Swierzko, K., and Rokita, A. (2017). Doubly disadvantaged? The relative age effect in poland's basketball players. *J. Sports Sci. Med.* 16, 280–285.

Sarmento, H., Anguera, M. T., Pereira, A., and Araujo, D. (2018). Talent identification and development in male football: a systematic review. *Sports Med.* 48, 907–931. doi: 10.1007/s40279-017-0851-7

Sierra-Diaz, M. J., Gonzalez-Villora, S., Pastor-Vicedo, J. C., and Serra-Olivares, J. (2017). Soccer and relative age effect: a walk among elite players and young players. *Sports* 5:E5. doi: 10.3390/sports5010005

Smith, K. L., Weir, P. L., Till, K., Romann, M., and Cobley, S. (2018). Relative age effects across and within female sport contexts: a systematic review and meta-analysis. *Sports Med.* 48, 1451–1478. doi: 10.1007/s40279-018-0890-8

Steingrover, C., Wattie, N., Baker, J., Helsen, W. F., and Schorer, J. (2017). The interaction between constituent year and within-1-year effects in elite German youth basketball. *Scand. J. Med. Sci. Sports* 27, 627–633. doi: 10.1111/sms.12672

Till, K., Cobley, S., Morley, D., O'Hara, J., Chapman, C., and Cooke, C. (2016). The influence of age, playing position, anthropometry and fitness on career attainment outcomes in rugby league. *J. Sports Sci.* 34, 1240–1245. doi: 10.1080/02640414.2015.1105380

Till, K., Cobley, S., Wattie, N., O'Hara, J., Cooke, C., and Chapman, C. (2010). The prevalence, influential factors and mechanisms of relative age effects in UK Rugby League. *Scand. J. Med. Sci. Sports* 20, 320–329. doi: 10.1111/j.1600-0838.2009.00884.x

Wattie, N., Schorer, J., and Baker, J. (2015). The relative age effect in sport: a developmental systems model. *Sports Med.* 45, 83–94. doi: 10.1007/s40279-014-0248-9

Werneck, F., Coelho, E., de Oliveira, H., Júnior, D. R., Almas, S., de Lima, J., et al. (2016). Relative age effect in olympic basketball athletes. *Sci. Sports* 31, 158–161. doi: 10.1016/j.scispo.2015.08.004

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Self-Control in Aiming Supports Coping With Psychological Pressure in Soccer Penalty Kicks

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This study addressed the question whether coaches better allow athletes to self-control their decisions when under pressure or whether to impose a decision upon them. To this end, an experiment was conducted that manipulated the soccer kickers' degree of control in decision-making. Two groups of elite under-19 soccer players (n = 18) took penalty kicks in a self-controlled (i.e., kickers themselves decided to which side to direct the ball) and an externally controlled condition (i.e., the decision to which side to direct the ball was imposed upon the kickers). One group performed the penalty kick under psychological pressure (i.e., the present coaching staff assessed their performance), while the second group performed without pressure. Just before and after performing the kicks, CSAI-2 was used to measure cognitive and somatic anxiety and self-confidence. Further, the number of goals scored, ball placement and speed, and the duration of preparatory and performatory behaviors were determined. The results verified increased levels of cognitive and somatic anxiety after performing the kicks in the pressured group compared to the no-pressure group. In addition, degree of self-control affected the participants' performance, particularly in the pressured group. They scored more goals and placed the kicks higher in the self-controlled than in the externally-controlled condition. Participants also took more time preparing and performing the run-up in the self-controlled condition. Findings indicate that increased self-control helps coping with the debilitating effects of pressure and can counter performance deteriorations. The findings are discussed within the framework of self-control theories, and recommendations for practitioners and athletes are made.

Keywords: football (soccer), autonomy, anxiety, performance, penalties

INTRODUCTION

In the last decade or so, and particularly with the introduction of mobile gaze-trackers, soccer penalty kicking has attracted a growing interest among researchers. The soccer penalty kick provides a well-defined situation, granting researchers to study the (isolated) effects of constraints manipulation on interpersonal interactions in well-controlled (competitive) situations. At the same time, soccer penalty kicks, for example by winning or losing penalty shoot-outs in international soccer tournaments, have a tremendous socio-economic impact.

The probability of scoring a penalty kick is approximately 80% (Palacios-Huerta, 2003). This high success rate basically reflects the spatio-temporal demands of the situation; typically, a goalkeeper has less time available than they require to dive and intercept the ball (Van der Kamp et al., 2018). In other words, the advantage is clearly for the kicker (and should be, given that it was introduced as a punishment). The advantage for the penalty kicker comes with high expectancies of success. Such high expectancies can provoke adverse psychological effects, such as increased pressure and enhanced anxiety levels, which in turn may hamper performance. Psychological pressure is further increased when players are being evaluated or socially judged (reviews on Hill et al., 2010; Mesagno and Beckmann, 2017). Accordingly, when there is much at stake, and pressure is high, penalty takers' performance is negatively affected (Dohmen, 2008; Arrondel et al., 2019).

In addition, previous work has shown that soccer penalty kickers under pressure may behave in ways that can hinder performance maximization. Under pressure, players are more inclined to rush the preparation and the execution of the run-up toward the ball. Players who do show these avoidance coping behaviors converted 20% fewer penalties than those who take their time (Jordet et al., 2009). Research also shows that psychological pressure directly affects players' aiming. For example, in competition, penalty kicks are shot over four times more frequently toward lower zones of the goal than to the upper zones, despite the probability of scoring being significantly higher when the ball is directed toward upper areas of the goal (Bar-Eli and Azar, 2009; Almeida et al., 2016). Players seem to prefer the risk of a (low) ball being stopped by the goalkeeper over the risk of directing the (high) ball over the goal. Possibly, with respect to the latter failure, players may be apprehensive to be perceived as unskilled (Bar-Eli et al., 2009; Bar-Eli and Azar, 2009). In addition, experimental laboratory studies have indicated that increased anxiety negatively impacts attentional control and the aiming of the kick. Specifically, penalty takers looked longer toward the goalkeeper (and less toward the aiming location and/or the ball) and placed the penalties closer to the goalkeeper under high anxiety conditions (Wilson et al., 2009; c.f., Noël and Van der Kamp, 2012).

One influential account for explaining how athletes successfully cope to achieve their goals under pressure focusses on *perceived control* of the task, which refers to the athlete's beliefs about the degree of control they have over the task (Hanton et al., 2003; Jordet et al., 2006). Perceived control is conceptualized to consist of contingency expectations and self-competence. Contingency relates to the expectations of relationship between the athlete's action and the outcome, whereas self-competence perceptions relate the beliefs about the own ability (Skinner, 1996). Evidence suggests that increased anxiety can actually have a facilitative effect on performance provided the athletes maintain a good level of confidence of competence (Hanton and Connaughton, 2002; Hanton et al., 2003). Accordingly, with respect to soccer penalty kicks, Jordet et al. (2006) carried out retrospective interviews among elite players, who participated in a shoot-out during the European Championship for nation teams. They reported that penalty takers with relatively low perceived competence and contingency (i.e., players who attribute performance success to luck rather than skill) experienced enhanced cognitive anxiety and/or interpreted their somatic anxiety as more debilitative to their performance compared to players with high perceived competence and contingency. More recently, Wood and Wilson (2012) found that penalty kickers who followed a perceptual training (i.e., directing visual attention toward the aiming location prior to the kick) not only improved gaze but also reported enhanced perceived control of the task both with regard to contingency and self-competence. The enhanced perceived control was accompanied by an increment in the players' ability to cope with the pressure and to score. Yet, while these works show that perceived control is associated with the ability to cope with psychological pressure during penalty kicks (Jordet et al., 2006; Wood and Wilson, 2012; Wood et al., 2015), it has remained unclear to what extent the purported advantages of those (often retrospective) perceptions are underpinned by *actual control* of the task (rather than perceived control). Actual control is defined as the extent to which an individual can intentionally produce a desired outcome. Although actual control and perceived control are typically related, changes in actual control does entail modifications in objective control of context conditions and/or persons interactions or actions, unlike perceived control which might just be illusionary (Skinner, 1996).

One modality within actual control is an individual's autonomy in the control of and/or making decisions about intended actions, that is, the degree to which the individual can modulate the means that define task control. For example, self-controlled and externally controlled actions differ in the degree to which an athlete can choose (or not) pertinent aspects of task execution when trying to achieve the task goal. Typically, increasing self-control (e.g., having players decide upon amount of practice, the order of different practice trials, the use of models for observation, the use of assistive devices, or provision of feedback) enhances motor performance and/or learning (for overview, Wulf, 2007). For instance, in an early study by Janelle et al. (1997), which originated this line of research, participants showed better retention in the far-aiming task of ball throwing when they allowed to choose when to use evaluative video-feedback during practice in comparison to yoked counterparts who were not free to choose when to use feedback. Yet, these effects of self-control have not been thorougly investigated in elite players under condition of psychological pressure.

In soccer penalty kicks, Scurr and Hall (2009) manipulated the autonomy of players regarding the choice of the angle of approach during the run-up of kicks in no-pressure situations. In this case, the non-professional, intermediately skilled players showed similar kicking accuracy irrespective of whether they self-controlled the approach angle or whether it was pre-scribed or externally controlled. Other experimental studies in penalty kicking have used both self-controlled and externally controlled instructions for choosing the side and/or height for the placement of the ball (Morris and Burwitz, 1989; Furley et al., 2012), often in interaction with other penalty kick strategies (Castillo et al., 2010). Yet, these studies did not systematically manipulate and compare the efficacy of self- and externally controlled kicks.

In sum, the evidence indicates that with increased psychological pressure penalty kick performance deteriorates, among others because of poor decision-making about ball placement. It may therefore be anticipated that players would improve performance when they would follow instructions that would result in a more rational distribution of ball placement. However, the associated reduction of self-control over the task may adversely affect coping in pressure situations, which in turn would deteriorate performance. This has not been directly investigated. Hence, the present study manipulated the degree of autonomy of soccer penalty takers in choosing the aiming location (i.e., side and height). The players took penalty kicks in a self-controlled condition (i.e., they decided about the aiming location themselves) and in an externally controlled condition (i.e., the aiming location was imposed upon them). One group performed the kicks in a pressured condition and the second group in a no-pressure condition. It was predicted that self-control would lead to superior performance (i.e., goal scoring, ball placement and speed) and execution (i.e., preparatory and execution durations), in particular in the pressured group.

MATERIALS AND METHODS

Participants

Eighteen elite under-19 soccer players (*M* = 17.72 years old, SD = 0.83) volunteered to participate. Participants were all playing for a club that competes in the highest league in Spain for under-19 players (i.e., playing experience: *M* = 12.28 years, SD = 1.45). In addition, four goalkeepers, who were matched to the penalty takers in age (*M* = 17.40 years old, SD = 1.14), level (same league), and experience (*M* = 10.80 years, SD = 1.6) were recruited to act as actual goaltenders. Ethical approval was obtained from the local University's ethics committee, and all players provided written consent prior to the start of the experiment.

Equipment

The experiment was conducted on an outdoor artificial turf pitch. Dimensions of the goal (7.32 m × 2.44 m), ball type (size 5), and distance to the penalty mark (11 m) were in accordance with FIFA laws (IFAB, 2016). The goalmouth was fully covered with a canvas, which was divided in six equal areas of 2.44 m × 1.22 m (**Figure 1**, left). Each area was subdivided in 15 zones of 0.48 m × 0.40 m. Two cameras were employed to record the penalties. The first camera (Casio Exilim FH 100, Japan, 120 fps mode) was placed 2 m to the side and 1 m behind the penalty spot (**Figure 1**, left), in such way that recording perspective captured both the penalty taker's football contact and the outcome of the kick (i.e., the moment and location of the ball landing in the goal). A second camera (Casio Exilim FH 100, Japan, 30 fps mode) placed 3 m to the side and 2 m in front of the penalty spot recorded the preparatory actions of penalty takers (**Figure 1**, right). All recordings were analyzed with Kinovea V.0.8.25.

Finally, the anxiety of the players was assessed by means of the Competitive State Anxiety Inventory-2 (CSAI-2; Martens et al., 1990) in its revised Spanish version (CSAI-2R; Andrade et al., 2007). The questionnaire consists of 16 items (Likert-type scale from 1 to 4) distributed in three dimensions: (1) cognitive anxiety (five items), typified by negative self-images and self-doubts; (2) somatic anxiety (six items), which refers to physiological responses (e.g., increased heart rate, tense muscles, and clammy hands); and (3) self-confidence (five items) regarding the positive expectations of success (Andrade et al., 2007).

Procedure and Design

Data collection was carried out at the players' habitual training venue. Each participant received the same general instructions about the experimental session beforehand in the dressing room. They were, however, not told about the experimental conditions and/or the exact aims of the experiment. After having received the general instructions, they completed the CSAI-2R. After a self-selected warm up (i.e., lasting approximately 10 min), the participants performed four familiarization trials. Then, each participant took 10 experimental penalty kicks, and then, immediately afterward, completed the CSAI-2R once again.

The 10 experimental kicks were divided in five self-controlled and five externally controlled kicks. The players were encouraged to score as many of the 10 kicks as possible, whereas goalkeepers were told to do their very best to save them. In the self-controlled condition, the penalty takers were instructed to freely choose the area of the goal to which to aim the ball. In the externally

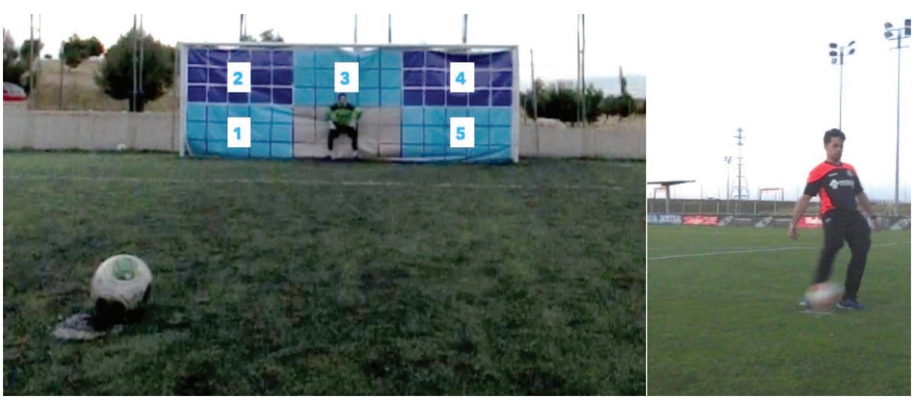

FIGURE 1 | Set up of the experiment depicting the perspective of the goal (left) and the penalty takers (right).

controlled condition, the experimenter instructed the players before the start of the run-up about the area of the goal where they had to place the ball, one shot toward each of the five outer areas (i.e., areas 1 to 5, **Figure 1**, left). The order of self-controlled and externally directed kicks was randomized using the Excel's "random" algorithm. In order to prevent that the goalkeeper became of aware of the two conditions, penalty takers followed the same routine regardless the condition. Players approached to researcher to take the ball from outside the penalty box and were shown that the goal area could be freely chosen or to which area to aim. By instructing them to pick a goal area before the start of the run-up, the procedure in the self-controlled condition promoted players to use the keeper-independent strategy (Van der Kamp, 2006; Noël et al., 2014). However, players were not explicitly instructed about it to prevent ironic effects (Bakker et al., 2006). In both conditions, there were no additional instructions regarding deception (Dicks et al., 2010) or run-up length (Van der Kamp, 2006), or angle of approach (Scurr and Hall, 2009). Finally, the players placed the ball on the penalty spot, prepared for the run-up, and executed the run-up to the ball and the kick.

Participants were ranked on the basis of the individual ability on penalty kicks and assigned to the pressure and no-pressure groups such that the two groups matched in ranking. To this end, information of the individual ability of the players was provided by the technical staff (i.e., coach and/or trainers) based on players' performance records, skill level, and previous involvement experience on competitive penalty kicks (Plessner et al., 2009). The pressure group performed the penalty kicks in the presence of the head coach and two members of the technical staff (i.e., assistant coach and physical trainer who took written notes of their performance) and were told that further decision regarding upcoming penalty shout outs of the team would be based on their performance (Note: players were fully debriefed after the experiment). By contrast, the no-pressure group took the penalty kicks only in the presence of the goalkeeper and researcher, and no further information on the importance of their performance was given.

Data Analysis

To verify anxiety, the cognitive, somatic, and self-confidence scores on the CSAI-2R were used. Performance was assessed offline from the video recordings. First, the number of penalties scored was counted. Second, the location of the kicks was determined by the area of the goal (i.e., at the center of the 15 smaller rectangles of the six areas) the ball contacted the canvas (or was intercepted) and calculated in vertical distance from the ground (i.e., height of the kick in cm) and horizontal distance from the goal center (i.e., extent of the kick in cm). Finally, the speed of the kick was calculated based on ball-flight time (i.e., differences between the moment of foot-ball contact and the moment the ball contacted the canvas or was intercepted) and the distance the ball travelled.

Two measures were used to calculate the duration of the preparatory and execution phase of the penalty kick (Jordet et al., 2009; Furley et al., 2012). The duration of the preparation phase was defined as the time between the placement of the ball on the penalty spot and the start of the run-up. The duration of the execution phase was defined as the time from the start of the run-up toward the ball until the football contact.

Statistics

To verify the effectiveness of the pressure manipulation, the ratings for anxiety were submitted to Mann-Whitney test to compare groups, whereas Wilcoxon tests were performed to compare differences between the two assessments before the experiment and immediately after. Effect sizes were expressed in *r*, with 0.1, 0.3, and 0.5 for small, medium, and large effects, respectively (Cohen, 1988). The remaining dependent variables were submitted to separate 2 (group: pressure vs. no-pressure) by 2 (autonomy: self-controlled vs. externally-controlled) Mixed Design Analysis of Variance (ANOVA). *Post hoc* comparisons were performed with t-test and Bonferroni corrections. Partial effect sizes of ANOVA's were expressed using (η_p^2), with values of 0.01, 0.06, and 0.14 representing small, medium, and large effects, respectively (Cohen, 1988). In case that the homogeneity and sphericity assumptions of the measures were not met, Mann-Whitney and Wilcoxon tests were conducted instead. IBM SPSS V. 24 was used to carry out statistical analysis.

RESULTS

Anxiety Measures

Figure 2 suggests that anxiety levels were similar between groups before taking the penalty kicks but lower for the

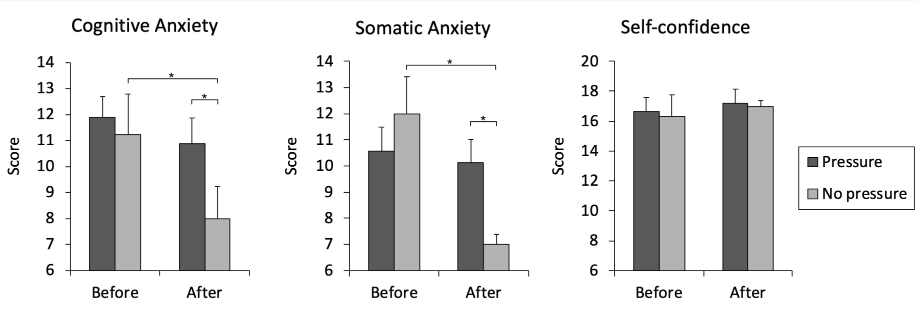

FIGURE 2 | Scores of CSAI-2R of the players before and after performing the penalty kicks. *$p < 0.05$.

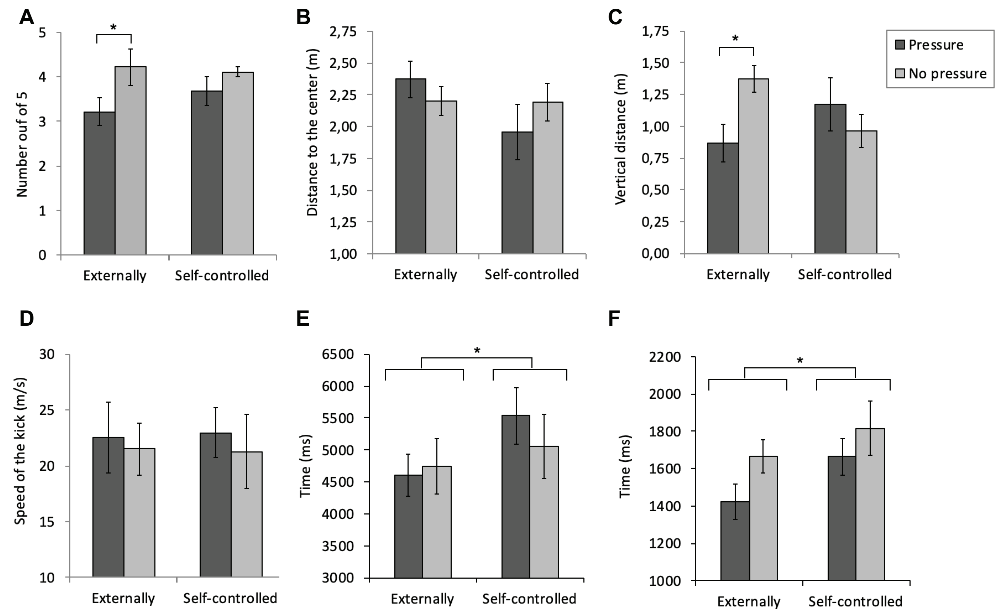

FIGURE 3 | Performance measures of the kicks **(A–D)** and penalty takers behavior **(E,F)**. Error bars represent standard error of the mean. *$p < 0.05$.

no-pressure group directly after the experiment. In other words, whereas participants of the pressure group reported moderately to high levels of anxiety throughout the experiment, these levels showed a steep drop for the no-pressure group. Accordingly, just before the experiment, no differences were found between groups for cognitive anxiety ($U = 39.50$, $p = 0.465$, $r = -0.02$), somatic anxiety ($U = 27.50$, $p = 0.129$, $r = -0.27$), or self-confidence ($U = 35.00$, $p = 0.333$, $r = -0.12$). However, immediately after the experiment, the no-pressure group showed significant lower levels of cognitive anxiety ($U = 20.00$, $p = 0.038$, $r = -0.43$), and somatic anxiety ($U = 17.50$, $p = 0.020$, $r = -0.49$) compared to pressure group (exact, unilateral). The self-confidence scores did not differ significantly between groups.

Furthermore, the no-pressure group significantly decreased both the cognitive anxiety ($z = -1.97$, $p = 0.047$, $r = -0.66$) and somatic anxiety ($z = -2.67$, $p = 0.004$, $r = -0.89$) during the experiment, whereas the pressure group maintained the scores over time (p's > 0.40). Differences in self-confidence across time were not found (**Figure 2**).

Performance Measures

Figure 3A shows that number of goals scored by the pressure group was lower than by the no-pressure group. Interestingly, it also suggests smaller differences between groups for the self-controlled compared to externally controlled condition. This was confirmed by Mann-Whitney test showing an effect of group on the number of goals scored only within the externally controlled condition ($U = 19.00$, $z = -1.97$, $p = 0.042$, $r = -0.46$) and not for the self-controlled condition ($U = 33.00$, $z = -0.79$, $p = 0.543$, $r = -0.19$). The remaining comparisons were not significant.

Autonomy had no effect on the horizontal extent (i.e., how far the ball was aimed from the goal center) as the mixed ANOVA did not reveal a significant main effect for autonomy, $F(1,16) = 2.30$, $p = 0.149$, $\eta_p^2 = 0.13$, and also not for group, $F(1,16) = 0.031$, $p = 0.862$, $\eta_p^2 < 0.01$, or their interaction, $F(1,16) = 1.98$, $p = 0.178$, $\eta_p^2 = 0.11$ (**Figure 3B**). With respect to vertical distance, the effects of autonomy and group seem to interact (**Figure 3C**). Accordingly, mixed ANOVA did not found an effect for autonomy, $F(1,16) = 0.12$, $p = 0.74$, $\eta_p^2 = 01$, and group, $F(1,16) = 1.04$, $p = 0.323$, $\eta_p^2 = 0.06$, but did reveal a significant interaction between autonomy and group ($F(1,16) = 4.81$, $p = 0.043$, $\eta_p^2 = 0.23$). *Post hoc* comparisons indicated that the pressure group placed the kicks lower than the no-pressure group but only in externally controlled condition (**Figure 3C**). In addition, we considered for the externally controlled condition to what degree the participants adhered to the instructions regarding the to-be-kicked height[1]. One-sample t-tests revealed that the pressure group aimed the kicks lower than instructed, $t(8) = -3.18$, $p = 0.013$, $df = -0.47$, $d = -1.05$, while no such difference with the instructed height was found for the no-pressure group, $t(8) = 0.30$, $p = 0.773$, $df = 0.03$, $d = 0.11$ (**Figure 3C**).

The speed of the kicks ranged between 17.9 and 28.2 m/s. Mixed ANOVA did not reveal significant effects of autonomy, $F(1,16) = 0.026$, $p = 0.875$, $\eta_p^2 < 0.01$, group, $F(1,16) = 1.39$, $p = 0.256$, $\eta_p^2 = 0.08$, or the interaction between the two factors, $F(1,16) = 0.28$, $p = 603$, $\eta_p^2 = 0.02$ (see **Figure 3D**).

Penalty takers took less time to prepare the kick in the externally controlled than during self-controlled condition, but

[1]During externally-directed condition, three kicks were intended towards the upper areas of the goal (areas 2, 3 and 4, **Figure 1**, left) and two kicks towards the lower areas (1 and 5). Taking the midpoints of the upper (1.83 m) and lower areas (0.61 m), the weighted average of the instructed height is 1.34 m.

this was not affected by pressure (**Figure 3E**). Accordingly, mixed ANOVA showed a main effect with a large effect size for autonomy on preparation time, $F(1,16) = 7.76$, $p = 0.013$, $\eta_p^2 = 0.33$, but no effects for group, $F(1,16) = 0.08$, $p = 0.776$, $\eta_p^2 < 0.1$, or between autonomy and group, $F(1,16) = 1.87$, $p = 0.191$, $\eta_p^2 = 0.10$) were found. Finally, **Figure 3F** illustrates the duration of the execution phase. Again, the duration for the externally controlled condition was shorter than in the self-controlled condition, $F(1,16) = 11.64$, $p = 0.004$, $\eta_p^2 = 0.42$. The mixed ANOVA did not reveal further effects of group, $F(1,16) = 1.84$, $p = 0.194$, $\eta_p^2 = 0.10$, or the interaction between the two factors, $F(1,16) = 0.60$, $p = 0.451$, $\eta_p^2 = 0.04$, on the run-up time.

DISCUSSION

This study examined the effect of actual self-control on coping with psychological pressure in a soccer penalty kick situation. To this end, we compared *in situ* performance of two groups of young, elite soccer players in conditions with different degrees of autonomy with respect to choosing the aiming location. Psychological pressure was effectively modulated by requiring them to take the penalty kicks in the presence of members of training staff, who–purportedly–would selectively evaluate their performances.

Research has shown that increased psychological pressure negatively affects the rate of scoring in penalty kicking (Dohmen, 2008; Wilson et al., 2009; Arrondel et al., 2019). In particular, increased pressure is associated with a hasted preparation and execution (Jordet et al., 2009) and sub-optimal ball placement (Bar-Eli and Azar, 2009; Almeida et al., 2016). The present study confirmed this: performances of the pressured group was worse compared to the no-pressure group. Importantly, however, this difference in performance was not found for the self-controlled condition. By contrast, in externally controlled condition, players under pressure actually showed signs of unsuccessful coping. They scored less goals and placed the kicks lower. Thus, the reduction in autonomy seems to be related to a reduction in the players' ability to cope with anxiety, possibly resulting in the observed drop in performance.

This finding is in line with studies that examined individual self-control or autonomy in the performance and learning of motor skills. Typically, self-control in deciding when to obtain feedback or assistance has been shown to enhance learning and performance (e.g., Janelle et al., 1997). In our study, although participants were enticed to follow a goalkeeper-independent strategy (i.e., aim the ball toward an early chosen location, irrespective of the goalkeeper's actions; Van der Kamp, 2006) in all instances, the reduction of autonomy in the externally controlled condition made the task constraints even more strict (i.e., the kicker was not allowed to change ball direction even if the goalkeeper would very clearly move in one direction long before the kick was completed). Consequently, penalty takers may have experienced a reduction of the control over the task during externally controlled kicks. The benefits of self-control have been explained by referring to motivational effects of increased autonomy, as indicated by concomitant increase in task interest, engagement, satisfaction, and self-efficacy (Sanli et al., 2013; Wulf and Lewthwaite, 2016). We did not gauge the motivational beliefs of the players in detail. Yet, we did find that the current participants' ratings of self-confidence remained high across the entire experiment and equally so in both groups. It stands to reason, therefore, that the observed benefits of self-control or autonomy in coping with pressure should also be attributed to an increase in *actual* control on task performance –and not exclusively– to a change in perceived control or other motivational beliefs. Although we meant to elicit a goalkeeper-independent strategy (see above), it cannot be ruled out that sometimes (and more often under pressure) they switched to a goalkeeper-dependent strategy. This might (partly) explain the observed advantage in self-controlled condition in the pressured group. If so, that would be contrary to previous experimental work that showed a clear advantage of GK-independent strategy (Van der Kamp, 2006; Noël and Van der Kamp, 2012; c.f., Noël et al., 2014), or at least it raises further questions on how autonomy affects the degree of adherence to either a goalkeeper independent or dependent strategy. For instance, a kicker may intend to aim to a beforehand chosen area (i.e., independent strategy) unless she/he recognizes that the goalkeeper clearly moves in advance (e.g. longer than 600 ms before ball contact, Van der Kamp, 2011) toward that intended location.

The results also showed that durations of the different phases in the penalty kick sequence was affected to a greater extent by the degree of autonomy than by psychological pressure. The pressure group did not show a significant hastening behavior (c.f., Jordet et al., 2009), but they did significantly reduce the preparation and run-up times in the externally controlled compared to the self-controlled condition. For the preparatory phase, this may be due to absent and/or reduced decision-making and planning behaviors in the externally controlled condition. During run-up phase, the slightly extra time might suggest adaptive behaviors to the actual situation, such as, responding to the goalkeeper (see above).

For future work, we recommend to include more qualitative measures (e.g., extra measures as perceived control or contingency, but also including confrontation interviews; Jordet et al., 2006) to find out in more detail what players experience in in the different conditions. For instance, whether the anxiety levels are linked to the degree of autonomy control, or how the players experience cope with pressure during the performance of the penalty kicks. In this sense, note that anxiety levels of the penalty takers were already high in the period that preceded the kicks. The group exposed to pressure maintained those levels moderately high, whereas perceived anxiety of the no-pressure group dropped. This particular fluctuation of anxiety is consistent with previous observations among expert penalty takers (Jordet and Elferink-Gemser, 2012). In this respect, it is obviously also important to verify whether adopting self-control in soccer training programs indeed can effectively increase penalty kicking performance in competitive environments.

Future research may also want to more forcefully instruct penalty takers on the strategy to be adopted (i.e., goalkeeper-independent), as well as consider the interaction between goal achievement (intended vs. reached location) and degree of autonomy control of actions. Finally, as is often the case in studies that involve elite players, the present study is low in the number of participants. Although we had the opportunity to include more, but lower skilled participants, we decided against this in order to ensure the high technical ability of participants. Hence, it is important not to overgeneralize the current findings to other groups.

CONCLUSION

This is the first experimental evidence that *actual* task control can influence coping with psychological pressure in soccer penalty kicking. Reduced degree of task control in the soccer penalty kicks can enhance the debilitating effects of high pressure as performance was shown to deteriorate when strictly following instruction of others about the aiming location. In addition, a reduced degree of autonomy also was found to result in more rushed behaviors in penalty kickers, irrespective of pressure. Finally, a coach may be inclined to forcefully instruct the players about the distribution of the penalty kicks, especially in a penalty shoot-out. However, such instructions may reduce the degree of task control and, consequently, hinder rather than improve performance, especially in stressful situations. Therefore, and based on the current observations, it seems more advisable to leave to the penalty takers themselves to choose the aiming location.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Comité de Ética de la UPM with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Comité de Ética de la UPM.

AUTHOR CONTRIBUTIONS

JN and JA contributed to the design of the study and data collection. JN performed data analysis. JK led the writing of the paper, and CA and JN significantly contributed to writing process.

REFERENCES

Almeida, C. H., Volossovitch, A., and Duarte, R. (2016). Penalty kick outcomes in UEFA club competitions (2010–2015): the roles of situational, individual and performance factors. *Int. J. Perform. Anal. Sport* 16, 508–522. doi: 10.1080/24748668.2016.11868905

Andrade, E., Lois, G., and Arce, C. (2007). Propiedades psicométricas de la versión española del inventario de ansiedad competitiva CSAI-2R en deportistas. *Psicothema* 19, 150–155.

Arrondel, L., Duhautois, R., and Laslier, J.-F. (2019). Decision under psychological pressure: the shooter's anxiety at the penalty kick. *J. Econ. Psychol.* 70, 22–35. doi: 10.1016/j.joep.2018.10.008

Bakker, F., Oudejans, R., Binsch, O., and Van der Kamp, J. (2006). Penalty shooting and gaze behavior: unwanted effects of the wish not to miss. *Int. J. Sport Psychol.* 37, 265–280.

Bar-Eli, M., and Azar, O. H. (2009). Penalty kicks in soccer: an empirical analysis of shooting strategies and goalkeepers' preferences. *Soccer Soc.* 10, 183–191. doi: 10.1080/14660970802601654

Bar-Eli, M., Azar, O. H., and Lurie, Y. (2009). (Ir)rationality in action: do soccer players and goalkeepers fail to learn how to best perform during a penalty kick? *Prog. Brain Res.* 174, 97–108. doi: 10.1016/S0079-6123(09)01309-0

Castillo, J. M., Oña, A., Raya, A., Bilbao, A., and Serra, E. (2010). Tactical skills and ball speed during a field simulation of penalty kick strategies in soccer. *Percept. Mot. Skills* 111, 947–962. doi: 10.2466/05.23.24.27.PMS.111.6.947-962

Cohen, J. (1988). *Statistical power analysis for the behavioural science.* 2nd edn. (New York: Academic Press).

Dicks, M., Button, C., and Davids, K. (2010). Availability of advance visual information constrains association-football goalkeeping performance during penalty kicks. *Perception* 39, 1111–1124. doi: 10.1068/p6442

Dohmen, T. J. (2008). Do professionals choke under pressure? *J. Econ. Behav. Organ.* 65, 636–653. doi: 10.1016/j.jebo.2005.12.004

Furley, P., Dicks, M., Stendtke, F., and Memmert, D. (2012). "Get it out the way. The wait's killing me." hastening and hiding during soccer penalty kicks. *Psychol. Sport Exerc.* 13, 454–465. doi: 10.1016/j.psychsport.2012.01.009

Hanton, S., and Connaughton, D. (2002). Perceived control of anxiety and its relationship to self-confidence and performance. *Res. Q. Exerc. Sport* 73, 87–97. doi: 10.1080/02701367.2002.10608995

Hanton, S., O'Brien, M., and Mellalieu, S. D. (2003). Individual differences, perceived control and competitive trait anxiety. *J. Sport Behav.* 26, 39–55.

Hill, D. M., Hanton, S., Matthews, N., and Fleming, S. (2010). Choking in sport: a review. *Int. Rev. Sport Exerc. Psychol.* 3, 24–39. doi: 10.1080/17509840903301199

IFAB (2016). *Laws of the game*. (Zurich: FIFA).

Janelle, C. M., Barba, D. A., Frehlich, S. G., Tennant, L. K., and Cauraugh, J. H. (1997). Maximizing performance feedback effectiveness through videotape replay and a self-controlled learning environment. *Res. Q. Exerc. Sport* 68, 269–279. doi: 10.1080/02701367.1997.10608008

Jordet, G., and Elferink-Gemser, M. T. (2012). Stress, coping, and emotions on the world stage: the experience of participating in a major soccer tournament penalty shootout. *J. Appl. Sport Psychol.* 24, 73–91. doi: 10.1080/10413200.2011.619000

Jordet, G., Elferink-Gemser, M. T., Lemmink, K. A., and Visscher, C. (2006). The "Russian roulette" of soccer?: perceived control and anxiety in a major tournament penalty shootout. *Int. J. Sport Psychol.* 37, 281–298.

Jordet, G., Hartman, E., and Sigmundstad, E. (2009). Temporal links to performing under pressure in international soccer penalty shootouts. *Psychol. Sport Exerc.* 10, 621–627. doi: 10.1016/j.psychsport.2009.03.004

Martens, R., Burton, D., Vealey, R. S., Bump, L. A., and Smith, D. E. (1990). "Development and validation of the competitive state anxiety inventory-2" in *Competitive anaxiety in sport*. eds. R. Martens, R. S. Vealey, and D. Burton (Champaign: Human Kinetics), 117–190.

Mesagno, C., and Beckmann, J. (2017). Choking under pressure: theoretical models and interventions. *Curr. Opin. Psychol.* 16(Suppl. C), 170–175. doi: 10.1016/j.copsyc.2017.05.015

Morris, A., and Burwitz, L. (1989). Anticipation and movement strategies in elite soccer goalkeepers at penalty kicks. *J. Sports Sci.* 7, 79–80.

Noël, B., Furley, P., Van der Kamp, J., Dicks, M., and Memmert, D. (2014). The development of a method for identifying penalty kick strategies in association football. *J. Sports Sci.* 33, 1–10. doi: 10.1080/02640414.2014.926383

Noël, B., and Van der Kamp, J. (2012). Gaze behaviour during the soccer penalty kick: an investigation of the effects of strategy and anxiety. *Int. J. Sport Psychol.* 41, 1–20.

Palacios-Huerta, I. (2003). Professionals play minimax. *Rev. Econ. Stud.* 70, 395–415. doi: 10.1111/1467-937X.00249

Plessner, H., Unkelbach, C., Memmert, D., Baltes, A., and Kolb, A. (2009). Regulatory fit as a determinant of sport performance: how to succeed in a soccer penalty-shooting. *Psychol. Sport Exerc.* 10, 108–115. doi: 10.1016/j.psychsport.2008.02.001

Sanli, E., Patterson, J., Bray, S., and Lee, T. (2013). Understanding self-controlled motor learning protocols through the self-determination theory. *Front. Psychol.* 3. doi: 10.3389/fpsyg.2012.00611

Scurr, J., and Hall, B. (2009). The effects of approach angle on penalty licking accuracy and kick kinematics with recreational soccer players. *J. Sports Sci. Med.* 8, 230–234.

Skinner, E. A. (1996). A guide to constructs of control. *J. Pers. Soc. Psychol.* 71, 549–570. doi: 10.1037/0022-3514.71.3.549

Van der Kamp, J. (2006). A field simulation study of the effectiveness of penalty kick strategies in soccer: late alterations of kick direction increase errors and reduce accuracy. *J. Sports Sci.* 24, 467–477. doi: 10.1080/02640410500190841

Van der Kamp, J. (2011). Exploring the Merits of Perceptual Anticipation in the Soccer Penalty Kick. *Motor Control* 15, 342–358.

Van der Kamp, J., Dicks, M., Navia, J. A., and Noël, B. (2018). Goalkeeping in the soccer penalty kick. *Ger. J. Exerc. Sport Res.* 48, 169–175. doi: 10.1007/s12662-018-0506-3

Wilson, M., Wood, G., and Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *J. Sport Exerc. Psychol.* 31, 761–775. doi: 10.1123/jsep.31.6.761

Wood, G., Jordet, G., and Wilson, M. R. (2015). On winning the "lottery": psychological preparation for football penalty shoot-outs. *J. Sports Sci.* 33, 1758–1765. doi: 10.1080/02640414.2015.1012103

Wood, G., and Wilson, M. R. (2012). Quiet-eye training, perceived control and performing under pressure. *Psychol. Sport Exerc.* 13, 721–728. doi: 10.1016/j.psychsport.2012.05.003

Wulf, G. (2007). Self-controlled practice enhances motor learning: implications for physiotherapy. *Physiotherapy* 93, 96–101. doi: 10.1016/j.physio.2006.08.005

Wulf, G., and Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: the OPTIMAL theory of motor learning. *Psychon. Bull. Rev.* 23, 1382–1414. doi: 10.3758/s13423-015-0999-9

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Longitudinal Study of Individual Exercises in Elite Rhythmic Gymnastics

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The performance evolution in rhythmic gymnastics depends on changes in code of points. At the beginning of each Olympic cycle the code of points changes and therefore, the content of the competition exercises, as well. This study aimed to analyze – for each apparatus – the evolution of number of technical elements and final score over the last two decades (last 13 world championships), how they have been affected by changed code of points, and how the final score relates to the number of technical elements performed. The sample consisted of 416 exercises in five apparatus: ball (96), rope (40), hoop (96), ribbon (88), and clubs (96). The following variables were gathered: code of points, apparatus, technical group, total number of elements, final classification, and final score. Linear mixed-effects models were used to examine the effects on the number of elements and final score in each apparatus. The number of technical elements increased in all apparatus, between 7.4 and 20% over a 10-year period. There were mixed evolutions of final score between the different apparatus, between −6.3 and 14% over a 10-year period. There is small increase in number of elements in hoop and a small decrease in rope after a code change. There was a small decrease in final score in championships after a code change in hoop, moderate in clubs and ribbon, and large in rope. There was a negative relationship between number of elements performed and final score in clubs. In conclusion, the code change generally effects the final score negatively, but there were apparatus specific effects of code change on number of elements and relationship between number of elements and final score.

Keywords: code of points, apparatus, technical elements, performance analysis, rule change, world championship

INTRODUCTION

Rhythmic gymnastics is a sport that combines technical, aesthetic, and artistic parameters with the aim of reproducing an optimal execution model, both in matter of form and execution (Díaz-Pereira et al., 2014). When a gymnast performs her competition routine, she coordinates her body movements with handling of an apparatus (ball, clubs, tape, hoop or rope) in a choreographic composition accompanied by music.

The optimal execution model that the gymnast strive for is determined by both quantitative and qualitative criteria specified in the code of points. The code of points is set by the International Gymnastics Federation and are updated each Olympic cycle. It is therefore, considered the basis for the internal logic of the sport or strategy (the possibilities of interaction of gymnast with space, time, apparatus, with other gymnast, and with the criteria of success or failure), as well as a key factor when composing the competition routines and practice planning (Ávila-Carvalho et al., 2012a; Massidda and Calò, 2012; Leandro et al., 2017).

In the last 20 years, the International Gymnastics Federation has made numerous changes to the code of points aiming to increase the objectivity of the judges scoring, and to stimulate the development of the sport. These code changes have resulted in structural changes to the competition routines. For example, Ávila-Carvalho et al. (2011) have shown that the compositions of the routines have evolved toward increasing the difficulty and variety in body movements, and toward a higher technical mastery and enrichment in the apparatus handling.

In an attempt to understand the competitive model and performance in the rhythmic gymnastics, several studies have analyzed the composition of competition routines, both in group and individual events (Ávila-Carvalho et al., 2011, 2012a; Trifunov and Slovodanka, 2013; Agopyan, 2014). However, most have analyzed a single competition, and none have considered the changes in the code of points over time. Moreover, they have focused solely on the artistic content or on the difficulty of the body movements. Further, the results of these studies have highlighted the constant and rapid evolution of the sport, stressing the need to continuously perform these kind of studies (Čuk et al., 2012; Hökelmann et al., 2012; Massidda and Calò, 2012; Bučar et al., 2013; Pelin, 2013).

Given the limitations in earlier studies, there is a need for longitudinal studies analyzing the evolution of competition routine compositions and performance over time, which would provide valuable new information on the factors affecting the performance in rhythmic gymnastics (Ávila-Carvalho et al., 2012b; Leandro et al., 2017). Further, it could provide new insight into the effects of changes to the code of points on the performance. Finally, it would provide valuable insights for rhythmic gymnastics coaches, enabling them to make more informed decisions when planning practices and learning activities to improve the skills in each apparatus. This study aims to analyze – for each apparatus – the evolution of number of technical elements and final score over the last two decades (last 13 world championships), how they have been affected by changed code of points, and how the final score relates to the number of technical elements performed.

MATERIALS AND METHODS

Sample

The sample consisted of 416 individual rhythmic gymnastics routines performed in the final round of each apparatus in the last 13 rhythmic gymnastics world championships (1997–2018). The total sample comprised 96 ball, 96 clubs, 96 hoop, 88 ribbon, and 40 rope routines. Only four of the apparatus are used in each competition, with the International Gymnastics Federation choosing which are to be included before each championship. Which apparatus were used in each championship is presented in **Table 1**. Eight routines were performed in all final rounds for each apparatus and championship. The study was conducted in accordance with the ethical standards of sports science (Harris and Atkinson, 2009). The study did not require an ethical committee approval, as only publicly available data was used.

Procedure and Variables

Video recordings of all routines were obtained from the International Gymnastics Federation website[1]. All recordings were checked to ensure that the entire surface of the floor and the gymnast's performance were visible throughout the routine. Two international rhythmic gymnastics judges (Ph.D. in sports science and rhythmic gymnastics) with at least of 15 years of international judging experience observed the recordings and counted the number of elements performed in each routine. The final score was taken from the official records on the International Gymnastics Federation website. The year, apparatus, code of points used, number of elements, and final score was registered for each routine.

Each apparatus has a number of technical groups determined by the code of points (**Table 2**). The judges recorded the elements performed within each technical group of the apparatus used for the routine. The sum of elements in all technical groups was then considered as the total number of elements in the routine. To assess the reliability, 10 randomly chosen routines (two for each apparatus) were observed by both judges. After a period of 2 weeks, the routines were re-observed. The inter-rater reliability was, for ball ICC(2,1) = 1, clubs ICC(2,1) = 0.98, hoop ICC(2,1) = 1, ribbon ICC(2,1) = 0.96, rope = 0.87. The intra-rater reliability was, for ball ICC(2,1) = 0.96, clubs ICC(2,1) = 1, hoop ICC(2,1) = 1, ribbon ICC(2,1) = 0.96, rope = 0.87.

The code of points was transformed into a dichotomous variable (code change), indicating whether the code of points used was the same as in the previous championship or had changed. No change of code of points was considered as reference in all analyses. As the maximal obtainable score varied between the different code of points, all scores were rescaled to a maximum of 20 points, which is the maximum score. To measure the evolution over time, a continuous variable indicating the year of the championship was used. The maximum point and whether the code of points changed for each championship is presented in **Table 1**.

Statistical Analysis

All statistical analyses and graphics were produced using R 3.5.1. The mean and standard deviation (SD) for each apparatus and championship are presented graphically together with the occurrence of code change.

[1] www.gymnastics.sport

TABLE 1 | Code change, maximum score, and apparatus used in each championship.

Championship	Code change	Maximum score	Ball	Clubs	Hoop	Ribbon	Rope
Berlin 1997	Change	10	✓	–	✓	✓	✓
Madrid 2001	Change	30	✓	✓	✓	–	✓
Budapest 2003	Stable	30	✓	✓	✓	✓	–
Baku 2005	Change	20	✓	✓	✓	✓	–
Patras 2007	Stable	20	–	✓	✓	✓	✓
Mie 2009	Change	30	✓	✓	–	✓	✓
Moscow 2010	Stable	30	✓	✓	✓	–	✓
Montpelier 2011	Stable	30	✓	✓	✓	✓	–
Kiev 2013	Change	20	✓	✓	✓	✓	–
Izmir 2014	Stable	20	✓	✓	✓	✓	–
Stuttgart 2015	Stable	20	✓	✓	✓	✓	–
Pesaro 2017	Change	20	✓	✓	✓	✓	–
Sofia 2018	Stable	20	✓	✓	✓	✓	–

Linear mixed-effects models were used to assess the evolution over time and the effects of code change on the number of elements performed. A linear model was fitted to predict the number of elements for each apparatus, including year as continuous, and code change as dichotomous fixed effects. The models included random intercepts for the individual gymnasts, as well as for each competition. Further, linear mixed-effects models were also used to assess the evolution over time, effect of code change and of number of elements on the final score. A linear model was fitted to predict the final score for each apparatus, including year as continuous, code change as dichotomous, and number of elements as continuous fixed effects. The models included random intercepts for the individual gymnasts, as well as for each competition.

By using regression modeling, it is possible to assess the specific effects of each variable, accounting for the influence of the other ones. As each apparatus comprise its own independent competition, a model was fitted to each of them in both cases. To account for repeated measures of the same gymnast in several championships, gymnast was included as a random factor in the model. To account for the potential influence of different maximum scores in the championships on final score and number of elements, it was included as a fixed factor.

Initially, all two-way interactions were included in the model. However, the interaction between year and number of elements had no effect on the final score and was therefore excluded from the final models. The assumptions of normality and homoscedasticity of residuals were checked by inspecting qq-plots, plots of residual vs. predicted values, residuals vs. predictors and SDs for the different levels of the predictors. The inspection did not reveal violations of the assumptions.

The difference in number of elements and final score between championships with and without code change are presented using estimated marginal means, with 95% confidence intervals (CI). The evolution of number of elements and final score over a 10-year time period is presented by multiplying the simple effect of year by 10 and are also expressed as percentages of the grand mean. This is done both overall for the full sample and comparing between championships with and without code change. Finally, the relationship between final score and number of elements are presented as standardized effect sizes by multiplying the simple effects of number of elements by two SD of the number of elements in the original sample. Standardized effect sizes were also calculated by dividing the difference by the SD derived from all random variance components of the models (Westfall et al., 2014). The standardized effect sized for the number of elements are interpreted as small (≥0.2), moderate (≥0.6), large (≥1.2), very large (≥2.0) and extremely large (≥4.0) (Hopkins et al., 2009). For final score, the standardized effect sizes are interpreted as small (≥0.3), moderate (≥0.9), large (≥1.6), very large (≥2.5) and extremely large (≥4.0) (Malcata and Hopkins, 2014).

RESULTS

The mean and SD of number of elements and final score for each championship and apparatus are presented in **Figures 1**, **2**. The evolution over time, together with indications of when

TABLE 2 | Technical groups in each apparatus.

Apparatus	Technical groups
Ball	Throws and catches, bounces, roll on the floor, roll over body segments, unstable balance, and handling.
Clubs	Small circles, mills, throws and catches, tappings, asymmetric movements, unstable balance, and handling.
Hoop	Roll on the floor, roll over body segments, rotations, throws and catches, passing through, passing over, unstable balance, and handling.
Ribbon	Spirals, snakes, throws and catches, boomerang throw, releases, passing through, passing over, and handling.
Rope	Passing through with jump, passing through with a part of body, throws and catches, releases and catches, rotations, unstable balance, and handling.

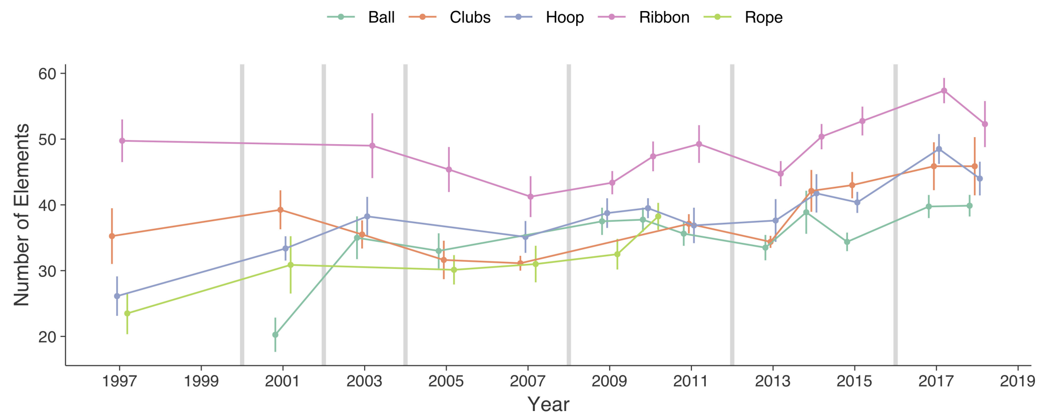

FIGURE 1 | Evolution of average number of elements with standard deviation for each apparatus. Vertical lines indicate code change.

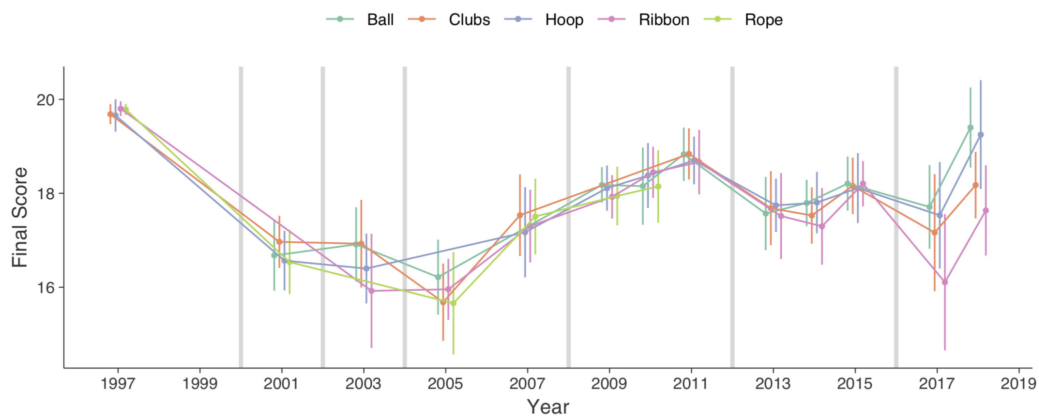

FIGURE 2 | Evolution of average final score with standard deviation for each apparatus. Vertical lines indicate code change.

TABLE 3 | Estimated means with and without code change for number of elements and final score.

	No code change			Code change								
		95% CI			95% CI			95% CI			95% CI	
	Estimate	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**	**Difference**	**Lower**	**Upper**	**ES**	**Lower**	**Upper**
Number of elements												
Ball	35.8	27.0	44.5	35.3	30.1	40.6	−0.4	−11.1	10.2	−0.1	−1.6	1.4
Clubs	38.3	32.8	43.8	37.9	32.2	43.6	−0.4	−8.7	7.8	0.0	−1.0	0.9
Hoop	37.4	34.9	39.9	39.7	36.8	42.6	2.3	−1.7	6.4	0.4	−0.3	1.1
Ribbon	48.7	44.3	53.0	48.4	43.3	53.6	−0.3	−7.1	6.6	0.0	−0.9	0.9
Rope	32.0	16.2	47.7	30.1	14.8	45.4	−1.9	−28.1	24.4	−0.3	−5.0	4.3
Final score												
Ball	17.5	17.0	18.1	17.5	17.2	17.9	0.0	−0.7	0.7	0.0	−0.5	0.6
Clubs	18.6	17.7	19.4	16.9	16.0	17.8	−1.7	−3.0	−0.4	−0.9	−1.7	−0.2
Hoop	18.3	17.5	19.2	17.4	16.5	18.4	−0.9	−2.2	0.4	−0.5	−1.2	0.2
Ribbon	18.2	17.8	18.6	16.6	16.1	17.0	−1.6	−2.2	−1.0	−1.1	−1.5	−0.7
Rope	19.0	16.1	21.8	16.1	13.6	18.6	−2.9	−9.0	3.2	−2.1	−6.6	2.4

CI, confidence interval; ES, effect size.

code changes occurred are presented graphically for number of elements (**Figure 1**) and final score (**Figure 2**).

The estimated means of number of elements and final score for championships with and without code change, when accounting for change over time and number of elements, are presented in **Table 3** together with the raw and standardized difference. There is no clear general difference in number of elements between championships with and without code change. There is small increase in number of elements in hoop and a small decrease in rope after a code change. The final score is generally lower in championships after a code change, with small difference in hoop, moderate in clubs and ribbon, and large in rope.

The estimated evolution over a 10-year period of number of elements and final score, when accounting for all other effects, are presented in **Table 4**. Moreover, the estimated evolution for championships with and without code change, as well as difference are also presented in **Table 4**. The number of elements has increased for all apparatus. Over a 10-year period, it increased 20% in ball, 12% in clubs, 20% in hoop, 7.4% in ribbon and 13% in rope. The final score seems to have increased in ball and decreased in clubs and rope. Over a 10-year period, the change was 14% in ball, −1.7% in clubs, 2.8% in hoop, −0.6% in ribbon and −6.3% in rope. The increase is higher in ribbon and rope.

The estimated standardized effect of number of elements on the final score, when accounting for all other effects, are presented in **Table 5** together with the separate effects for championships with and without code change and the difference. The effects are reported as the amount of change in final score produced by a change of 2 SD in number of elements. There is no clear general relationship between number of elements performed and final score. The only clear relationship is a negative one in clubs. In ball there is a small difference, with a negative relationship in championships without rule change, and a positive relationship in championships with code change. In rope, there is also a small difference, with a positive relationship in championships without rule change, and a negative relationship in championships with code change.

DISCUSSION

The aims of this study were to analyze the evolution of the performance in rhythmic gymnastics in the last two decades and describe how the number of technical elements performed with the apparatus are related to the performance of the gymnasts. In general, the changes to the code of points have affected the number of technical elements performed and the final score differently for the different apparatus. The relationship between number of technical elements and final score were also apparatus specific. According to Ávila-Carvalho et al. (2012b), the technical apparatus elements used in the routine composition varies according to the type of apparatus, stressing the importance of studying each apparatus separately. If the

TABLE 4 | Estimated 10-year evolution overall, with and without code change for number of elements and final score.

				No code change			Code change								
		95% CI			95% CI			95% CI			95% CI			95% CI	
	Estimate	Lower	Upper	Estimate	Lower	Upper	Estimate	Lower	Upper	Difference	Lower	Upper	ES	Lower	Upper
Number of elements															
Ball	7.1	−7.9	22.1	5.4	−18.8	29.6	8.8	−1.6	19.3	3.4	−18.8	25.6	0.5	−2.7	3.6
Clubs	4.7	−1.0	10.5	5.9	−2.6	14.4	3.5	−6.9	14.0	−2.4	−17.6	12.9	−0.3	−2.0	1.5
Hoop	7.6	4.6	10.6	7.8	3.7	12.0	7.3	1.9	12.8	−0.5	−8.0	7.1	−0.1	−1.4	1.2
Ribbon	3.6	−2.3	9.6	3.1	−4.3	10.5	4.2	−6.3	14.6	1.0	−12.6	14.6	0.1	−1.7	1.9
Rope	4.1	−27.7	35.8	6.3	−39.5	52.2	1.8	−42.2	45.7	−4.6	−68.2	59.0	−0.8	−12.1	10.4
Final score															
Ball	2.5	1.6	3.5	3.2	1.7	4.7	1.9	1.1	2.6	−1.4	−2.8	0.1	−0.2	−0.4	0.0
Clubs	−0.3	−1.2	0.7	−1.2	−2.6	0.2	0.7	−1.0	2.4	1.8	−0.7	4.3	0.2	−0.1	0.5
Hoop	0.5	−0.6	1.5	−0.2	−1.6	1.2	1.1	−0.7	3.0	1.3	−1.2	3.9	0.2	−0.2	0.7
Ribbon	−0.1	−0.7	0.5	−1.4	−2.1	−0.7	1.2	0.3	2.2	2.7	1.4	4.0	0.4	0.2	0.5
Rope	−1.1	−6.1	4.0	−3.5	−8.8	1.7	1.4	−10.4	13.3	5.0	−4.5	14.5	0.9	−0.8	2.6

CI, confidence interval; ES, effect size.

TABLE 5 | Estimated effect of two standard deviation change in number of elements on final score overall, with and without rule change.

				No code change			Code change								
		95% CI			95% CI			95% CI			95% CI			95% CI	
	Estimate	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**	**ES**	**Lower**	**Upper**
Ball	0.3	−0.4	1.1	−0.4	−1.6	0.8	1.1	0.1	2.0	1.5	0.0	3.0	0.3	0.0	0.5
Clubs	−0.6	−1.2	0.1	−0.3	−1.1	0.6	−0.9	−1.8	0.1	−0.6	−1.8	0.6	−0.1	−0.3	0.1
Hoop	0.0	−0.5	0.6	0.3	−0.7	1.3	−0.2	−0.8	0.4	−0.5	−1.7	0.6	−0.1	−0.2	0.1
Ribbon	0.2	−0.4	0.8	0.2	−0.6	1.0	0.2	−0.7	1.1	0.0	−1.1	1.2	0.0	−0.1	0.1
Rope	−0.1	−0.6	0.3	1.0	0.4	1.7	−1.3	−2.0	−0.7	−2.3	−3.2	−1.4	−0.3	−0.4	−0.2

CI, confidence interval; ES, effect size.

work with an apparatus implies a technique and a specific coordination with the body, it also implies specific motor and physical performance (Botti and Nascimento, 2011). However, care should be taken when interpreting the results for rope, as it has not been present in any world championship since 2010.

During the two decades observed, the number of technical elements has increased for all apparatus. This suggests that the impact of apparatus skills on the final score has increased, as well as the coordination between the movement of the apparatus and body (Tsopani et al., 2012). In the same way, this increase has meant that each modification to the code of points have sought an increased precision in the performance evaluation criteria. There was no clear effect of code change on the number of elements or its evolution over time, which might mean that the code changes had not substantial effect on the number of elements. It might also mean that the different code changes affected the number of elements differently. Leandro et al. (2015) points out that the updates to the code of points are directed toward increasing the complexity of the interaction between the gymnast and the apparatus in the routines, either through an increase in number of elements or the degree of coordination difficulty. The characteristics of the specific apparatus might affect the amount of possible ways for the gymnasts to interact with the apparatus.

In championships with a new code of points, the final score decreased. That is, a code change significantly affects the performance of the gymnasts, who must modify their workouts and learn new possible technical elements. Aspects such as the variety and diversity of the compositions can be compromised, and until a stabilization of the score code occurs, the richness and spectacularity of the compositions diminish. Similarly, a code change means both new evaluation criteria and implementations, as well as the fact that new technical elements are introduced. All this contributes to the quality of the artistic composition of a routine and to the development of the sport (Levre, 2011). Leandro et al. (2017) point out the difficulty of making an accurate judgment in the elements of the apparatus. Particularly, the technical elements of the apparatus, such as masters, are considered by the judges to be less objective to evaluate. The work with the apparatus sometimes demands an extraordinary coordination, perfect technical control and specificity that hinder the work of the judge. Each new code change requires a search by the coaches for skilful interaction (gymnast-apparatus) and the increase of technical elements of the apparatus in the compositions, with the aim of improving the performance in competition. In the same way, for the judges it requires the definition of new objective criteria that allows a correct and precise evaluation of the performance.

As for the relationship between number of elements and final score, the only clear findings were that higher number of elements relates to lower final score in clubs. As pointed out above, the specific characteristics of each apparatus affects the relationship between number of elements and final score. There seem to be a more positive relationship between number of elements and final score in competitions with rule change in ball and a negative one in rope. Probably, as with the hoop and clubs, the characteristics of the ball and the rope would allow us to understand this relationship. However, the lack of data related to rope does not allow us to have an objective assessment (it has not been in competition for the last 8 years).

The present study has some limitations that should be considered. The analysis of competition routines should also focus on qualitative aspects of the technical elements of each apparatus, such as variety and diversity. These aspects are determining factors in the quality and richness of the compositions and they contribute to the development and evolution of the sport, and therefore its modernization. Therefore, an evaluation of judges and coaches on the changes that the code of points makes, both in the training models and in the evaluation criteria, would increase the perspective of analysis of the presented data.

CONCLUSION

Throughout the evaluated period, the number of technical elements of the apparatus that the gymnasts perform in their competition routines has increased, although each time the code of points change the performance of the gymnasts decreases. With each Olympic cycle new forms of coordination between gymnast and apparatus must be developed, which has increased the repercussion of the technical elements of the apparatus in the score of the competition routines and the complexity of the compositions.

This type of analysis provides information about the performance indicators as well as knowing how they are affected by the changes in the code of points. This information can be used by coaches to improve the composition strategies of the exercises, both increasing the complexity of the technical elements and the interaction between gymnast and apparatus. It also provides information to the judges for the definition of new evaluation criteria that allows a better adjustment of the evaluation in competition.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors participated in the study design, documentation, development, and writing of the manuscript.

REFERENCES

Agopyan, A. (2014). Analysis of the body movement difficulties of individual elite rhythmic gymnastics at London 2012 Olympic games finals. *J. Sci. Res.* 19, 1554–1565.

Ávila-Carvalho, L., Klentrou, P., and Levre, E. (2012a). Handling, throws, catches and collaborations in elite group rhythmic gymnastics. *Sci. Gymnastics J.* 4, 37–47.

Ávila-Carvalho, L., Klentrou, P., Palomero, M., and Levre, E. (2012b). Analysis of the technical content of elite rhythmic gymnastics group routines. *Open Sports Sci. J.* 5, 146–153. doi: 10.2174/1875399x01205010146

Ávila-Carvalho, L., Palomero, M., and Levre, E. (2011). Estudio del valor artístico de los ejercicios de conjunto de Gimnasia Rítmica de la Copa del Mundo de Portimao 2017 y 2008. *Apunts Educ. Física y Deporte* 103, 68–75.

Botti, M., and Nascimento, J. V. (2011). The teaching-learning-training process in rhythmic gymnastics supported by the ecological theory. *Sci. Gymnastics J.* 3, 35–48.

Bučar, M., Čuk, I., Pajek, J., Kovac, M., and Leskosek, B. (2013). Is the quality of judging in women artistic gymnastics equivalent at major competitions of different levels? *J. Hum. Kinet.* 37, 173–181. doi: 10.2478/hukin-2013-0038

Čuk, I., Fink, H., and Leskošek, B. (2012). Modeling the final score in artistic gymnastics by different weights of difficulty and execution. *Sci. Gymnastics J.* 4, 73–82.

Díaz- Pereira, M. P., Gómez-Conde, I., Escalona, M., and Olivieri, D. M. (2014). Automatic recognition and scoring of olympic rythmic gymnastic movements. *Hum. Mov. Sci.* 34, 63–80. doi: 10.1016/j.humov.2014.01.001

Harris, D. J., and Atkinson, G. (2009). Ethical standards in sport and exercise science research. *Int. J. Sport Med.* 30, 701–702. doi: 10.1055/s-0029-1237378

Hökelmann, A., Breitkreutz, T., and Livioty, G. (2012). "Changes in performance structure during group competitions in rhythmic gymnastics," in *Book of Abstracts of the World Congress of the Performance Analysis of Sport IX*, eds M. Peters and P. O. Ďonoghue (Worcester: University of Worcester).

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–12. doi: 10.1249/MSS.0b013e31818cb278

Leandro, C., Ávila-Carvalho, L., Sierra-Palmeiro, E., and Bobo Arce, M. (2015). Accuracyin judgment the difficulty score in elite rhythmic gymnastics individual routines. *Sci. Gymnastics J.* 7, 81–93.

Leandro, C., Ávila-Carvalho, L., Sierra-Palmeiro, E., and Bobo Arce, M. (2017). Judging in rhythmic gymnastics at diferente levels of performance. *J. Hum. Kinet.* 60, 159–165. doi: 10.1515/hukin-2017-0099

Levre, E. (2011). *Technical principles for the new framework. Crossroads to the future*. Switzerland: International Federation of Gymnastics Scientific Commission, 1–8.

Malcata, R. M., and Hopkins, W. G. (2014). Variability of competitive performance of elite athletes: a systematic review. *Sports Med.* 44, 1763–1774. doi: 10.1007/s40279-014-0239-x

Massidda, M., and Calò, M. C. (2012). Performance scores and standings during the 43rd artistic gymnastics world championships, 2011. *J. Sports Sci.* 30, 1415–1420. doi: 10.1080/02640414.2012.710759

Pelin, R. A. (2013). Studies regarding the rhythmic gymnastics from the olympic games. *Sport Soc.* 13:61. doi: 10.1136/bjsports-2017-09 7972

Trifunov, T., and Slovodanka, D. (2013). The structure of difficulties in the routines of the best world and serbian rhythmic gymnastics. *Fizička Kultura* 67, 120–129. doi: 10.5937/fizkul1302120t

Tsopani, D., Dallas, G., Tasika, N., and Tinto, A. (2012). The effect of different teaching system in learning rhythmic gymnastics apparatus motor skills. *Sci. Gymnastics J.* 4, 55–62.

Westfall, J., Kenny, D. A., and Judd, C. M. (2014). Statistical power and optimal design in experiments in which samples of participants respond to samples of stimuli. *J. Exp. Psychol. Gen.* 143, 2020–2045. doi: 10.1037/xge000 0014

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Making Every "Point" Count: Identifying the Key Determinants of Team Success in Elite Men's Wheelchair Basketball

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Wheelchair basketball coaches and researchers have typically relied on box score data and the Comprehensive Basketball Grading System to inform practice, however, these data do not acknowledge how the dynamic perspectives of teams change, vary and adapt during possessions in relation to the outcome of a game. Therefore, this study aimed to identify the key dynamic variables associated with team success in elite men's wheelchair basketball and explore the impact of each key dynamic variable upon the outcome of performance through the use of binary logistic regression modeling. The valid and reliable template developed Francis et al. (2019) was used to analyze video footage in SportsCode from 31 games at the men's 2015 European Wheelchair Basketball Championships. The 31 games resulted in 6,126 rows of data which were exported and converted into a CSV file, analyzed using R (R Core Team, 2015) and subjected to a data modeling process. Chi-square analyses identified significant ($p < 0.05$) relationships between Game Outcome and 19 Categorical Predictor Variables. Automated stepwise binary regression model building was completed using 70% of the data (4,282 possessions) and produced a model that included 12 Categorical Predictor Variables. The accuracy of the developed model was deemed to be acceptable at accurately predicting the remaining 30% of the data (1,844 possessions) and produced an area under the receiver operating characteristic curve value of 0.759. The model identified the odds of winning are more than double when the team in possession are in a state of winning at the start of the possession are increased five-fold when the offensive team do not use a 1.0 or 1.5 classified player, but are increased six-fold when the offensive team use three or more 3.0 or 3.5 players. The final model can be used by coaches, players and support staff to devise training and game strategies that involve selecting the most appropriate offensive and defensive approaches when performing ball possessions to enhance the likelihood of winning in elite men's wheelchair basketball.

Keywords: sport performance analysis, Paralympic, European championships, logistic regression, predictive modeling

INTRODUCTION

Wheelchair basketball is a very popular disability sport (Sporner et al., 2009), with over 105 nations registered with the sport's international body, the International Wheelchair Basketball Federation [IWBF] (2019b). The rules of wheelchair basketball are very similar to running basketball albeit with basic rule adaptions to meet the needs of playing the game in a wheelchair, and with the primary objective of scoring more points than their opponents (International Wheelchair Basketball Federation [IWBF], 2019a). In an attempt to ensure fair and equitable competition the IWBF introduced a "Functional Player Classification System" in 1984 to assess a player's functional capacity to push, pivot, shoot, rebound, dribble, pass and catch (International Wheelchair Basketball Federation [IWBF], 2014a). The current classification system comprises of eight sport classes (Classes 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 4.5) with half-point classes being used for borderline cases. As the level of an individual's functional ability increases so does the individual's level of classification, with those players with a Class 4.5 being described as those individuals with the least eligible impairment. During a game, the maximum points of the five on-court players per team must not exceed 14 points.

With the growth in the sport, the performance gap between participation and qualification into a World Championships or Paralympic Games has increased and resulted in teams becoming more strategic in the way athletes and teams prepare for competitions (de Bosscher et al., 2008). One of the newest sports science disciplines to be used in wheelchair basketball, in collaboration with coaches' knowledge, involves the labeling and recording of sports specific actions and behaviors and is referred to as performance analysis (Sampaio et al., 2013). Despite performance analysis research in wheelchair basketball being published since 1995, wheelchair basketball programs have only recently employed performance analysts to bridge the gap in the coaches' knowledge and unlock objective marginal gains. This finding continues to highlight the frequent disconnect between research and the application of the findings into practice due to a lack of situation-specific context (Hughes and Franks, 2004; Mackenzie and Cushion, 2013).

Vanlandewijck et al. (1995) were the first researchers to use box-score data from performances during the 1992 Paralympic Games to explore the relationship between classification and on-court performance. Boxscore data was used to present a summary of an individual's in-game performance and made use of 13 specific actions and behaviors. The box score data was used to evaluate an individual's quality in relation to game performance through the Comprehensive Basketball Grading System (CBGS) (Byrnes, 1989). The system considered the following variables when calculating an individual's performance, and assigned a total score and an average score based on the minutes played: "field goals made (+5), field goals attempted (–2), free throws made (+5), free throws attempted (–2), offensive rebound (+3), defensive rebound (+2), loss of ball possession (–5), personal and technical fouls (–5), assists (+5), turnovers (–5), blocked shots (+3), steals (+5) and forced turnovers on defense (–5)" (Vanlandewijck et al., 1995, p. 141).

Vanlandewijck et al. (1995) reported that an individual's game efficiency is dependent on their classification, however, no variables were included to consider the individual's disability nor the skills of players in a wheelchair. Attempts were made by Vanlandewijck et al. (2003, 2004) to address this issue through the development of a modified CBGS, but the following variables were removed due to a misunderstanding in the operational definitions: back picks, forced turnovers in defense, and both fouls. Subsequently, further performance analysis research in wheelchair basketball (Molik and Kosmol, 2001; Molik et al., 2009) has also elected to only use 12 instead of the 16 action variables proposed by Byrnes and Hedrick (1994) (Offensive Rebound, Defensive Rebound, Steals, Blocked Shots, Assists, Free-Throws Made, Two-Point Shots Made, Three-Point Shots Made, Free-Throws Missed, Two-Point Shots Missed, Three-Point Shots Missed and Turnovers). These variables, referred to as discrete action variables, lack contextually specific information and do not provide researchers or coaches with an understanding of the dynamic actions completed by individual player's and team's that occur in game or training performances.

More recent research in performance analysis completed by Gómez et al. (2014). Gómez et al. (2015a) has combined the individual player box-score data of teams, with situational variables, in an attempt to provide an objective insight into team performance in relation to the outcome of a game and address the lack of situation-specific context. According to Gómez et al. (2014), the data and calculations have the potential to evaluate a team's performance and inform the decisions coaches are required to make during games. However, the studies still used discrete action variables which do not provide insight into how or why an individual's or team's action occurred. If coaches are relying on data collected from individual player discrete action variables to inform their team decisions, the information is one-dimensional and does not acknowledge how the dynamic perspectives of teams change, vary and adapt during possessions in relation to the outcome of a game. Subsequently, this collected discrete action variable data were argued to be both inaccurate and unreliable to inform future team strategic actions (Ziv et al., 2010).

Within wheelchair basketball, the actions and subsequent changes in the offensive and defensive strategies can be recorded to identify reoccurring patterns. Garganta (2009) found that players only have a set number of available options to them in any given situation, which is influenced by the interactions and actions of the opposing team. Therefore, it is possible to record these patterns and identify reoccurring trends to enhance the understanding of a team's tactics (Perl et al., 2013). The sequential data, that includes situational action variables, such as the state of the game or which players are on the court, enables a greater understanding of the actions within a possession to be gained in relation to the end result of a game (Game Outcome: win or lose). For example, if the offensive team have been shown to advance the ball toward the basket quickly following a turnover when there are two 2.0 or 2.5 players on the court, then, the defensive team's coaches can address this and inform their players to unsettle the offensive team by adjusting the defensive system when a turnover occurs. The change in how the possession starts could be measured in relation to the offensive team's adjustments and the subsequent actions of the defensive team. It is these decisions and adjustments by the offensive and defensive team that can be collated, analyzed and interpreted in relation to the outcome of the game. Thus, the findings can be used to inform future decisions by exploring how and why a specific incident occurred (Kubatko et al., 2007).

Through the utilization of modeling techniques, the effect of each sequential action variable on the odds of Game Outcome can be calculated. For example, Gómez et al. (2013) used binary logistic regression modeling to identify the key action variables associated with achieving success in basketball and quantified the effect of each action variable on the "Game Outcome." The insights gained from this type of modeling can be used to assist coaches, players and members of support staff with understanding the potential positive or negative impact on game outcome based on the decisions they have made. The data can be used to assist decisions around the planning and delivery of training sessions as well as informing in-game decisions through exploiting performance factors which are most highly associated with success (Petersen et al., 2007; Passos, 2017). The use of binary logistic regression modeling in wheelchair basketball may, therefore, enhance the understanding of the coaches, players and support staff regarding the key requirements of the game and provide objective insight into the effect of individual action variable on the odds of the Game Outcome.

By collecting, analyzing and modeling performance data in this way it may be possible to identify reoccurring themes and trends within a team's performance. Francis et al. (2019) overcame the limitations of existing performance analysis templates in wheelchair basketball and developed a template to collect valid and reliable team performance data. The observers within the study were able to accurately notate the observed sequential actions of an elite game of wheelchair basketball regardless of performance analysis experience or wheelchair basketball knowledge. The researchers argued that the template has the potential to collect data concerning the interaction between offensive tactics (e.g., taking a shot within 6 s of being in possession) and defensive tactics (e.g., Press vs. Highline vs. Zone defense), acknowledging the effects of various different classification line-ups throughout the course of a single game or across multiple games. If significant trends are discovered, the data have the potential to identify the key components of success. The data would provide insights into the impact each action variable has on success and enable analysts and performance staff to contextualize a performance, answering the question of how and why a behavior or specific action occurred (Clemente et al., 2016). This information can be used to inform the decision-making of coaches, players and support staff (Busemeyer and Pleskac, 2009). Therefore, the aims of this paper were to use Francis et al. (2019) template to (i) identify the key dynamic variables associated with team success in elite men's wheelchair basketball and (ii) explore the impact of each key dynamic variable upon the outcome of a performance through the use of binary logistic regression modeling.

MATERIALS AND METHODS

Sample

The sample consisted of 6,126 possessions from the performances of 12 national teams that participated in the 2015 European Wheelchair Basketball Championships (Great Britain – 1st; Turkey – 2nd; Germany – 3rd; Netherlands – 4th; Spain – 5th; Italy – 6th; Poland – 7th; Israel – 8th; Sweden – 9th; Switzerland – 10th; France – 11th; Czech Republic – 12th). The tournament was a qualification event for the 2016 Rio de Janeiro Paralympic Games and the European Zone were given five qualification spots for the 2016 Paralympic Games and these were given to Germany, Great Britain, Netherlands, Spain and Turkey. A total of 31 games out of a total of 46 games were selected for the study (**Table 1**). The criteria for inclusion was that a game had to involve one of the qualified nations. Following the granting of ethical approval from the University of Worcester's Ethics and Research Governance Committee, written, voluntary informed consent, was obtained from the host nation to access the required game footage.

Variables, Performance Analysis Template and Reliability

The new reliable performance analysis template for quantifying action variables in elite men's wheelchair basketball developed by Francis et al. (2019) was utilized for analyzing the sample of games. The template included 109 action variables that were placed into 17 agreed Categorical Predictor Variable (CPV) categories by four wheelchair basketball staff and the lead researcher (**Table 2**). Francis et al. (2019) reported weighted kappa coefficients and percentage error values, for both intra-observer (<K0.980; <1.50%) and inter-observer (<K0.974; <3.00%) testing, that fell within the agreeable thresholds (Cohen, 1968; Bland and Altman, 1999).

Data Collection and Handling Procedure

The obtained game footage was filmed from a half-way elevated position and provided a half-court perspective with an overlay

TABLE 1 | Summary of the number of games included in the sample per team.

Team	Number of games	Number of possessions
Great Britain	8	788
Turkey	8	713
Germany	8	749
Netherlands	8	739
Spain	8	872
Italy	4	404
Poland	5	472
Israel	3	316
Sweden	2	201
Switzerland	2	217
France	3	321
Czech Republic	3	334
Total	**62 (31 unique games)**	**6,126**

TABLE 2 | Summary of the 109 action variables within the 17 categorical predictor variables.

Categorical predictor variables	Action variable	Categorical predictor variables	Action variable
Quarter	Quarter 1	Shot Taken	Shot
	Quarter 2		No Shot
	Quarter 3	Shot Outcome	Successful
	Quarter 4		Unsuccessful
	Over Time		No Shot
Game Status	Winning	Shot Point	One
	Drawing		Two
	Losing		Three
Home Team	4		No Shot
	5	Shot Clock Remaining	6–0.1 s
	6		12–7 s
	7		17–13 s
	8		24–18 s
	9		Dead
	10		No Shot
	11	Shot Location	2 Point – Left – Base
	12		2 Point – Left – 45
	13		2 Point – Left Elbow
	14		2 Point – Centre – Near
	15		2 Point – Centre – Mid
Away Team	4		2 Point – Centre – Long
	5		2 Point – Right – Base
	6		2 Point – Right – 45
	7		2 Point – Right Elbow
	8		3 Point
	9		Free Throw Line
	10		No Shot
	11	Man Out Offence	Equal Numbers
	12		Numbers Advantage
	13	Defensive Outcome	Successful Defense
	14		Unsuccessful Defense
	15	Possession	Maintained
Home Classification	1		Lost
	1.5		Basket Scored
	2	End of Possession	Foul Against
	2.5		Foul For
	3		Violation Against
	3.5		Defensive Rebound
	4		Offensive Rebound
	4.5		Basket Scored
Away Classification	1		Other
	1.5		Out of Bounds
	2		Free Throw
	2.5		Handling Error
	3	Defensive System	1 Man Press
	3.5		2 Man Press
	4		3 Man Press
	4.5		4 Man Press
Start of Possession	Inbound – Baseline		5 Man Press
	Inbound – Endline		Highline
	Sideline – Front		Zone
	Sideline – Back		No Defensive System
	Defensive Rebound		
	Offensive Rebound		
	Free Throw		
	Other Start		
	Turnover		

of the time clock and current scoreboard. The 31 games were analyzed over a two-month period at the end of 2015 by the lead author using the template developed by Francis et al. (2019). The lead author had been part of the template development process and spent an average of 2 h to analyze each game. On any given day, a maximum of two games were analyzed in an attempt to reduce errors and a five-minute break was taken at the end of each quarter (Liu et al., 2015). Periodic assessment checks were conducted in an attempt to limit the overall loss of accuracy (Kazdin, 1977). Following the analysis of every five games, 10 randomly selected possessions were re-observed to identify any discrepancies. No adjustments to the analyzed data were necessary.

Following data collection in SportsCode, the data were exported into Microsoft Excel using the "Sorter" function in SportsCode. The 31 games resulted in 6,126 rows of data, each of which related to a single ball possession consisting of 17 columns (one for each CPV referred to earlier). Additional information relating to Possession Number, Game Outcome and Stage of Competition were also added to the data, making the dataset consisting of 20 columns. Each row was subjected to data cleaning to identify any discrepancies within the data. If any missing or duplicated data were identified, the game and possession were identified and re-analyzed. In total, four possessions were re-analyzed to input missing data.

The Home Classification and Away Classification columns from the dataset were reformatted into eight new columns to demonstrate the number of each classification from the offensive and defensive team were involved in a possession. For example, if the offensive team comprised of two 1.0 players and three 4.0 players, the column Offensive Unit – 1.0–1.5 would present as Two, the Offensive Unit – 4.0–4.5 column would show Three, whilst both the Offensive Unit – 2.0–2.5 and Offensive Unit 3.0–3.5 would present as Zero. Likewise, if the defensive unit comprised of one 1.0 player, three 3.0 players and a 4.0 player, the column Defensive Unit – 1.0–1.5 would present as One, the Defensive Unit – 3.0–3.5 column would show Three, the column Defensive Unit – 4.0–4.5 would present as One, whilst the Defensive Unit – 2.0–2.5 would present as Zero. Through making this adjustment, the data could be used to explore whether there is an optimum unit combination that could be used dependent upon the opposition's line-up unit.

Following checking and sorting of the data and removal of redundant columns in the data set, it now consisted of 23 columns: Defensive Outcome, Defensive System, Defensive Unit – 1.0–1.5, Defensive Unit – 2.0–2.5, Defensive Unit – 3.0–3.5, Defensive Unit – 4.0–4.5, End of Possession, Game Status, Man Out Offence, Offensive Unit – 1.0–1.5, Offensive Unit – 2.0–2.5, Offensive Unit – 3.0–3.5, Offensive Unit – 4.0–4.5, Possession Outcome, Quarter, Shot Clock Remaining, Shot Location, Shot Outcome, Shot Point, Shot Taken, Stage, Start of Possession and Game Outcome (Dependent Variable). Recall that the title of each of the columns (apart from Game Outcome) is referred to as a CPV (Categorical Predictor Variable) and that the action variables within each CPV are referred to as action variables. The Excel file was converted into a CSV file (**Supplementary Material S1**) and subjected to statistical analysis procedures.

Statistical Methods

First, cross-tabulations were created to ensure all action variables within a CPV had a greater frequency of 40, such that any action variable that reported a low-frequency count was merged with other suitable action variables. Second, Pearson chi-square analysis was carried out to determine if there was an association between each independent variable (i.e., each CPV) and the dependent variable, "Game Outcome." Cramer's V was subsequently used as a post-test to determine the strength of any observed association. Third, assessment of inter-associations and multicollinearity were conducted, with any CPV reporting a variance inflation factor above the threshold of 10 (Myers, 1990) being removed. Therefore, the following CPVs were excluded from multivariable analyses: Defensive Outcome, Man Out Offence, Possession Outcome, Quarter, Shot Taken and Shot Location. Fourth, a binary logistic regression model was developed through an automated stepwise approach (Hosmer and Lemeshow, 2000) using 70% of the data (training sample) (Dobbin and Simon, 2011), which attributed to 4,282 possessions. The dependent variable used in the model was $Y = 0, 1, \ldots$ with 0 indicating a loss and 1 indicating a win for the game outcomes. Then, the binomial logistic regression model can be expressed as the expected value if Y given the data (X) for any individual possession as follows:

$$E\,(Y|X) = \frac{e^{(Z)}}{1 + e^{(Z)}}$$

where Z represents

$$\beta 0 + \beta 1 \times \text{GS} + \beta 2 \times \text{ST} + \beta 3 \times \text{O1} + \beta 4 \times \text{O3} + \beta 6 \times \text{O4} + \beta 7 \times \text{D1} + \beta 8 \times \text{D2} + \beta 9 \times \text{D3} + \beta 10 \times \text{D4} + \beta 11 \times \text{P} + \beta 12 \times \text{EP} + \beta 13 \times \text{DS}$$

where β0 is the constant of the equation and the independent variables were the CPVs: GS = Game Status, ST = Stage, O1 = Offensive Unit – 1.0–1.5, O2 = Offensive Unit – 2.0–2.5, O3 = Offensive Unit – 3.0–3.5, O4 = Offensive Unit – 4.0–4.5, D1 = Defensive Unit – 1.0–1.5, D2 = Defensive Unit – 2.0–2.5, D3 = Defensive Unit – 3.0–3.5, D4 = Defensive Unit – 4.0–4.5, SP = Start of Possession, EP = End of Possession, DS = Defensive System. To explore the individual contributions of each action variable within the binary logistic regression model, the estimated regression coefficients and their standard error values along with their p-values, Odds Ratio (OR) values and their 95% confidence intervals (CIs) were determined. The estimated regression coefficients demonstrated the action variables' contribution to the prediction of the outcome (game success), with a positive estimated regression coefficient being associated with an increase in the odds of winning the game.

The fifth and final stage involved exploring the fit of the model. McFadden (1974), Cox and Snell (1989), and Nagelkerke (1991) pseudo-R^2 values were determined to indicate the degree in which the model explained the amount of the variation in game outcomes. To calculate the model's ability to accurately predict out of sample game outcomes, the area under the receiver operating characteristic (ROC) curve (Hosmer and Lemeshow, 2000) was used to compute the sensitivity and specificity of the model against the remaining 30% of data (testing sample (1,844 possessions). The five stages of statistical analyses were performed using the software R (R Core Team, 2015), version 3.4.2, with the level of significance set at $p < 0.05$. The following packages were used: "car" package [Companion to Applied Regression (car): Fox et al. (2018)], the "caret" package [Classification and Regression Training (caret): Kuhn et al. (2018)], the "scales" package [Scale Functions for Visualization (Wickham, 2018)] and the "ROCR" package (Sing et al., 2015).

RESULTS

A Pearson chi-square test of independence was performed to examine the association between Game Outcome and 22 CPVs. The relationship between 19 of these CPV was found to be significant ($p < 0.05$) (**Table 3**). Cramer's V measure of nominal association showed that when a team was in a status of winning in comparison to losing or drawing the team were more likely to win the game ($\phi_C = 0.362$, $p < 0.001$). In addition, teams were significantly more likely to win a game when the offensive team comprised of two players who were classified as either a 2.0 or a 2.5 player ($\phi_C = 0.116$, $p < 0.001$). Furthermore, when the offensive team comprised of two 3.0 or 3.5 players the likelihood of winning the game increased ($\phi_C = 0.131$, $p < 0.001$). Whilst, if the defensive team comprised of either zero or two 3.0 or 3.5 players the likelihood of the offensive team winning increased ($\phi_C = 0.173$, $p < 0.001$).

In a binary logistic regression model, the Odds Ratio (OR) represents a measure of association between an independent variable and an outcome variable (Szumilas, 2010). If an OR of greater than one is found for an action variable, this describes a positive relationship and means that if this action variable occurs it is associated with higher odds of winning. Whereas, if an OR of less than one is found for an action variable, this describes a negative relationship, and means that if this action variable occurs it is associated with lower odds of winning. Therefore, if an action variable was included in the model and has an OR greater than one, the odds of winning the game increased. The results of the binary logistic regression (**Table 4**) showed the influence of Game Status, the offensive and defensive line-up combinations, how possession started and ended as well as the defensive system operated on the ability of a team to win a game of wheelchair basketball.

For the CPV Game Status, taking Drawing as the reference category, when a team changed to a status of Winning (as would be expected) the odds of finally winning the game were increased (OR: 2.359; 95% CI: 1.701–3.259; $p < 0.001$), whilst (again as would be expected) a fall in the odds of winning was registered when the status changed to Losing (OR: 0.409; 95% CI: 0.296–0.563; $p < 0.001$). The Stage CPV, highlighted that the reference category of Pool Stage resulted in the highest odds ratio with the various different knock-out rounds of the tournament registering

TABLE 3 | Chi-square tests of association with game outcome and each individual CPV.

CPV	χ^2	*df*	*p*
Defensive Outcome	39.58	1	<0.001
Defensive System	37.94	7	<0.001
Defensive Unit – 1.0–1.5	32.46	2	<0.001
Defensive Unit – 2.0–2.5	56.08	2	<0.001
Defensive Unit – 3.0–3.5	182.36	3	<0.001
Defensive Unit – 4.0–4.5	20.03	2	<0.001
End of Possession	53.84	10	<0.001
Game Status	803.49	2	<0.001
Man Out Offence	0.06	1	0.801~
Offensive Unit – 1.0–1.5	19.05	2	<0.001
Offensive Unit – 2.0–2.5	82.63	2	<0.001
Offensive Unit – 3.0–3.5	104.77	3	<0.001
Offensive Unit – 4.0–4.5	69.12	2	<0.001
Possession	50.78	3	<0.001
Quarter	0.81	3	0.848~
Shot Clock Remaining	14.14	4	<0.001
Shot Location	43.91	10	<0.001
Shot Outcome	10.40	2	0.005
Shot Point	26.14	3	<0.001
Shot Taken	0.51	1	0.473~
Stage	76.09	4	<0.001
Start of Possession	65.91	8	<0.001

~*Denotes CPV was removed from further analyses due to a non-significant relationship being found.*

TABLE 4 | Final model illustrating the estimated regression coefficients, standard errors, *p*-values and ORs for the intercept variable and for each action variable in a CPV.

	Estimate	SE	*z* value	*p*	OR	OR (95% CI)	
						Lower	Upper
(Intercept)	0.309	0.272	1.137	0.255	1.363	0.800	2.328
xGame Status (a)							
Losing	−0.894	0.164	−5.448	0.000***	0.409	0.296	0.563
Winning	0.858	0.166	5.178	0.000***	2.359	1.701	3.259
Stage (b)							
Ranking Game	−0.568	0.153	−3.723	0.000***	0.567	0.420	0.764
Quarter-Final	−0.430	0.115	−3.736	0.000***	0.651	0.519	0.815
Semi-Final	−0.069	0.162	−0.423	0.672	0.934	0.680	1.285
Medal Match	−0.631	0.148	−4.266	0.000***	0.532	0.398	0.711
Offensive Unit – 1.0–1.5 (c)							
Zero Players	1.658	0.370	4.479	0.000***	5.247	2.601	11.170
Two Players	0.557	0.265	2.101	0.036*	1.745	1.045	2.956
Offensive Unit – 2.0–2.5 (d)							
Zero Players	−1.265	0.323	−3.916	0.000***	0.282	0.149	0.527
Two Players	0.143	0.195	0.735	0.462	1.154	0.789	1.694
Offensive Unit – 3.0–3.5 (e)							
Zero Players	−2.219	0.477	−4.648	0.000***	0.109	0.042	0.273
One Players	−1.639	0.349	−4.694	0.000***	0.194	0.095	0.376
Three or More Players	1.801	0.368	4.899	0.000***	6.056	2.973	12.568
Offensive Unit – 4.0–4.5 (f)							
Two Players	1.860	0.394	4.723	0.000***	6.424	3.029	14.257
Three Players	−1.111	0.399	−2.785	0.005**	0.329	0.150	0.719
Defensive Unit – 1.0–1.5 (g)							
Zero Players	−0.619	0.432	−1.433	0.152	0.538	0.223	1.224
Two Players	3.067	0.756	4.056	0.000***	21.486	5.170	101.914
Defensive Unit – 2.0–2.5 (h)							
Zero Players	−2.115	0.741	−2.852	0.004**	0.121	0.026	0.488
Two or More Players	2.227	0.743	2.995	0.003**	9.268	2.291	42.959
Defensive Unit – 3.0–3.5 (i)							
Zero Players	−2.582	1.182	−2.185	0.029*	0.076	0.007	0.709
One Player	−1.461	0.499	−2.927	0.003**	0.232	0.085	0.604
Three or More Players	3.046	0.767	3.971	0.000***	21.035	4.931	101.503
Defensive Unit – 4.0–4.5 (j)							
Two Players	0.934	0.475	1.968	0.049*	2.546	1.023	6.623
Three Players	1.708	0.863	1.978	0.048*	5.519	1.058	31.685
Start of Possession (k)							
Free Throw	0.543	0.229	2.372	0.018*	1.721	1.097	2.692
Inbound – Baseline	−0.008	0.098	−0.077	0.938	0.992	0.819	1.202
Inbound – Endline	0.405	0.203	1.999	0.046*	1.500	1.010	2.238
Offensive Rebound	0.348	0.156	2.232	0.026*	1.417	1.045	1.926
Other Start	−0.003	0.511	−0.007	0.995	0.997	0.369	2.807
Sideline – Back	0.527	0.178	2.970	0.003**	1.694	1.200	2.408
Sideline – Front	0.329	0.154	2.130	0.033*	1.389	1.028	1.883
Turnover	0.320	0.176	1.818	0.069+	1.377	0.977	1.948
End of Possession (l)							
Basket Scored When Fouled	−0.111	0.280	−0.396	0.692	0.895	0.518	1.557
Defensive Rebound	−0.169	0.096	−1.758	0.079+	0.845	0.700	1.020
Foul Against	−0.034	0.234	−0.146	0.884	0.966	0.612	1.534
Foul For	0.268	0.128	2.087	0.037*	1.307	1.017	1.683
Free Throw	−0.532	0.258	−2.064	0.039*	0.587	0.356	0.979
Handling Error	−0.562	0.174	−3.236	0.001**	0.570	0.405	0.801

(Continued)

TABLE 4 | Continued

	Estimate	SE	*z* value	*p*	OR	OR (95% CI)	
Offensive Rebound	0.157	0.145	1.086	0.277	1.170	0.882	1.556
Other	0.603	0.246	2.452	0.014*	1.827	1.136	2.982
Out of Bounds	0.045	0.150	0.297	0.766	1.046	0.781	1.404
Violation Against	–0.045	0.269	–0.169	0.866	0.956	0.565	1.623
Defensive System (m)							
1 Man Press	0.177	0.203	0.872	0.383	1.194	0.802	1.780
2 Man Press	0.346	0.144	2.409	0.016*	1.413	1.067	1.876
3 Man Press	0.527	0.154	3.427	0.000***	1.694	1.255	2.294
4 Man Press	0.371	0.210	1.766	0.077+	1.450	0.962	2.193
5 Man Press	0.083	0.228	0.366	0.714	1.087	0.696	1.701
Highline	0.519	0.129	3.016	0.000***	1.681	1.306	2.169
No Defensive System	0.204	0.201	1.015	0.310	1.227	0.828	1.826

*+p < 0.1, *p < 0.05, **p < 0.01, ***p < 0.001; B, estimate coefficient; SE, standard error; OR, odds ratios; CI, confidence intervals. The baseline categories within the intercept were (a) Drawing; (b) Pool Stage; (c) One Player; (d) One Player; (e) Two Players; (f) One Player; (g) One Player; (h) One Player; (i) Two Players; (j) One Player; (k) Defensive Rebound; (l) Basket Scored; (m) Zone.*

lower odds ratios (Ranking Game: OR: 0.567; CI: 0.420–0.764; $p < 0.001$; Quarter-Final: OR: 0.651; CI: 0.519–0.815; $p < 0.001$; Semi-Final: OR: 0.934; CI: 0.680–1.285; $p = 0.672$; Medal Match: OR: 0.532; CI: 0.398–0.711; $p < 0.001$).

The number of 1.0–1.5, 2.0–2.5, 3.0–3.5 and 4.0–4.5 players involved in the offensive and defensive teams presented differences in the odds ratios. The reference categories for both the offensive team and the defensive team were One 1.0–1.5 player, One 2.0–2.5 player, Two 3.0–3.5 players and One 4.0–4.5 player. From an offensive perspective, it was observed that reducing the number of 1.0–1.5 players from One to Zero registered a higher odds ratio (OR: 5.247; 95% CI: 2.601–11.170; $p < 0.001$), increasing the number of 2.0–2.5 players from One to Two registered a slightly higher odds ratio (OR: 1.154; 95% CI: 0.789–1.694; $p < 0.001$), increasing the number of 3.0–3.5 players from Two to Three or More registered higher odds ratio (OR: 6.056; 95% CI: 2.973–12.568; $p < 0.001$) and increasing the number of 4.0–4.5 players from Zero or One to Two registered higher odds ratios ratio (OR: 6.424; 95% CI: 3.029–14.257; $p < 0.001$).

Whilst observing the defensive team, it was found that increasing the number of 1.0–1.5 players from One to Two resulted in a higher odds ratio (OR: 21.486; 95% CI: 5.170–101.914; $p = 0.152$), increasing the number of 2.0–2.5 players from One to Two or More registered a higher odds ratio (OR: 9.268; 95% CI: 2.291–42.595; $p = 0.003$), increasing the number of 3.0–3.5 players from Two to Three or More registered a higher odds ratio (OR: 21.035; 95% CI: 4.931–101.503; $p < 0.001$) and increasing the number of 4.0–4.5 players from Two to Three resulted in a higher odds ratio (OR: 5.519; 95% CI: 1.058–31.685; $p < 0.05$). However, due to the total classification points a team can have on-court teams would be restricted by some of these findings. Thus, the highest likelihood of winning a game of wheelchair basketball was achieved when the defensive team comprised of Two 1.0–1.5 players and Three 4.0–4.5 players (OR: 118.510), whereas an offensive team that comprised of Two 2.0–2.5 players and Three 3.0–3.5 players had the highest odds ratio (OR: 36.670).

When considering the Start of Possession CPV, Free Throw exhibited the highest odds ratio (OR: 1.721; 95% CI: 1.097–2.692; $p < 0.05$). Possessions that began within the defensive team's half of the court (Inbound – Endline: OR: 1.500; 95% CI: 1.010–2.238; $p < 0.05$; Offensive Rebound: OR: 1.417; 95% CI: 1.045–1.926; $p < 0.05$) or from an inbound just inside the offensive team's half (OR: 1.389, 95% CI: 1.028–1.883; $p < 0.05$) demonstrated odds ratios greater than one. Possessions that ended from a Handling Error had a negative impact on the ability of a team to win a game (OR: 0.570, 95% CI: 10.405–0.801; $p < 0.001$). Whilst, when the referees were required to stop the game, for example, due to a player being unable to push themselves back up after being tipped over, a higher odds ratio was registered (OR: 1.827, 95% CI: 1.136–2.982; $p < 0.05$).

Table 4 also showed that the effect of the opposition changing the Defensive System from Zone to either a 2 Man Press, 3 Man Press or a Highline was found to significantly increase the odds of the offensive team winning the game (2 Man Press: OR: 1.413, 95% CI: 1.067–1.876; $p < 0.05$; 3 Man Press: OR: 1.694, 95% CI: 1.255–2.294; $p < 0.001$; Highline: OR: 1.681, 95% CI: 1.306–2.169; $p < 0.001$).

McFadden, Cox and Snell, and Nagelkerke Pseudo-R^2 values were calculated to compare the maximum likelihood of the developed model against a null model (**Table 5**). The pseudo R^2 values presented indicated that the model does explain at least a reasonable amount of the variation in game outcomes. These values do have an upper limit of 1 when the model would explain all the variation but these Pseudo-R^2 values are well known for very rarely attaining values near this upper limit, even for well-fitting models (Heinzl and Mittlböck, 2003). The regression equation, derived from the model, was used for predicting the accuracy of the binary logistic regression model against the 30% out of sample testing data (1,844 possessions). An area under the ROC curve value of 0.759 was established for the model when predicting the possessions within the sample testing data. The model was therefore considered acceptable

TABLE 5 | Pseudo-R^2 values comparing the binary logistic regression model to a null model.

Pseudo-R^2 measure	Pseudo-R^2 value
McFadden R^2	0.158
Cox and Snell R^2	0.192
Nagelkerke R^2	0.260

(Hosmer and Lemeshow, 2000) at accurately predicting win probabilities in elite men's wheelchair basketball.

DISCUSSION

The aim of this paper was twofold, firstly, to identify the key variables associated with team success in elite men's wheelchair basketball and secondly to explore the impact of each key action variable upon the outcome of performance through the use of binary logistic regression modeling. Fifteen CPVs were found to relate to Game Outcome, with Game Status being identified as the most important CPV due to achieving the largest chi-square value and lowest *p*-value. The final model demonstrated the sequential action variables within the classification units CPVs and Game Status CPV had the largest impact on predicting Game Outcome. The Stage of the competition was also found to be an important factor, but this simply seemed to be explained by the fact that during the later stages, the teams that eventually win dominate possession less during the games as the quality of opposition increases. The findings from this study largely support previous research regarding stage of competition (van Rooyen et al., 2008, 2010; O'Donoghue et al., 2016), defensive structure (Gómez et al., 2006; Tenga et al., 2010) and in-game status (Lago-Peñas and Dellal, 2010; Marcelino et al., 2011; Almeida et al., 2014) in relation to the importance of game outcome.

Findings from previous wheelchair basketball studies have highlighted the importance of 4.0 and 4.5 classification players in relation to achieving higher CBGS scores and assisting toward a positive game outcome (Vanlandewijck et al., 2004; Gómez et al., 2015a), however, the findings in this study regarding classification challenge these. The findings around player classification identified the chance of winning is reduced if "Three" 4.0 or 4.5 players were used during a possession by odds of 0.329. Playing with three 4.0 players restricts the classification of each of the remaining two players on-court to 1.0 in order to stay within the 14-point total team classification score. Players who are classified as 1.0 players have been found to regularly achieve low or negative CBGS scores (Gómez et al., 2015a), typically accumulating higher frequency counts regarding the number of times possession is lost, the number of fouls committed and turnovers in comparison to other classification groups (Vanlandewijck et al., 1995). These players have limited trunk function in the forward plane and no active rotation which significantly impairs balance in both forward and sideways directions, impairing their pushing, dribbling, passing and shooting performance (Perriman, 2014). The players typically fulfil the role of a screen as they are reliant on the wheelchair for support in all planes of movement and are susceptible to losing the ball (Vanlandewijck et al., 1995). Thus, the model developed found that having two 1.0 classified players on the court and three 4.0 players at the same time was found to negatively impact the odds of success, due to the impairment of handling, pushing and shooting of the low classified players. This finding was identified through the produced odds ratio in the model (OR: 0.575) in comparison to the reference line-up of one 1.0–1.5 player, one 2.0–2.5 player, two 3.0–3.5 players and one 4.0–4.5 player. As highlighted, 1.0 players typically perform other roles that are not included within the CBGS, for example blocks and picks, however, the authors of this paper argue that if higher classified players perform these roles, in addition to their current role, they offer the team a higher offensive threat and would therefore increase the odds of success.

In contradiction to the work of Molik et al. (2009) who found similarities between low class players (classification 1.0–3.0) and low game efficiency, the model demonstrated that playing with "Three or More" Offensive Unit – 3.0–3.5 players on the court improves Game Outcome (OR: 6.056, 95% CIs: 2.973–12.568, $p < 0.001$). Subsequently, the limitations of physical movement associated with 1.0 players can be overcome by a combination of players with the following classification: 2.0, 2.5, 3.0 or 3.5 (OR: 36.670). These findings align with Vanlandewijck et al. (2004) who discovered that players who have a classification between 2.0 and 3.5 have similar technical abilities. However, within International Wheelchair Basketball Federation's classification system, Perriman (2014, p. 9) briefly stated that class 2.0 players have "partially controlled trunk movement in the forward plane, active upper trunk rotation but no low trunk function [and] no controlled sideways movement" whereas class 3.0 players have "good trunk movement in the forward plane, good trunk rotation [and] no controlled trunk movements sideways." Although, the good or partially controlled movements in the forward plane and the ability to engage all or some of the trunk for rotation enable both classification groups to hold the ball outstretched without inclining the head or trunk, return to an upright position with minimal effort when pushing, rotate the upper trunk to receive a pass from behind and are able to lean forward when shooting to propel the ball toward the basket (Perriman, 2014), and thus have a similar functional capacity. As a result, the ability to have some form of partial control in the forward and vertical planes could be argued to make them superior players to those with a 1.0 classification (Gil-Agudo et al., 2010). However, both these classification groups have limited sideways plane movement and are unable to incline to one side, unlike 4.0 or 4.5 players. Although, Gómez et al. (2014, 2015a) identified that similar performances are observed for players between adjacent classes, in particular around the mid-class players.

Furthermore, playing with a greater number of Offensive 3.0–3.5 players than Offensive 4.0–4.5 players could be due to 3.0 player's being able to sit 5 cm higher in the chair in comparison to 3.5, 4.0 and 4.5 players. These additional 5 cm would provide players, if they elect to position the top of the cushion at a height of 63 cm in comparison to 58 cm from the floor (International Wheelchair Basketball Federation

[IWBF], 2014b), with a potential advantage when being defended in the act of shooting or rebounding. Santos et al. (2014) highlighted the importance of trunk stability and movement when completing faster movement directions in the forward plane when rebounding. van der Slikke et al. (2016) also noted that international players average seat height is significantly higher to enable players to achieve greater upward reach. van der Woude et al. (1989) found that a higher cushion height negatively impacted a players turning capacity due to shift in the start and end position of the hand on the push rim. However, considerable changes in chair design have occurred since this research was published and thus the findings may be different. Coaches and players, therefore, are required to consider a player's seating height in relation to the role on the court and their capacity to execute the fundamental basketball movements of shooting, rebound the ball and turning. However, it is important to note that no anthropometric data was collected by the authors and that could influence a player and teams capabilities to execute the fundamental wheelchair basketball skills.

In addition, the capacity of mid-point classification players (class 2.0, 2.5, 3.0 and 3.5 players) to propel the chair has been found to be superior in both straight-line speed and weaving than low-class players (class 1.0 and 1.5) (Crespo-Ruiz et al., 2011). Therefore, our current findings support the notion that coaches need to carefully consider when and how they use class 1.0 and 1.5 players within line-ups. The odds ratios produced for different line-ups can be used to highlight the benefits of a team comprising of more 3.0–3.5 players than 4.0–4.5 players and using these players in the on-court five in relation to game outcome. These findings provide useful information for coaches to carefully consider the line-up configurations of players, acknowledging the strengths and limitations of certain classifications in order to identify an optimum line-up. Of course, this information also adds further debate around the classification system in wheelchair basketball and whether it is fit for purpose. Consideration, therefore, needs to be taken regarding the individual's technical characteristics and subsequently could challenge some of the findings and interpretations around classification and line-up configurations. However, it is important to note that technical and tactical characteristics of players do not depend on classification, as classification is "based on the player's physical capacity to execute fundamental basketball movements." The findings highlighted within this study also align with the International Wheelchair Basketball Federation [IWBF] (2019b) recent decision to introduce a more stringent review process. The revised process involves additional stages for new player's to ensure the sport's classification philosophy continues to be in agreement with the International Paralympic Committee Classification Code and that of the Paralympic Games.

The model also illustrated the chances of winning a game during the knock-out stages of the 2015 European Wheelchair Basketball Championships are more testing than winning a "Pool" stage game. O'Donoghue et al. (2016) found as teams advanced through a competition the points difference between the two teams decreased along with the probability of winning. Gómez et al. (2015a) also observed this trend in wheelchair basketball because the quality of opposition increased during each stage of the tournament. The researchers found that players in teams that finished in the top four teams achieved higher shooting efficiencies and CBGS scores than other players in lower ranked teams. This finding supports the notion that you have to win knock-out games, and achieve higher scores, and you do not have to win pool games to stay in the competition. However, as the analyzed event was a qualification tournament for the Paralympics, the increased points difference observed during the semi-final stage provided evidence to suggest teams were content with qualification as winning the quarter-finals automatically qualified the teams for the Rio de Janeiro Paralympic Games.

Furthermore, the 10-day wheelchair basketball tournament may have affected the probability of winning due to players becoming fatigued and thus leading to a reduction in skill execution. Montgomery et al. (2008) found this occurred during a three-day basketball tournament, reporting small to moderate impairments in players' performance due to physical fatigue. Lertwanich (2009) also found 1.0 players were susceptible to becoming physically fatigued at a quicker rate than amputees due to the impartment of sweating and vasomotor control. These findings, therefore, reiterate the importance of line-up combinations and minimizing the use of 1.0 players in an attempt to maintain consistent performances, especially in the later stages of a tournament. However, without recording the cardiovascular and locomotion demands of these players during the tournament it is unknown whether fatigue affected the odds ratios achieved. Thus, future international tournaments should incorporate cardiovascular and locomotion demands in addition to the sport performance analysis data to collate a broader picture of performance. However, the results of this study have clearly indicated that Stage, and thus the quality of opposition, affect Game Outcome.

Game Status was found to be a significant CPV in relation to Game Outcome (OR: 2.359) more than double if the team started a possession in a state of "Winning." Therefore, suggesting that the game winner can be predicted in wheelchair basketball earlier in the game in comparison to running basketball. This may be as a result of the NBA being a much more closely contested competition with longer breaks in between games (Horowitz, 2018), allowing for mental and physical recovery, than wheelchair basketball tournaments. It is important to note that rule adaptions have been made between wheelchair basketball and basketball, specifically relating to dribbling the ball and controlling the chair, and thus differences exist. However, the fundamental principles of the sport are the same and due to the limited existing knowledge within wheelchair basketball, basketball literature was drawn on to inform the discussion of this research. The increasing odds of winning the game, both in basketball and in wheelchair basketball highlight the importance of shooting effectiveness, however, no shooting related CPVs were presented in the final model. Despite this, Shot Location was included in the model developed using the automated forward selection approach and thus indicates it is potentially an important CPV.

The defensive system operated by the opposition in this research was found to significantly affect a team's ability to score more points, and thus win a game. The results found that the tighter and more structured the defensive system, the harder it was for the offensive team to break down the system and score points. Research surrounding dynamical systems theory confirms this interpretation (Reed and Hughes, 2006; Gréhaigne and Godbout, 2014; Araújo and Davids, 2016). Gómez et al. (2006) found within Spanish basketball Playoffs' series, the losing team found it difficult to break down a Zone defensive system and convert possession into points. By operating a zonal defensive system the attacker-defender dyads are closer and thus the available space is less. Therefore, restricting the ability of the attackers to create an open shot, which has been found to increase the shooting efficiencies of players (Zhang et al., 2017). The findings from the developed model confirmed this finding, highlighting that the odds of winning were greater than one when a Highline system was adopted as well as a number of the pressing systems. Recent technology advancements in terms of radio-frequency-based indoor (Rhodes et al., 2015), bluetooth-based systems (Figueira et al., 2018) or artificial intelligence (Kristan et al., 2009) could allow for more objective data in relation to defensive systems and attacker-defender dyads to be collected that could inform future practice. On the other hand, this finding may be the result that zonal type defenses are the most trained and developed systems in team sports (Gómez et al., 2015b). Despite these ideas for future exploration, the results from our analyses indicate that the defensive system, space and pressure are important factors for coaches to consider in training and when devising game strategies to prevent opponents from scoring and capitalizing on disorganized defensive systems (Tenga et al., 2010).

In agreement with capitalizing on disorganized defensive systems, possessions that began from an offensive rebounds or from a turnover registered odds ratios greater than one. These findings align with those of Sampaio et al. (2007) who found that if a team was able to capitalize on offensive rebound The results demonstrated if a team are in a state of winning when the possession started the probability of winning the game increases. Similarly, Gómez et al. (2016) identified that the starting quarter score in the fourth quarter was significantly related to final points differential in the NBA. The researchers found that teams who were ahead during the first possession of the fourth quarter were almost twice as likely to win the game (OR: 1.75). Although this point may seem obvious in relation to Game Outcome, the odds of winning the game utilizing the wheelchair basketball data were of a team to establish a lead and maintain the lead has been explored in a number of team sports in relation to the concept of momentum (see Hughes et al., 2015). The findings presented here agree with the work of Gómez et al. (2016) whereby the importance of capitalizing on each ball possession and ensuring individual players are able to convert under pressure shooting opportunities into points affects the final outcome. their likelihood of winning increased, although this was restricted to play-off games. Similarly, Gómez et al. (2006, 2010) identified that when teams adopted a zonal man-to-man defensive system a higher number of turnovers were generated, subsequently increasing the likelihood of gaining field goal positions nearer to the basket following a successful transition from defense into offence. Additionally, significant differences and odds greater than one were found for Inbound – Endline, Sideline – Front, Sideline – Back and other starts. Schmidt et al. (1999) speculated that this was not uncommon, as offensive teams in basketball look to exploit set-plays from these locations. Teams typically run "backdoor plays" where the offensive player attempts to free up space by initially moving toward their own basket before quickly turning to exploit the vacant space. The aim of these pre-planned patterns of play is to target a specific point on the playing area or an individual to try and provide a platform to open up space for team mates to attack (Barkell et al., 2016). This tactic is observed within wheelchair basketball. Once a defensive player has followed the ball player, other offensive players would use their chair to restrict the progress of defensive players in returning to a rigid defensive shape and allow the offensive player with the ball a less pressurized shooting opportunity. Thus, these findings reinforce the need for teams to have specific strategies for possessions that start from inbounds but also from open play situations that enable the creation of optimal space-time opportunities that enable players to take shooting opportunities under less pressure (Lamas et al., 2011; Fonseca et al., 2012, 2013).

CONCLUSION

This study has identified the key determinants of team success in elite men's wheelchair basketball that can contribute to a game-winning performance. The model indicated that the capacity to have the optimal line-up on the court who can score and prevent an opponent from scoring by creating defensive pressure is a key component in predicting winning odds. In addition, consideration needs to be taken regarding how team's play from possession that start from within the defensive team's half, as reducing the space between the attacker-defender dyads and the basketball was associated with lower ORs. The most significant and important finding from the model is regarding game status and maintaining a winning margin on the scoreboard. The application of these findings emphasizes the importance of key tactical and technical abilities of the players regarding the on-court decision making processes in the act of shooting. However, it is important to note that this study has focused on the performances of the qualified teams from the 2015 European Wheelchair Basketball Championships and thus different nations playing styles during different international competitions may not be transferable. Furthermore, variables associated with how team's advanced the ball toward the basket, including the number of passes and the number of players who handled the ball in the possession, were not recorded.

Despite this, this study is the first to have identified the key variables associated with team success and explored the impact of each key action variable upon the outcome of performance through the use of binary logistic regression modeling. These findings offer some practical implications to coaches, players and support staff to assist the players' learning and decision-making skills and enhance their likelihood of winning based on the accumulation of optimal CPV sequences. The information obtained regarding classification line-ups can be used to effectively improve a team's ability to win a game of wheelchair basketball and during the selection of players prior to major international tournaments. The information can also be used when planning training and game strategies to take advantage of an opponent's tactical strategies and assist team's with maximizing the ability to establish and maintain a lead throughout a game.

DATA AVAILABILITY

The dataset generated for this study can be found in the Worcester Research and Publications collection (https://eprints.worc.ac.uk/id/eprint/7551).

ETHICS STATEMENT

Following the granting of ethical approval from the University of Worcester's Ethics and Research Governance Committee, written, voluntary informed consent, was obtained from the host nation to access the required game footage.

AUTHOR CONTRIBUTIONS

JF devised the structure of the manuscript, collected and analyzed the data, and drafted the manuscript. AO provided guidance and support for statistical analyses and reporting, and commented on the final draft. DP devised the structure of the manuscript, oversaw the whole research process, commented on drafts, and approved the final draft.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01431/full#supplementary-material

MATERIAL S1 | Data set for team performances during the 2015 European Wheelchair Basketball Championship.

REFERENCES

Almeida, C. H., Ferreira, A. P., and Volossovitch, A. (2014). Effects of match lLocation, match status and quality of opposition on regaining possession in UEFA Champions League. *J. Hum. Kinet.* 41, 203–214. doi: 10.2478/hukin-2014-0048

Araújo, D., and Davids, K. (2016). Team synergies in sport: theory and measures. *Front. Psychol.* 7:1449. doi: 10.3389/fpsyg.2016.01449

Barkell, J. F., O'Connor, D., and Cotton, W. G. (2016). Characteristics of winning men's and women's sevens rugby teams throughout the knockout Cup stages of international tournaments. *Int. J. Perform. Anal. Sport* 16, 633–651. doi: 10.1080/24748668.2016.11868914

Bland, M., and Altman, D. (1999). Measuring agreement in method comparison studies. *Stat. Methods Med. Res.* 8, 135–160. doi: 10.1177/096228029900800204

Busemeyer, J., and Pleskac, T. (2009). Theoretical tools for understanding and aiding dynamic decision making. *J. Math. Psychol.* 53, 126–138. doi: 10.1016/j.jmp.2008.12.007

Byrnes, D. (1989). "Comprehensive basketball grading chart," in *Wheelchair Basketball*, eds B. Hedrick, D. Byrnes, and L. Shaver (Washington, DC: Paralyzed Veterans of America), 146.

Byrnes, D., and Hedrick, B. (1994). "Comprehensive basketball grading system," in *Wheelchair Basketball*, eds D. Byrnes, B. Hedrick, and L. Shaver (Washington, DC: Paralyzed Veterans of America), 79.

Clemente, F. M., Martins, F. M. L., and Mendes, R. S. (2016). *Social Network Analysis Applied to Team Sports Analysis*. New York, NY: Springer, doi: 10.1007/978-3-319-25855-3

Cohen, J. (1968). Weighted kappa: nominal scale agreement provision for scaled disagreement or partial credit. *Psychol. Bull.* 70, 213–220. doi: 10.1037/h0026256

Cox, D., and Snell, E. (1989). *The Analysis of Binary Data*, 2nd Edn. London: Chapman & Hall.

Crespo-Ruiz, B., Del Ama-Espinosa, A., and Gil-Agudo, Á (2011). Relation between kinematic analysis of wheelchair propulsion and wheelchair functional basketball classification. *Adapt. Phys. Act. Q.* 28, 157–173. doi: 10.1123/apaq.28.2.157

de Bosscher, V., Bingham, J., Shibli, S., van Bottenburg, M., and de Knop, P. (2008). *The Global Sporting Arms Race: An International Comparative Study on Sports Policy Factors Leading to International Sporting Success*. Oxford: Meyer & Meyer Sport Ltd., doi: 10.1080/16184742.2010.524242

Dobbin, K. K., and Simon, R. M. (2011). Optimally splitting cases for training and testing high dimensional classifiers. *BMC Med. Genomics* 4:31. doi: 10.1186/1755-8794-4-31

Figueira, B., Gonçalves, B., Folgado, H., Masiulis, N., Calleja-González, J., and Sampaio, J. (2018). Accuracy of a basketball indoor tracking system based on standard bluetooth low energy channels (NBN23®). *Sensors* 18, 1–8. doi: 10.3390/s18061940

Fonseca, S., Milho, J., Travassos, B., and Araújo, D. (2012). Spatial dynamics of team sports exposed by Voronoi diagrams. *Hum. Mov. Sci.* 31, 1652–1659. doi: 10.1016/j.humov.2012.04.006

Fonseca, S., Milho, J., Travassos, B., Araújo, D., and Lopes, A. (2013). Measuring spatial interaction behavior in team sports using superimposed Voronoi diagrams. *Int. J. Perform. Anal. Sport* 13, 179–189. doi: 10.1080/24748668.2013.11868640

Fox, J., Weisberg, S., Price, B., Adler, D., Bates, D., Baud-Bovy, G., et al. (2018). *R: package "car."* 1–147. Available at: http://socserv.socsci.mcmaster.ca/jfox/Books/Companion/index.html (accessed February 1, 2019).

Francis, J., Owen, A., and Peters, D. M. (2019). A new reliable performance analysis template for quantifying action variables in elite Men's wheelchair basketball. *Front. Psychol.* 10:16. doi: 10.3389/fpsyg.2019.00016

Garganta, J. (2009). Trends of tactical performance analysis in team sports: bridging the gap between research, training and competition. *Rev. do Porto Ciencias do Desporto* 9, 81–89. doi: 10.5628/rpcd.09.01.81

Gil-Agudo, A., Del Ama-Espinosa, A., and Crespo-Ruiz, B. (2010). Wheelchair basketball quantification. *Phys. Med. Rehabil. Clin. N. Am.* 21, 141–156. doi: 10.1016/j.pmr.2009.07.002

Gómez, M. -Á., Tsamourtzis, E., and Lorenzo, A. (2006). Defensive systems in basketball ball possessions. *Int. J. Perform. Anal. Sport* 6, 98–107. doi: 10.1080/24748668.2006.11868358

Gómez, M. -Á., Gasperi, L., and Lupo, C. (2016). Performance analysis of game dynamics during the 4th game quarter of NBA close games. *Int. J. Perform. Anal. Sport* 16, 249–263. doi: 10.1080/24748668.2016.11868884

Gómez, M. -Á., Lorenzo, A., Ibáñez, S. J., Ortega, E., Leite, N., and Sampaio, J. (2010). An analysis of defensive strategies used by home and away basketball teams. *Percept. Mot. Skills* 110, 159–166. doi: 10.2466/pms.110.1.159-166

Gómez, M. -Á., Lorenzo, A., Ibañez, S.-J., and Sampaio, J. (2013). Ball possession effectiveness in men's and women's elite basketball according to situational variables in different game periods. *J. Sports Sci.* 31, 1578–1587. doi: 10.1080/02640414.2013.792942

Gómez, M. -Á., Molik, B., Morgulec-Adamowicz, N., and Szyman, R. (2015a). Performance analysis of elite women's wheelchair basketball players according to team-strength, playing-time and players' classification. *Int. J. Perform. Anal. Sport* 15, 268–283. doi: 10.1080/24748668.2015.11868792

Gómez, M. -Á., Moral, J., and Lago-Peñas, C. (2015b). Multivariate analysis of ball possessions effectiveness in elite futsal. *J. Sports Sci.* 33, 2173–2181. doi: 10.1080/02640414.2015.1075168

Gómez, M. -Á., Pérez, J., Molik, B., Szyman, R., and Sampaio, J. (2014). Performance analysis of elite men's and women's wheelchair basketball teams. *J. Sports Sci.* 32, 1066–1075. doi: 10.1080/02640414.2013.879334

Gréhaigne, J.-F., and Godbout, P. (2014). Dynamic systems theory and team sport coaching. *Quest* 66, 96–116. doi: 10.1080/00336297.2013.814577

Heinzl, H., and Mittlböck, M. (2003). Pseudo R-squared measures for poisson regression models with over- or underdispersion. *Comput. Stat. Data Anal.* 44, 253–271. doi: 10.1016/s0167-9473(03)00062-8

Horowitz, I. (2018). Competitive balance in the NBA playoffs. *Am. Econ.* 63, 215–227. doi: 10.1177/0569434517747250

Hosmer, D., and Lemeshow, S. (2000). *Applied Logistic Regression*, 2nd Edn. Hoboken, NJ: John Wiley & Sons Inc., doi: 10.1002/0471722146

Hughes, M., and Franks, I. (2004). "Notational analysis - a review of the literature," in *Notational Analysis of Sport: Systems for Better Coaching and Performance in Sport*, eds M. Hughes and I. Franks (Abingdon: Routledge), 59–106.

Hughes, M., James, N., Hughes, M., Murray, S., Burt, E., and Heath, L. (2015). "Momentum and 'hot hands,'" in *Essentials of Performance Analysis in Sport*, eds M. Hughes and I. Franks (Abingdon: Routledge), 270–291. doi: 10.4324/9781315776743-16

International Wheelchair Basketball Federation [IWBF] (2019a). *Rules of Wheelchair Basketball*. Available at: https://iwbf.org/rules-of-wheelchair-basketball/ (accessed February 24, 2019).

International Wheelchair Basketball Federation [IWBF] (2019b). *Statement Regarding IWBF Classification Process and Regulations*. Available at: https://iwbf.org/wp-content/uploads/2019/03/Statement-regarding-IWBF-Classification-process-regulations.pdf (accessed April 4, 2019).

International Wheelchair Basketball Federation [IWBF] (2014a). *Official Player Classification Manual*. Available at: https://iwbf.org/wp-content/uploads/2017/09/CLASSIFICATION-MANUAL-2014-2018-ENGLISH-FINAL.pdf (accessed March 24, 2019).

International Wheelchair Basketball Federation [IWBF] (2014b). *Official Wheelchair Basketball Rules*. Available at: https://iwbf.org/wp-content/uploads/2016/08/2014_IWBF_Rules_V2.pdf (accessed March 24, 2015).

Kazdin, A. E. (1977). Artifact, bias, and complexity of assessment: the ABCs of reliability. *J. Appl. Behav. Anal.* 10, 131–150. doi: 10.1901/jaba.1977.10-141

Kristan, M., Perš, J., Perše, M., and Kovačič, S. (2009). Closed-world tracking of multiple interacting targets for indoor-sports applications. *Comput. Vis. Image Underst.* 113, 598–611. doi: 10.1016/j.cviu.2008.01.009

Kubatko, J., Oliver, D., Pelton, K., and Rosenbaum, D. (2007). A starting point for analyzing basketball statistics. *J. Quant. Anal. Sport* 3, 1–24. doi: 10.2202/1559-0410.1070

Kuhn, M., Wing, J., Weston, S., Williams, A., Keefer, C., Engelhardt, A., et al. (2018). *R: package "caret."*. 1–215. Available at: https://cran.r-project.org/web/packages/caret/caret.pdf (accessed February 1, 2019).

Lago-Peñas, C., and Dellal, A. (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. *J. Hum. Kinet.* 25, 93–100. doi: 10.2478/v10078-010-0036-z

Lamas, L., Junior, D., Santana, F., Rostaiser, E., Negretti, L., and Ugrinowitsch, C. (2011). Space creation dynamics in basketball offence: validation and evaluation of elite teams. *Int. J. Perform. Anal. Sport* 11, 71–84. doi: 10.1080/24748668.2011.11868530

Lertwanich, P. (2009). The disabled athletes and related medical conditions. *Siriraj Med. J.* 61, 104–106.

Liu, D., Jaramillo, M., and Vincenzi, D. (2015). The effects of system reliability and task uncertainty on autonomous unmanned aerial vehicle operator performance under high time pressure. *Hum. Factors Ergon. Manuf.* 25, 515–522. doi: 10.1002/hfm.20565

Mackenzie, R., and Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *J. Sport Sci.* 31, 639–676. doi: 10.1080/02640414.2012.746720

Marcelino, R., Mesquita, I., and Sampaio, J. (2011). Effects of quality of opposition and match status on technical and tactical performances in elite volleyball. *J. Sports Sci.* 29, 733–741. doi: 10.1080/02640414.2011.552516

McFadden, D. (1974). "Conditional logit analysis of qualitative choice behavior," in *Frontiers of Economics*, ed. P. Zarembka (New York, NY: Academic Press), 105–142.

Molik, B., and Kosmol, A. (2001). "In search of objective criteria in wheelchair basketball player classification," in *New Horizons in Sports for Athletes with a Disability, Proceedings of the International Vista '99 Conference*, eds G. Doll-Tepper, M. Kroner, and W. Sonnenschein (Koln: Meyer and Meyer Sport), 355–368.

Molik, B., Kosmol, A., Morgulec-Adamowicz, N., Laskin, J., Jezior, T., and Patrzalek, M. (2009). Game efficiency of elite female wheelchair basketball players during world championships (Gold Cup) 2006. *Eur. J. Adapt. Phys. Act.* 2, 26–38. doi: 10.5507/euj.2009.007

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., and Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *J. Sports Sci.* 26, 1135–1145. doi: 10.1080/02640410802104912

Myers, R. H. (1990). *Classical and Modern Regression with Applications*, 2nd Edn. Pacific Grove, CA: Duxbury Press.

Nagelkerke, N. (1991). A note on a general definition of the coefficient of determination. *Biometrika* 78, 691–692. doi: 10.2307/2337038

O'Donoghue, P., Ball, D., Eustace, J., McFarlan, B., and Nisotaki, M. (2016). Predictive models of the 2015 Rugby World Cup: accuracy and application. *Int. J. Comput. Sci. Sport* 15, 37–58. doi: 10.1515/ijcss-2016-0003

Passos, P. (2017). "Coaching processes in team sports - key differences to coaching in other sports," in *Performance Analysis in Team Sports*, eds P. Passos, D. Araújo, and A. Volossovitch (Abingdon: Routledge), 25–37. doi: 10.4324/9781315739687-9

Perl, J., Grunz, A., and Memmert, D. (2013). Tactics analysis in soccer - an advanced approach. *Int. J. Comput. Sci. Sport* 12, 33–44.

Perriman, D. (2014). *Classification: an Overview. Int. Wheel. Basketb. Fed*. Available at: https://iwbf.org/the-game/classification/ (accessed May 17, 2017).

Petersen, C., Pyne, D., Portus, M., Cordy, J., and Dawson, B. (2007). Analysis of performance at the 2007 Cricket World Cup. *Int. J. Perform. Anal. Sport* 7, 1–8. doi: 10.1080/24748668.2008.11868417

R Core Team (2015). *R: A Language and Environment for Statistical Computing*. Available at: http://www.r-project.org/ (accessed February 1, 2019).

Reed, D., and Hughes, M. (2006). An exploration of team sport as a dynamical system. *Int. J. Perform. Anal. Sport* 6, 114–125. doi: 10.1080/24748668.2006.11868377

Rhodes, J., Mason, B., Perrat, B., Smith, M., Malone, L., and Goosey-Tolfrey, V. (2015). Activity profiles of elite wheelchair rugby players during competition. *Int. J. Sports Physiol. Perform.* 10, 318–324. doi: 10.1123/ijspp.2014-0203

Sampaio, J., Ibáñez, S. J., Lorenzo, A., and Gómez, M. -Á. (2007). Discriminative game- related statistics between basketball starters and nonstarters when related to team quality and game outcome. *Percept. Mot. Skills* 103, 486–494. doi: 10.2466/pms.103.6.486-494

Sampaio, J., McGarry, T., and O'Donoghue, P. (2013). "Introduction," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (Abingdon: Routledge), 1–2. doi: 10.4324/9780203806913

Santos, S. D. S., Monteiro, C. B. D. M., de, M., Cantelli, B., Alonso, A. C., Mochizuki, L., et al. (2014). Analysis of velocity and direction of trunk movement in wheelchair basketball athletes. *Med. Express* 1, 77–80. doi: 10.5935/MedicalExpress.2014.02.04

Schmidt, R. C., O'Brien, B., and Sysko, R. (1999). Self-organization of between-persons cooperative tasks and possible applications to sport. *Int. J. Sport Psychol.* 30, 558–579.

Sing, T., Sander, O., Beerenwinkel, N., and Lengauer, T. (2015). *R: package "ROCR."*. Available at: https://cran.r-project.org/web/packages/ROCR/ROCR.pdf (accessed April 2, 2019).

Sporner, M. L., Grindle, G. G., Kelleher, A., Teodorski, E. E., Cooper, R., and Cooper, R. A. (2009). Quantification of activity during wheelchair basketball and rugby at the National Veterans Wheelchair Games: a pilot study. *Prosthet. Orthot. Int.* 33, 210–217. doi: 10.1080/03093640903051816

Szumilas, M. (2010). Explaining odds ratios. *J. Can. Acad. Child Adolesc. Psychiatry* 19, 227–229.

Tenga, A., Holme, I., Ronglan, L. T., and Bahr, R. (2010). Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. *J. Sports Sci.* 28, 245–255. doi: 10.1080/02640410903502766

van der Slikke, R., Berger, M., Bregman, D., and Veeger, D. (2016). Push characteristics in wheelchair court sport sprinting. *Procedia Eng.* 147, 730–734. doi: 10.1016/j.proeng.2016.06.265

van der Woude, L., Veeger, D.-J., and Rozendal, R. (1989). Seat height in handrim wheelchair propulsion. *J. Rehabil. Res. Dev.* 26, 31–50.

van Rooyen, M., Diedrick, E., and Noakes, T. (2010). Ruck frequency as a predictor of success in the 2007 Rugby World Cup tournament. *Int. J. Perform. Anal. Sport* 10, 33–46. doi: 10.1080/24748668.2010.11868499

van Rooyen, M., Lombard, C., and Noakes, T. (2008). Playing demands of sevens rugby during the 2005 Rugby World Cup Sevens Tournament. *Int. J. Perform. Anal. Sport* 8, 114–123. doi: 10.1080/24748668.2008.11868441

Vanlandewijck, Y., Evaggelinou, C., Daly, D., Houtte, S., Van Verellen, J., Aspeslagh, V., et al. (2003). Proportionality in wheelchair basketball classification. *Adapt. Phys. Act. Q.* 20, 369–380. doi: 10.1123/apaq.20.4.369

Vanlandewijck, Y., Evaggelinou, C., Daly, D., Verellen, J., van Houtte, S., Aspeslagh, V., et al. (2004). The relationship between functional potential and field performance in elite female wheelchair basketball players. *J. Sports Sci.* 22, 668–675. doi: 10.1080/02640410310001655750

Vanlandewijck, Y., Spaepen, A. J., and Lysens, R. J. (1995). Relationship between the level of physical impairment and sports performance in elite wheelchair basketball athletes. *Adapt. Phys. Act. Q.* 12, 139–150. doi: 10.1123/apaq.12.2.139

Wickham, H. (2018). *R: package 'scales.' Cran*. Available at: https://cran.r-project.org/web/packages/scales/scales.pdf (accessed April 2, 2019).

Zhang, S., Lorenzo, A., Gómez, M. -Á., Liu, H., Gonçalves, B., and Sampaio, J. (2017). Players' technical and physical performance profiles and game-to-game variation in NBA. *Int. J. Perform. Anal. Sport* 17, 466–483. doi: 10.1080/24748668.2017.1352432

Ziv, G., Lidor, R., and Arnon, M. (2010). Predicting team rankings in basketball: the questionable use of on-court performance statistics. *Int. J. Perform. Anal. Sport* 10, 103–114. doi: 10.1080/24748668.2010.11868506

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Interpersonal Dynamics in 2-vs-1 Contexts of Football: The Effects of Field Location and Player Roles

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This study analyzed the spatial-temporal interactions that sustained 2-vs-1 contexts in football at different field locations near the goal. Fifteen male players (under 15 years, age 13.2 ± 1.03 years, years of practice 4.2 ± 1.10 years), 5 defenders, 7 midfielders, and 3 attackers, participated in the study. Each participant performed a game to simulate a 2-vs-1 sub-phase as a ball carrier, second attacker, and defender at three different field locations, resulting in a total number of 142 trials. The movements of participants in each trial were recorded and digitized with TACTO software. Values of interpersonal distance between the ball carrier and defender and interpersonal angles between players and between the goal target, defender, and ball carrier were calculated. The results revealed a general main effect of field location. Generally, the middle zone revealed the lowest values of interpersonal distance and angle between players and the right zone and the highest values of interpersonal distance between players and interpersonal angle between players and the goal. Related with participants' roles, defenders revealed subtle differences as attackers on interpersonal distances and relative angles compared with midfielders and attackers. Findings supported that field location is a key constraint of players' performance and that players' role constraint performance effectiveness in football.

Keywords: football, patterns of play, affordances, effectiveness, players' roles

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INTRODUCTION

Team sports have been investigated, as complex adaptive systems, with the aim of describing and explaining emergent behaviors of players from an ecological dynamics perspective. This approach requires analysis of the continuous interactions between attacking and defending players who, fundamentally, compete to gain/retain possession of the ball and move it into favorable attacking positions in critical scoring spaces in the playing area (Araújo and Davids, 2016). McGarry (2009) highlighted the dynamical nature of these continuous interactions, which can be observed at different levels of analysis from the entire competitive context to relevant game sub-phases (i.e., 1-vs-1, 2-vs-1, 3-vs-2, etc.). For this reason, a team game has been conceptualized as a complex adaptive system whose behaviors are driven or perturbed by interactions of multiple, smaller sub-systems composed of attackers and defenders interacting under constraints (Travassos et al., 2013b). For instance, research has highlighted specific contextual performance constraints that change the emergent behaviors of players and teams. These task constraints include the number of players involved (Silva et al., 2014), the field dimensions (Vilar et al., 2014a), the number of goals (Travassos et al., 2014a), or even contextual performance constraints such as game pace or match outcome (Sampaio et al., 2013).

In line with the ecological dynamics perspective, the adaptive behaviors of players and teams to constant changes in contextual constraints is a result of information exchanges among the competing and cooperating players in relation to game demands (Travassos et al., 2012; Folgado et al., 2018). That is, players and teams constantly interact to create information, make decisions, and organize actions when functioning as a team during competitive performance. This view of competitive performance in teams, in ecological dynamics, is based on the sharing of spatial-temporal information that continuously supports the utilization of individual, sub-group, and team affordances (i.e., possibilities or opportunities for action to achieve a specific performance goal) (Silva et al., 2013). For each individual, as well as collective sub-systems, evidence has revealed that affordances are sustained by variations in space-time relations defined by the co-positioning of teammates and opponents, co-variations in their displacement trajectories and their movement velocities with respect to field markings and dimensions, and the location of scoring targets like goals, baskets, and try lines, for example (Vilar et al., 2012b; Silva et al., 2013; Gesbert et al., 2017). Also, players who have different team roles usually exhibit different physical, technical, and tactical capabilities (also effectivities) during performance (Varley et al., 2017; Lovell et al., 2018) and, consequently, explore and use the space-time relations in a different way for the identification of affordances for play (Laakso et al., 2017; Baptista et al., 2018). Previous research revealed that manipulating players' roles constraint the spatial-temporal patterns of play from 1-vs-1 (Laakso et al., 2017) to 7-vs-7 (Baptista et al., 2018).

Research investigations have explored and exemplified these ideas in many different team sports including basketball (Araújo et al., 2006; Esteves et al., 2012), rugby union (Passos et al., 2008), Futsal (Travassos et al., 2012; Vilar et al., 2013b), and also in association football (Duarte et al., 2012; Clemente et al., 2013; Laakso et al., 2017).

In the context of association football, research findings have revealed that attackers need to lead the interactions in spatial-temporal relations with defenders, by promoting unpredictable changes in the values of key variables such interpersonal distance, relative angles with players and with the goal, and relative velocity to achieve successful outcomes (Schulze et al., 2018). On the other hand, defenders try to constrain attackers' actions and maintain spatial-temporal equilibrium with them to enhance sub-system stability and successfully perform (Duarte et al., 2012; Clemente et al., 2013). That is, evidence suggests how attackers vary key movement displacement parameters to de-stabilize an "unwanted" symmetrical relationship with a marking defender in a dyad. In contrast, defenders use actions to maintain system stability and prevent attackers from breaking up their temporary dyad.

As previously reported, the field location of these ongoing interactions has a substantial effect to constrain the spatial-temporal relations in attacker-defender dyadic systems (Headrick et al., 2011; Vilar et al., 2012c; Laakso et al., 2017). Variations in proximity to the goal area or in field "longitudinal corridors of play" (middle or wing zones) result in emergence of different coordination dynamics of key variables like relative distance and the angle between an attacker and defender in relation to the goal (Headrick et al., 2011; Laakso et al., 2017). Although the effects of these constraints are clear, previous studies have mainly reported their influence in 1-vs-1 sub-phases of play.

In most team games, attackers try to gain an advantage by rapidly creating a temporary numerical overload against defenders in a specific location of the field. Particularly in association football, the creation of offensive or defensive numerical superiority near the ball is directly related to successful performance in terms of attacking space behind a defensive line or in recovering the ball (Vilar et al., 2013a). Thus, the 2-vs-1 sub-phase is the minimum sub-phase of game that represents such numerical (overload) advantage to an attacking team. During this sub-phase, the ball carrier and the support attacker need to manage the spatial-temporal relations with an immediate opponent to support emergence of two possibilities for action: (s)he can dribble and face the defender in a 1-vs-1 if the defender is protecting a passing line to the second attacker or (s)he can draw the defender and pass the ball to the support attacker if a passing line emerges by the defender being drawn toward the ball dribbler. Despite its relevance for understanding the spatial-temporal changes that support the emergence of possibilities for action in overloads, little research has been conducted to observe actual competitive interactions during performance in this important sub-phase. In addition, there is a need to improve understanding of how interpersonal patterns of coordination between attackers and a defender in 2-vs-1 sub-phases are influenced by field location effects relative to the goal. A key issue is whether a defender changes co-positioning behavior, when constrained by the field location in football. Clear implications for practice could result from this study. The implications of the manipulation of the relative position of the goal target (Coutinho et al., 2018) in relation to the 2-vs-1 sub-phases or the attacker-defender participants' performance roles (Laakso et al., 2017) allow coaches to improve the design of practice tasks according to the planned goals. Also, in line with previous studies, this study will allow to identify the task constraints that coaches can stress to improve players' decision and action according to each task condition (Correia et al., 2012). Thus, the aim of this study was to analyze the adaptive behaviors of players who sustained 2-vs-1 sub-phases in football at different field locations near the goal (left, middle, and right zones on field) and manipulate participants' team performance roles (i.e., divided into roles as attackers, midfielders, and defenders). In line with previous research in 1-vs-1 sub-phases (Laakso et al., 2017), we expected to observe changes in interpersonal distances and relative angles between players and the goal at different field location with high correlations between interpersonal distances and angles for right and left zones and low correlations in middle zone. Also, it was expected changes in interpersonal distances according to participants' team performance roles as attackers or defenders on the emergent spatial-temporal patterns of interaction in the 2-vs-1 sub-phase.

MATERIALS AND METHODS

Participants

Fifteen male players (under 15 years, age 13.2 ± 1.03 years, years of practice 4.2 ± 1.10 years) participated in this study. The sample size was calculated with G*Power (Version 3.1.5.1 Institut für Experimentelle Psychologie, Düsseldorf, Germany) for an effect size of 0.7, an α of 0.05, and a power of 0.8 (1–β). The total sample size computed by this method was a minimum of 15 players with a statistical power of 82.4%.

For the purposes of analysis, with the advice of the coaching staff, the participants were categorized into their main team performance role, resulting in sub-samples of five defenders (center-backs and full-backs), seven midfielders (center midfielders, lateral midfielders), and three attackers (forwards). All players belong to one youth team competing in a national Finnish level (2016/2017 season). All participants were right-footed and played in the first team of the club. The participants participated in five training sessions per week (90 min per session) and played an official competitive match at the weekend. The club, all parents, and the participants provided prior informed and written consent for participation in the study. The study was approved by the Ethics Committee of University of Jyväskylä according to the Declaration of Helsinki.

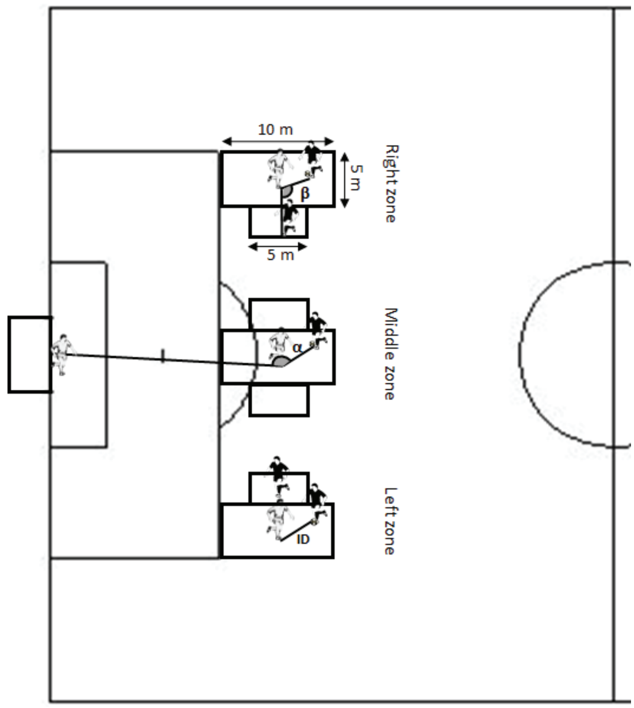

FIGURE 1 | Representation of the three areas of play (left, middle, right) of ball carrier and defender and the area of second attacker and their location in relation to the goal. α – interpersonal angle between ball carrier, defender and second attacker (IABDA); β – interpersonal angle between goal target, defender and ball carrier (IAGDB); ID – interpersonal distance between ball carrier and defender.

Task and Procedures

All players were tested during four sessions in 1 week of summer break of competitive season (July) in an artificial grass pitch. The temperature was about 17–19°. The first session was used for the players being familiarized with task conditions in all field zones, and the three next sessions were used for testing purposes. Each participant performed in a game to simulate a 2-vs-1 sub-phase as a ball carrier, second attacker, and defender at three different field locations. The 2-vs-1 sub-phases occurred in a predefined area of 10 × 5 m (Passos et al., 2008; Headrick et al., 2011) in three different field locations (Left, middle and right) under competitive performance conditions (See **Figure 1**). The task constraints included a regular size goal (2.44 m × 7.32 m) with a goalkeeper. The starting distance between attacker and defender was 3 m. When performing in the left or on the right side of the field, the second attacker was placed in the inner side of the field in order to maintain free the wing for a possible dribble. That is, when in the right-side zone of the field, the second attacker was placed to the left of ball carrier, and when in the left zone, to the right of ball carrier. In the middle zone, the second attacker was placed at the side of the first attacker's non-dominant foot. The area for the second attacker to move was 5 × 1.30 m (**Figure 1**). Before practice, all the players were informed about the rules and the goals of the tasks and encouraged to compete like in the game. The goalkeepers were also informed to act as in a competitive game. No coach feedback or encouragement was allowed during the conditions.

Before data collection, all participants engaged in a thorough warm-up routine. Each trial started when both the attacking and defending participants were ready in their starting positions and the attacking participant was requested to start the trial. As soon as the attacker moved the ball, the defender could start defending. After crossing the midline of the playing area (5 m from the end of attacking area), the attacker could dribble or pass the ball to the second attacker. The performance aim of attacking participants was to dribble past the defender and shoot to the goal or pass the ball to the second attacker who could shoot at goal. If these events occurred, the trial was over. The aim of the defender was to prevent the attackers from scoring a goal, within the laws of the game. The trial was considered over when defending participants intercepted the ball or when the ball moved outside the borders of the playing area. A regulation ball size 5 was used in all trials.

All participants performed the 2-vs-1 trials in all three zones acting as an attacker and as a defender, resulting in a total number of 142 trials. In each trial, two attacking players with the same positional roles attacking one defending player with a different positional role (e.g., Defender + Defender vs Midfielder or Midfielder + Midfielder vs Attacker). After each trial, the attacking teams and the opposition change to promote variability in pairs and roles in next trials. Any player performed two consecutive trials in the same zone nor playing with the same pair, or opponent. Participants rest about 3–4 min between trials to avoid fatigue. All trials were randomly allocated between left, middle, and right zones, comprising 50 trials in the left zone, 41 in the middle, and 51 in the right performance area. The experimental protocol allowed us to analyze the effects of participants' performance roles in attack, and the distribution of trials by role was defenders (49 trials), midfielders (45 trials), and attackers (48 trials).

Participant movements were captured by using a single digital video camera (Sony HRX-MC50E) placed 4 m above ground forming an angle of approximately 45° with the longitudinal axis of the performance area to capture participant movements during the whole experimental task. All video recordings captured the displacement trajectories of all participants without moving the camera. The movements of participants in each trial were digitized with TACTO software at 25 Hz (Fernandes and Malta, 2007; Duarte et al., 2010). The displacement trajectories of the participants and the ball were tracked using a computer mouse, by following, in every frame, a working point located between players' feet on the ground plan. After calibration of the pitch, with real measures of six control points for each zone (4 corners of the zone of play, and the two goalposts position), the x and y virtual coordinates of the players were extracted. The obtained virtual coordinates were transformed into real coordinates using the direct linear transformation method (2D-DLT) to avoid parallax error and filtered with a Butterworth low pass filter (6 Hz) to reduce the noise of the process of digitizing (Winter, 2005).

Reliability of the Digitizing Procedure

Fifteen trials were selected at random and the displacement trajectories of attackers and defenders ($n = 45$) were re-digitized after 1 month by the same experimenter. Intra-digitizer reliability values were assessed using technical error of measurement (TEM) and coefficient of reliability (R) statistics (for details see Goto and Mascie-Taylor, 2007). The intra-TEM yielded values of 0.235 m (2.25%) with a corresponding coefficient of reliability ($R = 0.991$).

Variables

According to our purposes, the interpersonal distance between the ball carrier and defender (ID) was calculated. Also, the interpersonal angles between (1) ball carrier, defender, and second attacker (IABDA) and (2) between the goal target (the center of the goal in order to maintain the reference fixed and allow a better understanding of the relationships between players and the goal), defender, and ball carrier (IAGDB) were calculated to investigate changes in interpersonal interactions between participants in the 2-vs-1 performance contexts (See **Figure 1**; Vilar et al., 2014a; Laakso et al., 2017).

Data Analysis

Descriptive statistics were reported for all performance measures recorded. Comparisons between field zones and participants' roles were assessed using standardized mean differences with 90% confidence intervals. The smallest worthwhile differences were estimated from the standardized units multiplied by 0.2 (Hopkins et al., 2009; Cumming, 2012). Effect size statistics were reported using the following ranges: trivial (0–0.19); small (0.2–0.59); moderate (0.6–1.19); large (1.2–1.99); and very large (≥2.0). Magnitudes of clear effects were considered at the following scale: 25–75%, possibly; 75–95%, likely; 95–99%, very likely; >99%, most likely (observed effects were represented by –ive and +ive directions) (Hopkins et al., 2009). Correlation values between variables were accessed through Pearson correlation using SPSS 22.0 software (IBM SPSS Inc., Chicago, USA). Thresholds for correlation coefficients (r) were: 0.30, small; 0.49, moderate; 0.69, large; 0.89, very large; and 1.00, near perfect (Hopkins et al., 2009).

RESULTS

Effects of Field Location

Analysis of ID revealed main effects for field zones. Small higher values were observed in comparisons of the left to middle zone (likely –ive). Moderate higher values were observed in comparisons of middle to right zone (very likely +ive). Unclear values were observed in comparisons of left to right zone (unclear). Generally, the middle zone revealed the lowest ID values, while the right zone revealed the highest ID values (see **Table 1** and **Figure 2**).

Analysis of IABDA revealed main effects for field zones. Moderate higher values were observed in comparisons of left to middle zone (very likely –ive). Small higher values were observed in comparisons of middle zone to right zone

TABLE 1 | Descriptive statistics and differences in means for field location and players' roles.

	(Mean ± SD)			Difference in means (d; 90% CL)		
			Field location			
Variables	**Left**	**Middle**	**Right**	**Left vs Middle**	**Left vs Right**	**Middle vs Right**
ID (meters)	3.21 ± 1.42	2.68 ± 1.49	3.67 ± 1.73	–0.35 [–0.7–0.01]	0.28 [–0.04 0.62]	0.60 [0.26 0.95]
IABDA (degrees)	121.34 ± 20.57	107.77 ± 22.28	115.94 ± 23.22	–0.63 [–0.98–0.27]	–0.24 [–0.57 0.608]	0.36 [0.01 0.07]
IAGDB (degrees)	122.9 ± 20.76	135.72 ± 23.87	140.40 ± 17.12	0.57 [0.22 0.92]	0.91 [0.58 1.24]	0.22 [–0.13 0.57]
			Players' role			
Variables	**Defenders**	**Midfielders**	**Attackers**	**Defenders vs Midfielders**	**Defenders vs Attackers**	**Midfielders vs Attackers**
ID (meters)	3.75 ± 1.81	3.30 ± 1.59	2.77 ± 1.13	–0.26 [–0.6 0.07]	–0.65 [–0.98–0.31]	–0.38 [–0.73–0.04]
IABDA (degrees)	120.83 ± 19.88	110.45 ± 19.22	114.74 ± 26.86	–0.52 [–4.7 3.62]	–0.25 [–3.69 3.18]	0.18 [–3.29 3.66]
IAGDB (degrees)	131.71 ± 20.55	136.77 ± 20.35	130.45 ± 24.07	0.24 [–3.72 4.21]	–0.06 [–3.67 3.57]	–0.28 [–3.92 3.36]

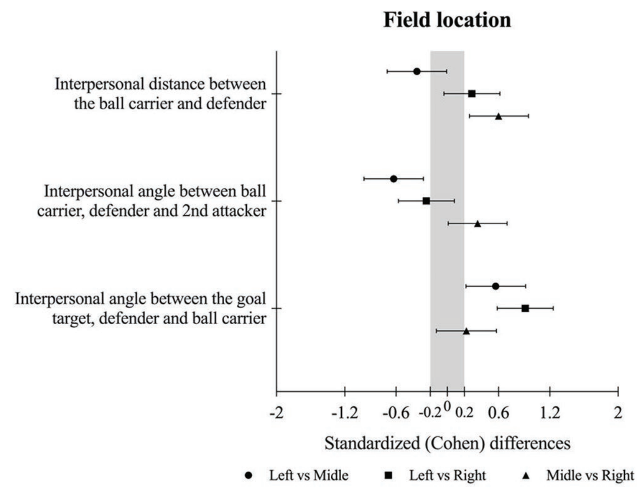

FIGURE 2 | Standardized (Cohen) differences of ID, IABDA, and IAGDB for field zones (left vs. middle vs. right).

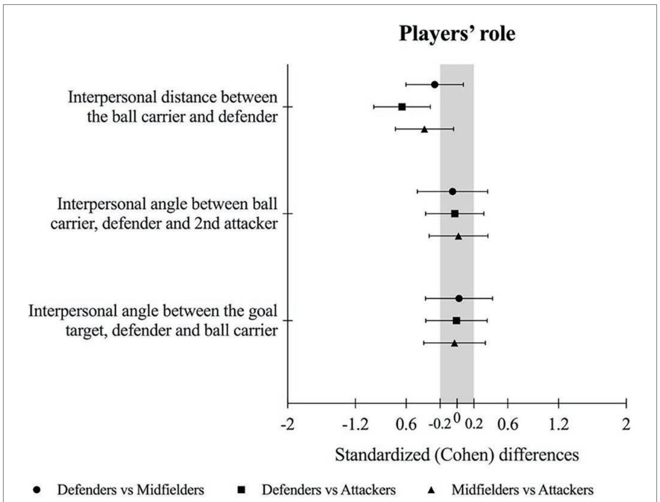

FIGURE 3 | Standardized (Cohen) differences of ID, IABDA, and IAGDB for players' role (defenders vs. midfielders vs. attackers).

(likely +ive). Unclear values were observed in comparisons of left to right zone (unclear). Generally, the left zone revealed higher values of IABDA, while the middle zone revealed lower values (see **Table 1** and **Figure 2**).

Analysis of IAGDB revealed main effects for field zones. Small lower values were observed in comparisons of left to middle zone (very likely +ive). Unclear values were observed in comparisons of middle to right zone (unclear). Moderate higher values were observed in comparisons of left to right zone (most likely +ive). Generally, the right zone revealed the higher values and the left zone revealed the lower values of IAGDB (see **Table 1** and **Figure 2**).

Analysis of relationships between ID, IABDA, and IAGDB for each field zone revealed interesting effects. In the left field zone, a large negative correlation was revealed between ID and IABDA values [r = −0.76, R^2 = 0.57 (90%CI: −0.84 to −0.64), most likely −ive], a large positive correlation between ID and IAGDB values [r = 0.72, R^2 = 0.52 (90%CI: 0.59–0.82), most likely +ive], and a moderate negative correlation between IABDA and IAGDB values [r = −0.46, R^2 = 0.21 (90%CI: −0.62 to −0.24), most likely −ive]. On the right, an unclear correlation was revealed between ID and IABDA values [r = 0.08, R^2 = 0.01 (90%CI: −0.16 to 0.31), unclear], a large negative correlation between ID and IAGDB values [r = −0.70, R^2 = 0.48 (90%CI: −0.8 to −0.55), most likely −ive], and a moderate negative correlation between IABDA and IAGDB values [r = −0.56, R^2 = 0.31 (90%CI: −0.7 to −0.37), most likely −ive]. In the middle zone, a near perfect positive correlation was revealed between ID and IABDA values [r = 0.93, R^2 = 0.87 (90%CI: 0.9 to 0.96), most likely +ive], and unclear correlations between ID and IAGDB [r = 0.15, R^2 = 0.02 (90%CI: −0.37 to 0.1), unclear] and IABDA and IAGDB values [r = 0.10, R^2 = 0.02 (90%CI: −0.14 to 0.33), unclear].

Effects of Players' Roles

Analysis of players' roles, as attacking players, revealed subtle changes in emergent interpersonal coordination tendencies (see **Table 1** and **Figure 3**). When defenders acted as attacking players, small higher values of ID were observed compared to midfielders (possibly −ive) and a moderate higher ID was observed compared to attackers (very likely −ive). Also, when midfielders acted as attacking players, small higher ID values were observed compared to attackers (possibly −ive). No other effects on IABDA and IAGDB were revealed in analysis of effects of players' roles when participants acted as attacking players (see **Table 1** and **Figure 3**). Analyses of relationships between ID, IABDA, and IAGDB for each player role were unclear.

DISCUSSION

The aim of the present study was to analyze the adaptive behaviors of players who sustained 2-vs-1 sub-phases in football at different field locations near the goal (left-, middle- and right- zones on field) and manipulate participants' team performance roles (i.e., divided into roles as attackers, midfielders, and defenders). As expected, results indicated a main effect of field location and a subtle effect of participants' roles on spatial-temporal coordination tendencies in the 2-vs-1 sub-phases. Generally, the findings reinforced effects noted in previous studies on performer interactions in football (Laakso et al., 2017).

Effect of Field Locations

Field location was confirmed as an important constraint on interpersonal coordination of players, not just in 1-vs-1 sub-phases (Headrick et al., 2011; Laakso et al., 2017) but also in 2-vs-1 sub-phases of football. As observed in performance context (Schulze et al., 2018), according to changes in field zones of performance, the relationship between values of interpersonal distances and relative angles between players and the goal revealed different relational dynamics. Analysis of interactions in the middle zone revealed lower values for ID and IABDA (near 1–10°) and medium values (near 135°) for IAGDB. These findings contrasted with data reported in previous research on performance in 1-vs-1 sub phases, in which higher values of ID and greater relative angles between players and the goal were observed in the middle zone, compared to performance in the other zones. In 2-vs-1 sub-phases, the additional teammate increases the available affordances for the ball carrier (dribbling, shooting, passing), not allowing the defender to perform as conservatively. Thus, defenders tried to cope with the increase in affordances for attackers by dividing their efforts to occupy passing lines and inhibit the emergence of dribbling/shooting lines for the ball carrier (Vilar et al., 2012c). The near perfect correlation values observed in mid zone between ID and IABDA variables reinforced such an interpretation. Similar results have been observed in previous research (Travassos et al., 2014b; Vilar et al., 2014b).

When a defending team performing with a numerical disadvantage usually adopts a zonal defense to simultaneously occupy space and close down options for the ball carrier at the same time (Travassos et al., 2014a). That is, the defenders or even the defensive team seeks to co-position themselves to mark the opponents and the space at the same time, inhibiting the emergence of the most advantageous affordances for attackers. This strategy of defenders can be explained by an attempt to adapt to the emerging informational constraints of the 2-vs-1 sub-phase, increasing the time for ball carriers to interact, that is, explore, decide, and perform actions (van Andel et al., 2017).

Observations of performance in left and right field zones revealed contrasting findings. Analysis of performance in the left zone revealed mid values for ID, higher values for IABDA, and lower values for IAGDB. In opposition, analysis of performance in the right zone revealed higher values for ID, mid values for IABDA, and higher values for IAGDB. These performance observations may be related to the fact that all the players were right-footed, constraining possibilities for the ball carrier to explore affordances for shooting or passing, consequently allowing different affordances for defenders (Paterson et al., 2016). It is worth noting that the ball carriers' preferred foot was the "outside" foot on the right field zone, providing the ball carrier with affordances to typically pass the defender on the right side. This affordance typically constrained the interactions for the defending players so that they could focus more on their alignment with the goal (IAGDB). These adaptations allowed defenders to maintain a large ID to provide an affordance for the ball carrier to dribble to the right and shoot at goal from the "outside" (with a narrow angle to the goal). The negative correlations between ID and IAGDB values support the use of this functional defensive strategy. It suggests that when the defender presses the ball carrier, he is seeking to maintain symmetry of the system with the goal to ensure that he could not shoot at goal with the preferred foot.

In contrast, in the left field zone, the starting position of the second attacking player was on the right side of the area. In this case, the ball carrier tried to open space to explore a dribble to the middle or to open a passing line to the second attacker. While this was happening, the defender sought to constrain the ball carrier to drive to the left and use the preferred foot and, simultaneously, seeking to occupy the passing line to the second attacker. These interactions were driven by increases in IABDA and decreases in IAGDB values. The emergent negative correlations between ID and IABDA and the positive correlations between ID and IAGDB supported the use of this defensive strategy. When a defender presses the ball carrier, a major aim is to cut the passing line from the ball carrier to the second attacker, increasing the value of IABDA and temporarily decreasing alignment with the goal. These dynamical interactions suggest that the exploration of affordances by attackers and defenders, during performance, was context-dependent and forged by variations in spatial-temporal relations between players (Vilar et al., 2012b; Silva et al., 2013; Gesbert et al., 2017) and their own effectivities (Silva et al., 2013; Paterson et al., 2016). Also, the findings clearly revealed how the location of the scoring target acted as a powerful constraint on emergent interpersonal spatial-temporal interactions of players and teams in football (Headrick et al., 2011; Vilar et al., 2012c; Laakso et al., 2017).

Effect of Team Roles

As expected, the participants' main performance roles constrained interpersonal coordination tendencies in the 2-vs-1 sub-phases. However, only subtle changes were revealed, particularly for defenders, compared with midfielders and attackers (Laakso et al., 2017). Compared to midfielders and attackers, defenders usually displayed different technical and tactical abilities, which constrained the identification of affordances and consequently shaped the coordination tendencies during performance (Laakso et al., 2017; Baptista et al., 2018). In this study, results revealed higher ID values for defenders, acted as attacking, compared to participants with other main performance roles. Midfielders revealed higher ID values than attackers, when acting also as attacking players. The findings suggested that the familiarity and past experience of players, acting in their main performance role or other, may influence their interaction tendencies with other participants, especially in exploiting affordances. For instance, defenders, in attack, revealed generally higher ID values than midfielders and attackers. In competition, defenders typically do not have as many opportunities to face 2-vs-1 situations near the opposite goal to achieve scoring box opportunities, as do midfielders and attackers in their team roles. Due to their typically less effective skills in attacking situations to create scoring box opportunities, defenders seek to manipulate the ball when well away from attackers. That is, defenders usually face the 2-vs-1 situations with the aim of keeping the ball possession and achieving in-depth passing opportunities, and for that, it makes sense to play with high distance from opponents to ensure secure passing lines or other options for play. In 2-vs-1 sub-phases, this lack of skill and experience may lead defenders to seek more possibilities to pass the ball to the second attacker rather than to try to dribble the defending player with the ball. These findings in contrast with previous results in a study of 1-vs-1 sub-phases show that, when defenders attack and attackers defend, lower values in interpersonal distance emerged in comparison to performance of participants with other role combinations (Laakso et al., 2017).

Our data suggest that an individual's team role is an individual constraint that can be related to performance effectiveness (Varley et al., 2017). Due to differences in performance contexts and the requisite actions, players of different team roles exploited affordances and performed differently in competition condition (Travassos et al., 2013a; Silva et al., 2014; Araújo et al., 2017). The findings signified that participants revealed different levels of effectiveness, especially the defenders in comparison to participants with other team roles.

CONCLUSIONS

Our findings supported the general idea that field location is a key constraint on interpersonal coordination tendencies in 2-vs-1 sub-phases of association football, as also observed in previous work on 1-vs-1 sub-phases (Headrick et al., 2011; Laakso et al., 2017). Taken together, these findings imply how coaches can design practice environments for team sport athletes. These findings in 2-vs-1 sub-phases suggested the need to analyze interactional dynamics of attackers and defenders in different relevant sub-phases of team games (i.e., 3-vs-2, 3-vs-3, 4-vs-3, 5-vs-5) (Laakso et al., 2017). These observations are important to understand how manipulated constraints in team games practice can change interpersonal coordination tendencies and how players explore such variations. The results also suggested that the manipulation of different field playing locations should be promoted in practice. Further research is also required to understand the dynamics of this game sub-phase during training sessions or in the game environment. That is, what is really the transfer between such spatial-temporal coordination tendencies in training and competition and how it happens at different levels of relations (from individuals to teams).

The manipulation of the relative position of the goal could highlight the behavior of defenders to effectively manage the spatial-temporal relations with opponents and constrain affordances according to the current effectivities (capacities) of players (for instance use of a preferred foot). Such manipulations have implications for specificity of practice, highlighting the importance of conditioning for footwork and management of spatial-temporal relations with opponents, which can be best attained in sub-phase practices (rather than ladder drills) because of the perception of information for action (affordances).

Despite the obtained results, some limitations should be acknowledged. In this study, only U15 players from one team were considered for analysis. Further research should be developed using larger sample of players and considering diferent ages and levels of practice to identify variations or similarities between spatial-temporal coordination tendencies. Also, independently of the age and level of practice, further studies should evaluate the technical/tactical proficiency of players and their level of fitness and maturation in order to understand the impact of individual characteristics on the spatial-temporal coordination tendencies developed in 2-vs-1 sub-phases of association football.

At the end, it was clear that changes in contextual game constraints such as relative position of the goal promote adaptive behaviors of players to perform. In line with that, coaches should constantly promote changes in the field location of 2-vs-1 sub-phases of game in order to promote the creation of new possibilities for action of players. Also, the definition of different couples of attackers and defenders according to different levels of effectivities seems to be a good constraint to create new spatial-temporal information and promote new possibilities for action of players according to their effectivities. Further research is required to understand the contribution of such manipulations to the learning process.

ETHICS STATEMENT

The club and all parents of participants provided prior informed consent for participation in the study. The study was approved by the Local Ethics Committee according to the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

TL, KD, JL, and BT participated in study design. TL and JL participated in data collection. TL, KD and BT participated in data analysis and in the first draft manuscript. All the authors participated and approved the final version of the manuscript and agree with the order of the presentation of the authors.

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REFERENCES

Araújo, D., and Davids, K. (2016). Team synergies in sport: theory and measures. *Front. Psychol.* 7:1449. doi: 10.3389/fpsyg.2016.01449

Araújo, D., Davids, K., and Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychol. Sport Exerc.* 7, 653–676. doi: 10.1016/j.psychsport.2006.07.002

Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., and Davids, K. (2017). Ecological cognition: expert decision-making behaviour in sport. *Int. Rev. Sport Exerc. Psychol.* 1–25. doi: 10.1080/1750984X.2017.1349826

Baptista, J., Travassos, B., Gonçalves, B., Mourão, P., Viana, J. L., and Sampaio, J. (2018). Exploring the effects of playing formations on tactical behaviour and external workload during football small-sided games. *J. Strength Cond. Res.* doi: 10.1519/jsc.0000000000002445 [Epub ahead of print].

Clemente, F., Couceiro, M., Martins, F., Dias, G., and Mendes, R. (2013). Interpersonal dynamics: 1v1 sub-phase at sub-18 football players. *J. Hum. Kinet.* 36, 179–189. doi: 10.2478/hukin-2013-0018

Correia, V., Araújo, D., Duarte, R., Travassos, B., Passos, P., and Davids, K. (2012). Changes in practice task constraints shape decision-making behaviours of team games players. *J. Sci. Med. Sport* 15, 244–249. doi: 10.1016/j.jsams.2011.10.004

Coutinho, D., Gonçalves, B., Santos, S., Travassos, B., Wong, D. P., and Sampaio, J. (2018). Effects of the pitch configuration design on players' physical performance and movement behaviour during soccer small-sided games. *Res. Sports Med.* 27, 298–313. doi: 10.1080/15438627.2018.1544133

Cumming, G. (2012). *Understanding the new statistics: effect sizes, confidence intervals, and meta-analysis*. New York: Routledge.

Duarte, R., Araújo, D., Davids, K., Travassos, B., Gazimba, V., and Sampaio, J. (2012). Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes in youth soccer. *J. Sport Sci.* 30, 871–877. doi: 10.1080/02640414.2012.675081

Duarte, R., Araújo, D., Fernandes, O., Fonseca, C., Correia, V., Gazimba, V., et al. (2010). Capturing complex human behaviors in representative sports contexts with a single camera. *Medicina* 46, 408–414.

Esteves, P., Araújo, D., Davids, K., Vilar, L., Travassos, B., and Esteves, C. (2012). Interpersonal dynamics and relative positioning to scoring target of performers in 1 vs. 1 sub-phases of team sports. *J. Sports Sci.* 30, 1285–1293. doi: 10.1080/02640414.2012.707327

Fernandes, O., and Malta, P. (2007). Techno-tactics and running distance analysis using one camera. *J. Sports Sci. Med.* 6, 204–205.

Folgado, H., Duarte, R., Marques, P., Gonçalves, B., and Sampaio, J. (2018). Exploring how movement synchronization is related to match outcome in elite professional football. *Sci. Med. Football* 2, 101–107. doi: 10.1080/24733938.2018.1431399

Gesbert, V., Durny, A., and Hauw, D. (2017). How do soccer players adjust their activity in team coordination? An enactive phenomenological analysis. *Front. Psychol.* 8:854. doi: 10.3389/fpsyg.2017.00854

Goto, R., and Mascie-Taylor, C. G. N. (2007). Precision of measurement as a component of human variation. *J. Physiol. Anthropol.* 26, 253–256. doi: 10.2114/jpa2.26.253

Headrick, J., Davids, K., Renshaw, I., Araújo, D., Passos, P., and Fernandes, O. (2011). Proximity-to-goal as a constraint on patterns of behaviour in attacker-defender dyads in team games. *J. Sport Sci.* 30, 247–253. doi: 10.1080/02640414.2011.640706

Hopkins, W., Marshall, S., Batterham, A., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exer.* 41, 3–12. doi: 10.1249/MSS.0b013e31818cb278

Laakso, T., Travassos, B., Liukkonen, J., and Davids, K. (2017). Field location and player roles as constraints on emergent 1-vs-1 interpersonal patterns of play in football. *Hum. Mov. Sci.* 54, 347–353. doi: 10.1016/j.humov.2017.06.008

Lovell, T. W. J., Bocking, C. J., Fransen, J., Kempton, T., and Coutts, A. J. (2018). Factors affecting physical match activity and skill involvement in youth soccer. *Sci. Med. Football* 2, 58–65. doi: 10.1080/24733938.2017.1395062

McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in sport: scientific issues and challenges. *Int. J. Perform. Anal. Sport* 9, 128–140. doi: 10.1080/24748668.2009.11868469

Passos, P., Araújo, D., Davids, K., Gouveia, L., Milho, J., and Serpa, S. (2008). Information-governing dynamics of attacker-defender interactions in youth rugby union. *J. Sports Sci.* 26, 1421–1429. doi: 10.1080/02640410802208986

Paterson, G., Van der Kamp, J., Bressan, E., and Savelsbergh, G. (2016). Action-specific effects on perception are grounded in affordance perception: an examination of soccer players' action choices in a free-kick task. *Int. J. Sport Pshychol.* 47, 318–334. doi: 10.7352/IJSP2016.47.318

Sampaio, J., Lago, C., Gonçalves, B., Maçãs, V. M., and Leite, N. (2013). Effects of pacing, status and unbalance in time motion variables, heart rate and tactical behaviour when playing 5-a-side football small-sided games. *J. Sci. Med. Sport* 17, 229–233. doi: 10.1016/j.jsams.2013.04.005

Schulze, E., Mendes, B., Maurício, N., Furtado, B., Cesário, N., Carriço, S., et al. (2018). Effects of positional variables on shooting outcome in elite football. *Sci. Med. Football* 2, 93–100. doi: 10.1080/24733938.2017.1383628

Silva, P., Garganta, J., Araújo, D., Davids, K., and Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Med.* 43, 765–772. doi: 10.1007/s40279-013-0070-9

Silva, P., Travassos, B., Vilar, L., Aguiar, P., Davids, K., Araújo, D., et al. (2014). Numerical relations and skill level constrain co-adaptive behaviors of agents in sports teams. *PLoS One* 9:e107112. doi: 10.1371/journal.pone.0107112

Travassos, B., Araújo, D., Davids, K., O'Hara, K., Leitão, J., and Cortinhas, A. (2013a). The effect of expertise on decision making in sport – a meta-analysis. *Psychol. Sport Exerc.* 14, 211–219. doi: 10.1016/j.psychsport.2012.11.002

Travassos, B., Araújo, D., Duarte, R., and McGarry, T. (2012). Spatiotemporal coordination patterns in futsal (indoor football) are guided by informational game constraints. *Hum. Mov. Sci.* 31, 932–945. doi: 10.1016/j.humov.2011.10.004

Travassos, B., Davids, K., Araujo, D., and Esteves, P. (2013b). Performance analysis in team sports: advances from an ecological dynamics approach. *Int. J. Perform. Anal. Sport* 13, 83–95. doi: 10.1080/24748668.2013.11868633

Travassos, B., Gonçalves, B., Marcelino, R., Monteiro, R., and Sampaio, J. (2014a). How perceiving additional targets modifies teams' tactical behavior during football small-sided games. *Hum. Mov. Sci.* 38, 241–250. doi: 10.1016/j.humov.2014.10.005

Travassos, B., Vilar, L., Araújo, D., and McGarry, T. (2014b). Tactical performance changes with equal vs unequal numbers of players in small-sided football games. *Int. J. Perform. Anal. Sport* 14, 594–605. doi: 10.1080/24748668.2014.11868745

van Andel, S., Cole, M., and Peping, G. J. (2017). A systematic review on perceptual-motor calibration to changes in action capabilities. *Hum. Mov. Sci.* 51, 59–71. doi: 10.1016/j.humov.2016.11.004

Varley, M. C., Gregson, W., McMillan, K., Bonanno, D., Stafford, K., Modonutti, M., et al. (2017). Physical and technical performance of elite youth soccer players during international tournaments: influence of playing position and team success and opponent quality. *Sci. Med. Football* 1, 18–29. doi: 10.1080/02640414.2016.1230676

Vilar, L., Araújo, D., Davids, K., and Bar-Yam, Y. (2013a). Science of winning soccer: emergent pattern-forming dynamics in association football. *J. Syst. Sci. Complex.* 26, 73–84. doi: 10.1007/s11424-013-2286-z

Vilar, L., Araújo, D., Davids, K., Correia, V., and Esteves, P. T. (2013b). Spatial-temporal constraints on decision-making during shooting performance in the team sport of futsal. *J. Sports Sci.* 31, 840–846. doi: 10.1080/02640414.2012.753155

Vilar, L., Araújo, D., Davids, K., and Travassos, B. (2012b). Constraints on competitive performance of attacker–defender dyads in team sports. *J. Sport Sci.* 30, 459–469. doi: 10.1080/02640414.2011.627942

Vilar, L., Araújo, D., Davids, K., Travassos, B., Duarte, R., and Parreira, J. (2012c). Interpersonal coordination tendencies supporting the creation/prevention of goal scoring opportunities in futsal. *Eur. J. Sport Sci.* 14, 28–35. doi: 10.1080/17461391.2012.725103

Vilar, L., Duarte, R., Silva, P., Chow, J., and Davids, K. (2014a). The influence of pitch dimensions on performance during small-sided and conditioned soccer games. *J. Sports Sci.* 32, 1–9. doi: 10.1080/02640414.2014.918640

Vilar, L., Esteves, P. T., Travassos, B., Passos, P., Lago-Peñas, C., and Davids, K. (2014b). Varying numbers of players in small-sided soccer games modifies action opportunities during training. *Int. J. Sports Sci. Coach.* 9, 1007–1018. doi: 10.1260/1747-9541.9.5.1007

Winter, D. (2005). *Biomechanics and motor control of human movement*. 3rd ed. New York: John Wiley & Sons.

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Designing and Validating a Basketball Learning and Performance Assessment Instrument (BALPAI)

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Introduction: The assessment of learning in basketball in the PE class, and in training sessions of young players, requires valid, reliable, and trustworthy tools. The purpose of this research was to design and validate the Basketball Learning and Performance Assessment Instrument (BALPAI) that assesses simultaneously decision making, technical execution and efficacy. The play actions are codified using a categorical system, awarding a score for each category (1 = inadequate action; 2 = neutral action 3 = adequate action). An example of a summative procedure for assessing decision making in dribbling is: (1) Dribbling to a place where there is defensive pressure and there is a free teammate able to receive the pass; (2) Dribbling to a place where there is defensive pressure or a free teammate able to receive the pass; (3) Dribbling through a space where there is no defensive pressure and no free teammate able to receive the pass.

Methods: A pilot study was performed following this procedure. A group of 13 experts participated in the assessment of the 33 elements (66 items) included in the BALPAI. Aiken's V formula was used to analyze content validity, and internal consistency was calculated using Cronbach's α. Inter-observer reliability was determined among three observers who used the BALPAI to record the play actions in a 3 $\times$ 3 basketball match (N = 45 possessions) and was calculated with the Multirater κfree, obtaining an almost perfect agreement with values between 0.84 and 1.

Results: The BALPAI has very high internal consistency (0.969), Interobserver reliability was almost perfect (>0.84 in all items) and Aiken's V coefficient (>0.71 in all items) attained a high value.

Conclusion: The BALPAI proved to be a valid tool, with high internal consistency and reliability that makes it possible to perform a complete assessment of basketball in PE classes.

Keywords: team sport, evaluation, validity, reliability, basketball, assessment

INTRODUCTION

A mandatory prerequisite for making a valid and reliable qualitative analysis is the organization of the information by competent analysts. A systematic observational strategy (SOS) has to be planned (Knudson and Morrison, 2002) that contains all the relevant information about human movements. Therefore, the designing of instruments for the assessment of team sports using observation has become increasingly important as a research topic in the last few years. Between the 60s and the 80s, objective tests were the predominant method for assessing motor skills (Lopez-Pastor et al., 2013).

These tests presented certain limitations for being applied to the different playing skills in invasion sports as they did not include decision making (Oslin et al., 1998), and actual play during games (Bar-Eli and Raab, 2006). Later, test focused on the speed decision-makings occurs in real game (Thiffault, 1980), and evolve to measure the accuracy of these decisions (French and Thomas, 1987). Advances in the assessment of game performance behaviors help PE teachers to draw solid conclusions about their interventions during team sports teaching. The development of valid and reliable instruments will help not only teachers, but also other students for peer assessment in classroom settings (Memmert and Harvey, 2008). Moreover, linking what is being taught to what will be assessed, helps students to focus on what is important, making the teaching-learning cycle more congruent (Grehaigne et al., 2005). Accordingly, specific research should be undertaken in the evolution and development of observation tools that overcomes these limitations.

Thus, several instruments have been developed to assess play performance using systematic observation (Morgan et al., 2014), like the *Game Performance Assessment Instrument* (GPAI) (Oslin et al., 1998), or the *Team Sport Assessment Procedure* (TSAP) (Gréhaigne et al., 1997). These instruments represent a starting point for the observation of different team sports, and were designed to offer tools for PE teachers to assess their students. Based on these tools, new specific ones have been developed for different sports like soccer (García-López et al., 2013), handball (Tallir et al., 2003), futsal (Gonzalez-Villora and da Costa, 2015), or basketball (Tallir et al., 2007; Chen et al., 2013; Folle et al., 2014). These tools including the observation and assessment of a greater number of offensive actions with the ball (for example: shooting technique, dribbling technique, passing and catching, in and out 1 × 1, etc.) and without the ball (for example: jump stop and pivoting, 2 × 2 and 3 × 3 game play, etc.). In fact, off-the-ball actions are essential to be successful (Oslin et al., 1998), due the quantity of game play that occurs away from the ball.

In basketball, the tactical instrument proposed by Tallir et al. (2007) is more complete that the one proposed by Chen et al. (2013), as it analyses three different components for each play action (decision making, execution of the motor skill and efficacy). In each one of these components, appropriate and inappropriate actions are defined using a system of categories. Thus, it specifies what decisions are *correct* and *incorrect*, what technical actions are executed *correctly* and *incorrectly* and finally if the results of the actions are *successful* or *unsuccessful*. However, the limitation of these aforementioned instruments is that they only observe and assess offensive actions, not taking into account defensive ones.

The tools for observation and evaluation of the game must not only be reliable and valid, but must also be designed so they do not generate doubts in the observers, possessing high inter and intra-observer reliability. For this reason, it is necessary to complement the designs and validation of tools with real-time testing by observers or coders (Painczyk et al., 2018). These instruments present limitations as they do not take into account all the phases of the game (offense and defense), all the playing skills (with and without the ball) or the three components of play actions (decision making, technical execution and efficacy). In addition, as Knudson and Morrison (2002) stated, although their book is primarily based on technique, it is necessary to establish the level of the analysis. These instruments should assess the long- or short-term improvement of a motor skill, called *Learning* and *Performance*. Short-term changes in motor skills refer to performance, whereas long-term changes are called learning. Therefore, the objectives of the present study were (i) to design and validate an instrument for the specific and overall assessment of basketball, and (ii) to assess its inter-observer reliability. This instrument should make it possible to evaluate the learning of the basic concepts of the game that can be used in a 3 × 3, because it can be used to evaluate students in school (basic learning) and young basketball players who are beginning their training (basic performance).

MATERIALS AND METHODS

Instrument

The measures tool, the Basketball Learning and Performance Assessment Instrument (BALPAI), e.g., the protocol to obtain the variables to be analyzed (see **Supplementary Annex 1**), includes a total of 11 play actions, 7 offensive play actions with and without the ball (Dribbling; Shooting; Passing; Receiving; Passing game; Occupying free spaces without the ball; Offensive rebound), and 4 on ball and off ball in defense (On ball defense; Off ball defense; Defensive help/defensive change; Defensive rebound). All these actions belong to the taxonomy of contents drawn up by Ibáñez (2002) for basketball training categories. Complex actions of the 3 × 3 game (pick and roll or pop, pin downs, hand-off, etc.) are not included, since the instrument has been designed to evaluate basic learning and performance. The inclusion of complex tactical actions, with multiple solutions, requires specific instruments, such as those designed to analyze the pick and roll (Gómez et al., 2015) or the inside pass (Courel-Ibáñez et al., 2016). The instrument assesses three differentiated components of play actions: decision making, technical execution and final efficacy. Each of these three components of the play action is codified according to its adequacy. Thus, each action is codified as: (i) Inadequate; (ii) Neutral; or (iii) Adequate. This codification proposal is different from the majority of existing instruments, as it is a development from two levels of assessment (appropriate/inappropriate; adequate/inadequate; successful/unsuccessful) to three, being similar to the one suggested by Folle et al. (2014), including an intermediate level of adequacy. The play actions are codified using a categorical system (**Supplementary Annex 1**), awarding a score for each category (1 = inadequate action; 2 = neutral action 3 = adequate action). Once all the play actions have been codified, the match participation and performance indicators are calculated for each player.

Two procedures were followed to establish the adequacy of the game action in each of the components of the instrument, [based on Chen et al. (2013) and Tallir et al. (2007)]: (i) the summative procedure, (ii) the levels procedure.

Summative Procedure

Two criteria were established to assess a game action. If the game action fulfills both established criteria, it is considered adequate; if it only fulfills one criterion it is considered neutral; and if it does not fulfill any criterion it is considered inadequate. An example of a summative procedure for assessing decision making in dribbling is: (1) Dribbling to a place where there is defensive pressure and there is a free teammate able to receive the pass; (2) Dribbling to a place where there is defensive pressure or a free teammate able to receive the pass; (3) Dribbling through a space where there is no defensive pressure and no free teammate able to receive the pass.

Levels Procedure

Three levels of adequacy were established for the action. Depending on how the action is observed, its level of adequacy is determined (inadequate, neutral or adequate). In addition, an example of the levels procedure for assessing final efficacy in shooting is: (1) The shot is blocked by a defender and/or does not touch the hoop or backboard; (2) The shot does not go through the hoop but touches the hoop or backboard; (3) The shot goes through the hoop.

After all the play actions have been codified, the indicators are calculated for participation in the game (PG), decision making (DM), technical execution (TE) and final efficacy (FE). The Performance Index (PI) in the game is calculated from these together with the decision-making performance index (DM-PI), the technical execution performance index (TE-PI), the final efficacy performance index (FE-PI); and the total performance index (Total-PI) (**Table 1**). These indices offer information on each of the analyzed dimensions and the game performance of the student or player.

Research Design

This research represents an instrumental investigation as it involves the design and validation of an instrument for its subsequent application (Ato et al., 2013). For this reason, this section is organized in two studies.

Study 1: Design and Validation of an Instrument for the Specific and Overall Assessment of Basketball

Participants

In this study, the selection of the sample was intentional, as all the subjects chosen had to fulfill determined inclusion criteria to be able to be identified as experts. These criteria were based on their experience in making judgments, their reputation in the community, their availability and motivation for participating in the study, and their impartiality and inherent qualities, like self-confidence and adaptability (Skjong and Wentworth, 2001). Thus all the experts had to fulfill at least four of the following six criteria: (i) have a Ph.D. in Sports Sciences; (ii) be or have been a university lecturer; (iii) have the highest federative qualification in a team sport; (iv) have 10 years' experience as a university lecturer; (v) have 10 years' experience as a team sport coach in any category, and (vi) have published articles on the topic of team sports (Blomqvist et al., 2005; Villarejo et al., 2014; García-Martín et al., 2016; Ortega-Toro et al., 2019). All the experts were from the same country (Spain), and did not have a direct relationship with the research team. None of the experts received any gratification for participating in the project, their intervention being voluntary. Participation was requested from 25 experts who met the aforementioned requirements, and a response was received from 13 (52% participation). All experts signed written informed consents prior to the development of the study.

Measures

Content validity, which is the degree to which each item represents the content (Thomas et al., 2015). This variable was measured by expert judgment. The group of experts evaluated both the degree of pertinence of each item to the object of study (Adequacy), and the degree of accuracy and correctness in its explanation (Wording). Both concepts were evaluated with a Likert-type scale from 1 to 10. They were also asked for a general qualitative evaluation of each item to express possible alternatives when they deemed it necessary (Villarejo et al., 2014; García-Martín et al., 2016). The validity of the instrument was measured with Aiken's V coefficient (Aiken, 1985).

Internal consistency or the reproducibility of the measure shows the internal reliability of the instrument A test cannot be valid if lacks of reliability. The have to be consistent to be trustworthy, results cannot depend on successive trials to achieve the same results (Thomas et al., 2015).

Procedures

For the first study, a literature review was previously conducted on designed instruments to assess performance in team sports in general and basketball in particular. The authors then defined all the items included in the first version of the tool. In the second stage of the study, the necessary criteria were established for being considered an expert. All the necessary documentation for the qualitative and quantitative assessment of the instrument was sent by email to 25 experts: a formal presentation of the study, the BALPAI and a template where they could make their assessments. Positive answers were received by email from the experts participating in the study. The experts were asked about: (i) the level of pertinence of the components of play actions (decision making, technical execution and final efficacy) and coding levels (inadequate action; neutral action; adequate action) to be evaluated; (ii) the level of comprehension of the components of play actions from the observational instrument; (iii) the need to include other play actions, or qualitative comments about play actions.

TABLE 1 | Calculation of indicators of participation and performance in the game.

	Decision making (DM)	Technical execution (TE)	Final Efficacy (FE)
PLAYER A	**Sum of points for decision making (Pts DM)**	**Sum of points for technical execution (Pts TE)**	**Sum of points for final efficacy (Pts FE)**
Participation in the game (PG)		PG = N° of total actions performed by player A	
Performance Index (PI)	PI-DM = Pts DM/PG	PI-TE = Pts TE/PG	PI-FE = Pts FE/PG
		Total PI = (PI-DM+PI-TE+PI-FE) /3	

After the assessment of the experts, the criteria were defined for the modification, elimination or approval of the items according to the value obtained for Aiken's (1985) V coefficient. The analysis of the internal consistency of the items was calculated with Cronbach's α based on the values provided by the experts for the two content validity variables of adequacy and wording of each item.

Study 2: Assessment the Instrument Inter-Observer Reliability

Participants

For reliability purposes, youth players were recorded and assessed. The youth participants were attending the same state school class. A total of 25 fifth graders students (14 boys aged 10.78 years and 11 girls aged 10.85 years), from two different class groups (13 students from group A and 12 students from group B) from a school in the southwest of Spain took part in the study. Teachers, students and experts were informed of the study protocol, the participation of both groups and the research purposes. The students were informed that they would be filmed for later analysis. The basketball half court matches were part of the Physical Education classes, included in a basketball program of 15 sessions (55 min each) (González-Espinosa et al., 2017). The games were filmed in the last two sessions. The teams were created for the study and they did not have prior experience as a team. The teams were balanced by considering technical-tactical skills of all the students involved (Gracia et al., 2014). Teams were formed together by the teacher and the research staff.

Measures

Inter-observer reliability, or internal reliability, understood as the degree of agreement among the observers. In this case, the agreement among different observers concerning the description of several events is assessed (Thomas et al., 2015). In order to achieve high levels of reliability, all observers have received training in the use of instrument.

Procedures

Finally, the level of inter-observer reliability of the instrument was determined among three observers who used the BALPAI to record the play actions in a 3 × 3 basketball match. Only one hoop is used in the game and when a defense rebound occurs, the ball have to be returned outside the traditional three point-line before start attacking (Montgomery and Maloney, 2018). The three observers who intervened in this phase fulfilled all the previously defined inclusion criteria for being considered expert and, in addition, have time availability. For the observers to attain a minimum of reliability and objectivity in the codification, it was necessary to reach an agreement among them to permit an increase in the accuracy of the recordings of this human behavior (Medina and Delgado, 1999). The three observers received five training sessions (Muñoz et al., 2018).

The last two corresponded to the test of reliability among the observers for which each one recorded all the play actions in a filmed 3 × 3 basketball match. This game modality offers the players a greater opportunity to participate more successfully than in more numerous game modalities (Martínez-Fernández et al., 2015). Games were recorded with a SONY Full HD 1080 video camera at 60 fps; allowing experts to use slow motion and watch the videos as many times as they needed. The experts collected the data using an excel sheet designed for this purpose. This test assessed six subjects at the same time. Thus, the reliability analysis was made on the first 15 possessions in a match of 5 min duration on the part of each observer. The teams were established randomly, to avoid the polluting variable of the game level. The sample that participated in this study was composed of six students, three students per team. For this study, a game was selected in which only boys played, to avoid the contaminating variable of gender. The same clips were evaluated by the experts, who had no relation with the players nor were known to them. The experts were able to watch the video clips using Gamebreaker software (Sylvan Advantage, Hartford, Vermont) as many times as they thought fit, until they could make an adequate judgment. This option was determined, as they were continuous game actions, occurring simultaneously.

The parents of the players were informed about the study and gave their written consent in accordance with the Declaration of Helsinki. The study, with a full description of the protocols regarding recruitment and participation of the experts, was approved by the Ethics Committee of the University of Extremadura (no. 67/2017).

DATA ANALYSIS

Firstly, content validity was calculated with Aiken's V coefficient (Aiken, 1985). Its value goes from 0 to 1, with the latter marking perfect concordance among the experts with regard to the contents assessed. Aiken's V coefficient score establishes which items should be eliminated, modified or retained. Aiken's V was calculated following the algebraic equation modified by Penfield and Giacobbi (2004).

$$V = \frac{\bar{X} - l}{\mathrm{k}}$$

Calculations were made using the free software program Visual Basic 6.0 (Merino and Livia, 2009), which makes it possible to obtain three factors: the range of valuations (maximum valuation − minimum valuation), Aiken's V coefficient and the confidence intervals of 90, 95, and 99% using the score method (Penfield and Giacobbi, 2004).

The exact critical reference value for the acceptance of Aiken's V was calculated using the initial formula proposed by Aiken (1985), applying the central limit theorem for large samples (m > 25). The number of experts was 13 (n), the number of items 66 (m), with an answer range of 10 (c); applying the value of the constant of content validity of 95 and 99% (z).

$$\frac{z}{0.2\sqrt{\frac{3mn(c-1)}{(c+1)}}} + 0.5$$

The confidence level of 95% was considered to obtain the exact critical value for an item to be included and a value of 0.68 was attained. Similarly, the confidence level of 99% was considered to obtain the cut-off point for the modification of the tasks attaining a value of 0.75. **Table 2** shows the criteria used for the acceptance, modification or elimination of the items from the instrument.

Cronbach's α was then used for the analysis of internal consistency. This coefficient presents values between 0 and 1 and shows the reliability of the studied instrument. A value of 1 is perfect reliability but >0.70 is considered valid (Field, 2009). SPSS 21.0 software was used to analyze the internal consistency of the instrument (IBM SPSS Statistics for Windows. Armonk, NY: IBM Corp.).

Finally, the inter-rater agreement of the instrument was studied. As three raters intervened in the reliability analysis and the number of cases which had to be distributed in each of the categories of the instrument was unknown, it was necessary to use the *Free-Marginal Multirater Kappa* (*Multirater* κ_{free}) (Randolph, 2005). The computer application Online Kappa Calculator[1] was used for the interobserver reliability analysis. The variables analyzed were categorical. The following values were used to interpret the strength value of the Multirater κ_{free}: (i) a value of 0.00 or less was considered poor agreement; (ii) a value of 0.00 to 0.20 slight agreement; (iii) a value of 0.21 to 0.40 fair agreement; (iv) a value of 0.41 to 0.60 moderate agreement; (v) a value of 0.61 to 0.80 substantial agreement; and (vi) a value of 0.81 to 1 was considered almost perfect agreement (Landis and Koch, 1977; Altman, 1991).

RESULTS

Table 3 shows the mean values obtained for each of the items in the BALPAI instrument as well as the value of Aiken's V coefficient. These high values suggest a high content validity in our results.

The values obtained indicate that it was not necessary to eliminate any of the items according to the criteria established in the literature. A very demanding criterion was established for the elimination or modification of the items. However, there was no need to make any changes in Adequacy (A). Changes only had to be made in the Wording (W) of the following items: DM in dribbling; TE in shooting; DM in passing. The contributions that the group of experts made in their subjective valuations were used as a reference to carry out the necessary modifications. These modifications were made in all the items suggested with the aim of improving the instrument, despite not being necessary in some items. The instrument was sent back to the experts, who accepted the final version.

All the variables in the instrument attained a value for Cronbach's α of greater than 0.90 except Decision Making (0.87) (**Table 4**). The results of the internal consistency and IO reliability tests indicated high levels of reliability for this instrument. The analysis confirmed the high level of internal consistency.

Finally, **Table 5** shows the results regarding inter-observer reliability where all the items attained a value of above 0.81 and some equal to 1.

DISCUSSION

The purpose of the present study was to design an instrument for the specific and general assessment of basketball play. It had to assess offensive and defensive play actions, with and without the ball, and their three components. The results show that the BALPAI is the most complete of the existing instruments and has a high level of content validity, internal reliability and inter-observer reliability.

To validate the instrument, it was necessary to have expert opinion on its application (García-Martín et al., 2016). In the case of studies involving the judgment of experts a series of recommendations have to be taken into account, like those mentioned by Bulger and Housner (2007), Dunn et al. (1999), Escobar-Pérez and Cuervo-Martínez (2008) and Skjong and Wentworth (2001): the quality of the inclusion criteria, the number of experts necessary for this type of study, the preparation of the instructions and assessment templates, the procedure for collecting the quantitative and qualitative statistics as well as the adequate statistical analysis to give the instrument validity and reliability.

With regard to the sample of experts used in the investigation, several studies have established the range between two and twenty (Rubio et al., 2003), other researchers consider that ten is a reliable number (Hyrkäs et al., 2003), or three minimum, five acceptable, and ten, the ideal number (Lynn, 1986). In this study the number of experts who participated by offering their assessment of all the items in the instrument was 13, corresponding to 53% of the initially detected population according to demanding inclusion criteria, and fulfilling the requisites established in the literature.

The qualitative assessments of the experts are equally important when developing and perfecting the items of the instrument (Bulger and Housner, 2007; Carretero-Dios and Pérez, 2007; Padilla et al., 2007), and in this case, a deficiency was revealed in the quantification of the values of the questionnaire in some items. The experts' contributions were directed at

[1] http://justusrandolph.net/kappa/

TABLE 2 | Criteria for the acceptance, modification or elimination of the items.

		Wording		
		>0.75	[0.68–0.75]	<0.68
Adequacy	>0.75	Correct	Wording is modified	Wording is modified
	[0.68–0.75]	Adequacy is modified	Adequacy and Wording are modified	Adequacy and Wording are modified
	<0.68	Eliminated	Eliminated	Eliminated

TABLE 3 | Results of Aiken's V coefficient for the 11 variables of the BALPAI in each of the play action components.

	Dribbling						Shooting						Passing					
	DM*		TE		FE		DM		TE*		FE		DM*		TE		FE	
	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W
M	7.57	7.50	8.50	8.14	8.57	8.71	9.00	8.29	8.50	7.36	8.07	9.07	8.14	7.57	8.29	8.07	9.15	9.50
V	0.79	0.72	0.83	0.79	0.84	0.86	0.89	0.81	0.83	0.71	0.79	0.90	0.79	0.73	0.81	0.79	0.91	0.94

	Receiving						Passing and playing						Occupying free spaces					
	DM*		TE		FE		DM		TE*		FE		DM*		TE		FE	
	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W
M	8.86	8.14	8.86	8.29	8.57	9.50	8.08	8.08	9.07	8.50	9.29	8.50	9.07	8.21	8.93	8.64	8.79	8.71
V	0.87	0.79	0.87	0.81	0.84	0.94	0.79	0.79	0.90	0.83	0.90	0.83	0.90	0.80	0.88	0.85	0.87	0.86

	Offensive rebound						Defensive rebound						On ball defense					
	DM*		TE		FE		DM		TE*		FE		DM*		TE		FE	
	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W
M	9.21	8.86	8.93	9.14	8.86	8.71	9.36	9.21	9.21	8.79	9.36	9.07	9.29	8.93	9.36	8.50	9.00	9.00
V	0.91	0.87	0.88	0.90	0.87	0.86	0.93	0.91	0.91	0.87	0.93	0.90	0.92	0.88	0.93	0.83	0.89	0.89

	Off ball defense						Assisting and recovery/defensive change					
	DM*		TE		FE		DM		TE*		FE	
M	9.21	8.21	8.93	8.64	9.21	8.79	8.57	8.21	8.50	8.14	9.14	8.65
V	0.91	0.80	0.88	0.85	0.91	0.87	0.84	0.80	0.83	0.79	0.90	0.85

*M, Arithmetic mean; V, Aiken's V; A, Adequacy; W, Wording; DM, Decision making; TE, Technical execution; FE, Final efficacy. * = Item where W was modified.*

TABLE 4 | Results of the analysis of the internal consistency of the instrument.

	Adequacy	Wording	Offense	Defense	DM	TE	FE	Instrument
α	0.959	0.950	0.953	0.933	0.876	0.917	0.921	0.969
N	33	33	42	24	22	22	22	66

DM, Decision making; TE, Technical execution; FE, Final efficacy; N, Number of items.

improving the wording, clarifying the expressions so that they did not generate doubts in the future codifiers. The value 2 did not correctly discriminate between the values one and three of the instrument. Thus, according to the suggestions of several experts, the value 2 was re-worded so that the difference with the other values was even clearer. Furthermore, although not as clearly as in the previous assessments, the experts indicated that the item on the technical execution of the shot led to misunderstandings in the way it was expressed. It was suggested that the description be modified, especially with regard to the part referring to "the starting point for the shot." Many of the assessments of the experts were reflections on the instrument which, in some cases, made it possible to define its items more clearly and accurately (Wiersma, 2001).

The content validity showed values in all the items of over 0.70 for Aiken's V, so that it was only necessary to modify the wording

TABLE 5 | Results of Interobserver reliability for each of the 11 variables in the BALPAI in each of the components of the play actions.

	Dribbling			Shooting			Passing			Receiving			Passing and playing			Occupying free spaces		
	DM	TE	FE	DM	TE	FE	DM	TE	FE	DM	TE	FE	DM	TE	FE	DM	TE	FE
Po	0.94	0.94	0.89	0.93	0.99	0.99	0.94	0.99	0.99	1	0.94	1	1	1	1	0.94	1	0.92
κ_{free}	0.92	0.92	0.84	0.90	0.99	0.99	0.92	0.99	0.99	1	0.91	1	1	1	1	0.91	1	0.88

	Offensive rebound			Defensive rebound			On Ball defense			Off ball defense			Assisting and recovery/defensive change		
	DM	TE	FE	DM	TE	FE	DM	TE	FE	DM	TE	FE	DM	TE	FE
Po	0.97	1	1	0.97	0.93	1	0.93	0.96	0.96	1	1	0.98	0.99	0.99	0.99
κ_{free}	0.96	1	1	0.96	0.90	1	0.90	0.95	0.95	1	1	0.97	0.99	0.99	0.99

Po, Percentage of global agreement; κ_{free}, Free-marginal kappa; DM, Decision making; TE, Technical execution; FE, Final efficacy; N, Number of items.

of three of the 66 items. The demands of inclusion, modification and exclusion criteria were increased, 95% confidence criterion was established for acceptance or elimination of an item, and 99% for its modification (Penfield and Giacobbi, 2004). Previous studies have had lower levels of demand (Ortega et al., 2008; García-Martín et al., 2016; García-Santos and Ibáñez, 2016). These items were reworded as in previous studies (Bulger and Housner, 2007; Ortega et al., 2008; Villarejo et al., 2014). When the internal consistency of the instrument was analyzed, it was seen that other tools (questionnaires, interviews, instruments...) that had already been published and validated, present lower values than those attained by the BALPAI, overall Cronbach's $\alpha = 0.97$ vs. Cronbach's $\alpha = 0.72$ of IOVAB for basketball referees (García-Santos and Ibáñez, 2016); vs. Cronbach's $\alpha = 0.94$ of Socio-emotional questionnaire (Gómez-Carmona et al., 2014); and vs. Cronbach's $\alpha = 0.96$ of programs for sports education in the school context (Gonzalez-Espinosa et al., 2017). The values for inter-observer reliability were over 0.84 in Kappa coefficient thus being perfect or nearly perfect (Altman, 1991; Landis and Koch, 1977). The BALPAI tool has demonstrated very good inter-observer reliability in its practical application, with values of the Kappa coefficient between 0.84 and 1 in the 11 variables and the three components of the play actions (decision making, technical execution and efficacy), considered as an almost perfect agreement (Landis and Koch, 1977; Altman, 1991). Painczyk et al. (2018) used Cohen's Kappa coefficient to determine the interobserver reliability of a match evaluation notational system in Rugby Union, with values lower than those found in this study. These results confirm the quality of the design of the tool, since the observers who have used it have shown great concordance evaluating game actions. All the analyses carried out confirmed the validity and reliability of the designed instrument.

Differences between instruments have been pointed out, but possible explanation for these differences have to be exposed. Painczyk et al. (2018) analyzed seven complete rugby union games, observing several performance indicators with different operational definitions. BALPAI variables and operational definitions used for reliability purposes in our study were smaller. In addition, BALPAI was design for make easier observations, in the number of variables analyzed as in player's skill level. Moreover, main concerns of reliability studies are the clear operational definitions of each variable (Painczyk et al., 2018; O'Donoghue, 2007) and the observers training processes (Liu et al., 2017). Researchers that carried out the BALPAI reliability analysis have participated in the development and validation of the instrument, showing a great understanding of variables and definitions. Moreover, these researchers have been defined as experts, that achieve better reliability values that inexperienced ones (Painczyk et al., 2018).

The importance of observational tools has been previously reported in other sports and contexts (Llobet-Martí et al., 2016). Other testing procedures have reported different approaches such as creativity or divergent thinking (Memmert, 2010). These approaches will have to be taken into consideration in future research. In addition, further research should also suggest the analysis of coaches in order to improve the learning process with the validation of observational tools (Nicholls and Worsfold, 2016).

LIMITATIONS

Basketball Learning and Performance Assessment Instrument contains many items and components, thus the assessment process can be quite hard. This process can be focused on a single item at a time, or two or several. As well as helping students to pay attention to important information that they should learn, it simplifies the assessment process for teachers and coaches. Moreover, before using the BALPAI, teachers and coaches must undergo a training period in how to implement it, leading to a better use and recognition of play behaviors that can be quite subjective.

CONCLUSION

The BALPAI, has shown, during this first phase of validation, to be a valid and reliable instrument for assessing learning in basketball in PE classes, and has proved to be more complete than previously published tools, on which its design was based. It also possesses a high level of reliability in the codification of the play actions.

Teachers can use BALPAI in their teaching programs in Physical Education as part of the evaluation. The use of this tool will make it possible to assess the progress of players in the educational context, assessing students' learning during the school year. In addition, teacher can assess different teaching programs, comparing studentsŕesults in both programs. The repetition of the assessment of students will make it possible to confirm if the intervention programs used in their training are effective.

ETHICS STATEMENT

This study have been approved by the Ethics Committee of the University of Extremadura.

AUTHOR CONTRIBUTIONS

SI: conceptualization, data collection, formal analysis, investigation, methodology, writing review, and editing. SM-F: data collection, formal analysis, investigation, writing original draft. SG-E: data collection, formal analysis and investigation. SF: supervision, writing review, and editing. JG-R: supervision, writing original draft, writing review, and editing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01595/full#supplementary-material

REFERENCES

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educ. Psychol. Meas.* 45, 131–142. doi: 10.1177/0013164485451012

Altman, D. G. (1991). *Practical Statistics for Medical Research*. London: Chapman & Hall.

Ato, M., López, J. J., and Benavente, A. (2013). Un sistema de clasificación de los diseños de investigación en psicología. *Anal. Psicol.* 29, 1038–1059.

Bar-Eli, M., and Raab, M. (2006). Judgment and decision making in sport and exercise: rediscovery and new visions. *Psychol. Sport Exerc.* 7, 519–524. doi: 10.1016/j.psychsport.2006.07.003

Blomqvist, M., Vänttinen, T., and Luhtanen, P. (2005). Assessment of secondary school students' decision-making and game-play ability in soccer. *Phys. Educ. Sport Pedagogy* 10, 107–119. doi: 10.1080/17408980500104992

Bulger, S. M., and Housner, L. D. (2007). Modified delphi investigation of exercise science in physical education teacher education. *J. Teach. Phys. Educ.* 26, 57–80. doi: 10.1123/jtpe.26.1.57

Carretero-Dios, H., and Pérez, C. (2007). Normas para el desarrollo y revisión de estudios instrumentales: consideraciones sobre la selección de tests en la investigación psicológica. *Int. J. Clin. Health Psychol.* 7, 863–882.

Chen, W., Hendricks, K., and Zhu, W. (2013). Development and validation of the basketball offensive game performance instrument. *J. Teach. Phys. Educ.* 32, 100–109. doi: 10.1123/jtpe.32.1.100

Courel-Ibáñez, J., McRnobert, A. P., Ortega, E., and Cárdenas, D. (2016). Inside pass predicts ball possession effectiveness in NBA basketball. *Int. J. Perform. Anal. Sport* 16, 711–725. doi: 10.1080/24748668.2016.11868918

Dunn, J. G., Bouffard, M., and Rogers, W. T. (1999). Assessing item content-relevance in sport psychology scale-construction research: issues and recommendations. *Meas. Phys. Educ. Exerc. Sci.* 3, 15–36. doi: 10.1207/s15327841mpee0301_2

Escobar-Pérez, J., and Cuervo-Martínez, A. (2008). Validez de contenido y juicio de expertos: una aproximación a su utilización. *Av. Medición* 6, 27–36.

Field, A. (2009). *Discovering Statistics Using SPSS*, 3rd Edn. Londres: Sage publications.

Folle, A., Quinaud, R. T., Barroso, M. L. C., Rocha, J. C. S., Ramos, V., and Nascimento, J. V. D. (2014). Construção e validação preliminar de instrumento de avaliação do desempenho técnico-tático individual no basquetebol. [Preliminary development and validation of an assessment instrument of basketball individual technical-tactical performance]. *Revista da Educação Física UEM* 25, 405–418. doi: 10.4025/reveducfis.v25i3.23085

French, K. E., and Thomas, J. R. (1987). The relation of knowledge development to children's basketball performance. *J. Sport Psychol.* 9, 15–32. doi: 10.1123/jsp.9.1.15

García-López, L. M., González-Víllora, S., Gutiérrez, D., and Serra, J. (2013). Development and validation of the game performance evaluation tool (GPET) in soccer. *Sport Rev. Eur. Cienc. Dep.* 2, 89–99.

García-Martín, A., Antúnez, A., and Ibáñez, S. J. (2016). Análisis del proceso formativo en jugadores expertos: validación de instrumento/analysis of expert players' training process: validation of tools. *Rev. Int. Med. Cienc. Ac.* 16, 157–182. doi: 10.15366/rimcafd2016.61.012

García-Santos, D., and Ibáñez, S. J. (2016). Diseño y validación de un instrumento de observación para la valoración de un árbitro de baloncesto (IOVAB). *Sport Rev. Eur. Cienc. Dep.* 5, 15–26.

Gómez, M. A., Battaglia, O., Lorenzo, A., Lorenzo, J., Jiménez, S., and Sampaio, J. (2015). Effectiveness during ball screens in elite basketball games. *J. Sports Sci.* 33, 1844–1852. doi: 10.1080/02640414.2015.1014829

Gómez-Carmona, P. M., Cervera, V., and Benito, P. J. (2014). Diseño y validación de un cuestionario socio-emocional para jóvenes futbolistas de élite. *Rev. Int. Med. Cienc. Ac.* 14, 545–559.

González-Espinosa, S., Ibáñez, S. J., and Feu, S. (2017). Design of two basketball teaching programs in two different teaching methods. *E-Balonmano. com* 13, 131–152.

Gonzalez-Espinosa, S., Ibáñez, S. J., Feu, S., and Galatti, L. (2017). Intervention programs for sports education in the school context, PETB and PEAB: preliminary study. *Retos* 31, 107–113.

Gonzalez-Villora, S., and da Costa, I. T. (2015). How to evaluate the soccer tactics? System of tactical assessment in soccer (fut-sat). *Educ. Fís. Dep.* 34, 467–505. doi: 10.17533/udea.efyd.v34n2a08

Gracia, F., García, J., Cañadas, M., and Ibáñez, S. J. (2014). Heart rate differences in small-sided games in formative basketball. *E-Balonmano.com* 10, 23–30.

Gréhaigne, J.-F., Godbout, P., and Bouthier, D. (1997). Performance assessment in team sports. *J. Teach. Phys. Educ.* 16, 500–516.

Grehaigne, J. F., Richard, J. F., and Griffin, L. (2005). *Teaching and Learning Team Sports and Games*. New York, NY: Routledge Falmer.

Hyrkäs, K., Appelqvist-Schmidlechner, K., and Oksa, L. (2003). Validating an instrument for clinical supervision using an expert panel. *Int. J. Nurs. Stud.* 40, 619–625. doi: 10.1016/s0020-7489(03)00036-1

Ibáñez, S. J. (2002). "Los contenidos de enseñanza del baloncesto en las categorías de formación," in *Novos Horizontes para o Treino do Basquetebol*, eds S. J. Ibáñez and M. Macías (Lisbon: FMH Edições), 111–135.

Knudson, V., and Morrison, S. (2002). *Qualitative Analysis of Human Momento*. Champaign, IL: Human Kinetics.

Landis, J. R., and Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics* 33, 159–174.

Liu, H., Hopkins, W., Gomez, M. A., and Molinuevo, J. (2017). Inter–operator reliability of live football match statistics from OPTA sportsdata. *Int. J. Perf. Anal. Sport* 13, 803–821. doi: 10.1080/24748668.2013.11868690

Llobet-Martí, B., López-Ros, V., Barrera-Gómez, J., and Comino, J. (2016). Assessing novices' game performance in rugby union: the Rugby attack assessment instrument (RAAI). *J. Teach. Phys. Educ.* 35, 181–186. doi: 10.1123/jtpe.2014-0134

Lopez-Pastor, V. M., Kirk, D., Lorente-Catalan, E., MacPhail, A., and Macdonald, D. (2013). Alternative assessment in physical education: a review of international literature. *Sport Educ. Soc.* 18, 57–76. doi: 10.1080/13573322.2012.713860

Lynn, M. R. (1986). Determination and quantification of content validity. *Nurs. Res.* 35, 382–386.

Martínez-Fernández, S., García, J., and Ibáñez, S. J. (2015). Incidence of type of game mode in player participation in minibasket. *Rev. Psi Dep.* 24, 65–68.

Medina, J., and Delgado, M. Á (1999). Metodología de entrenamiento de observadores para investigaciones sobre EF y deporte en las que se utilice como método la observación. *Rev. Mot.* 5, 69–86.

Memmert, D. (2010). Game test situations: assessment of game creativity in ecological valid situations. *Int. J. Sport Psychol.* 41:94.

Memmert, D., and Harvey, S. (2008). The game performance assessment instrument (GPAI): some concerns and solutions for further development. *J. Teach. Phys. Educ.* 27, 220–240. doi: 10.1123/jtpe.27.2.220

Merino, C., and Livia, J. (2009). Intervalos de confianza asimeìtricos para el índice la validez de contenido: un programa visual basic para la V de Aiken. *Anal. Psicol.* 25, 169–171.

Montgomery, P. G., and Maloney, B. D. (2018). Three-by-three basketball: inertial movement and physiological demands during elite games. *Int. J. Sports Physiol. Perf.* 13, 1169–1174. doi: 10.1123/ijspp.2018-0031

Morgan, G., Muir, B., and Abraham, A. (2014). "Systematic observation," in *Res MethSport Coach*, eds L. Nelson, R. Groom, and P. Potrac (London: Routledge), 123–131.

Muñoz, J., Gamonales, J. M., León, K., and Ibáñez, S. J. (2018). Formación de codificadores y fiabilidad de los registros. Una aplicación al goalball / training of coders and reliability. an application to the goalball. *Rev. Int. Med. Cienc. Ac.* 18, 669–691.

Nicholls, S. B., and Worsfold, P. R. (2016). The observational analysis of elite coaches within youth soccer: the importance of performance analysis. *Int. J. Sports Sci. Coach.* 11, 825–831. doi: 10.1177/1747954116676109

O'Donoghue, P. (2007). Reliability issues in performance analysis. *Int. J. Perf. Anal. Sport* 7, 35–48. doi: 10.1080/24748668.2007.11868386

Ortega, E., Jimenez, J. M., Palao, J. M., and Sainz de Barranda, P. (2008). Diseño y validación de un cuestionario para valorar las preferencias y satisfacciones en jóvenes jugadores de baloncesto. *Cuad. Psicol. Dep.* 8, 39–58.

Ortega-Toro, E., García-Angulo, A., Giménez-Egido, J. M., García-Angulo, F. J., and Palao, J. M. (2019). Design, validation, and reliability of an observation instrument for technical and tactical actions of the offense phase in soccer. *Front. Psychol.* 10:22. doi: 10.3389/fpsyg.2019.00022

Oslin, J. L., Mitchell, S. A., and Griffin, L. L. (1998). The game performance assessment instrument (GPAI): development and preliminary validation. *J. Teach. Phys. Educ.* 17, 231–243. doi: 10.1123/jtpe.17.2.231

Padilla, J. L., Gómez, J., Hidalgo, M. D., and Muñiz, J. (2007). Esquema conceptual y procedimientos para analizar la validez de las consecuencias del uso de los test. *Psicothema* 19, 173–178.

Painczyk, H., Hendricks, S., and Kraak, W. (2018). Intra and inter-reliability testing of a south african developed computerised notational system among western province club rugby coaches. *Int. J. Sports Sci. Coach.* 13, 1163–1170. doi: 10.1177/1747954118796368

Penfield, R. D., and Giacobbi, P. R. (2004). Applying a score confidence interval to Aiken's item content-relevance index. *Meas. Phys. Educ. Exerc. Sci.* 8, 213–225. doi: 10.1207/s15327841mpee0804_3

Randolph, J. J. (2005). Free-marginal multirater kappa: an alternative to fleissñ fixed-marginal multirater kappa. *Paper Presented at the Joensuu University Learning and Instruction Symposium 2005*, Joensuu.

Rubio, D. M., Berg-Weger, M., Tebb, S. S., Lee, E. S., and Rauch, S. (2003). Objectifying content validity: conducting a content validity study in social work research. *Soc. Work Res.* 27, 94–104. doi: 10.1093/swr/27.2.94

Skjong, R., and Wentworth, B. H. (2001). Expert judgment and risk perception. *Paper Presented at the The Eleventh International Offshore and Polar Engineering Conference*, Stavanger.

Tallir, I. B., Lenoir, M., Valcke, M., and Musch, E. (2007). Do alternative instructional approaches result in different game performance learning outcomes? Authentic assessment in varying game conditions. *Int. J. Sport Psychol.* 38, 263–282.

Tallir, I. B., Musch, E., Lanoo, K., and Van de Voorde, J. (2003). Validation of video-based instruments for the assessment of game performance in handball and soccer. *Paper Presented at the 2nd International Conference Teaching Sport and Physical Education for Understanding*, Melbourne.

Thiffault, C. (1980). "Construction et validation d'une mesure de la rapidité de la pensée tactique des jouers de jockey sur glace (The construction and validation of a measure of tactical thought of ice jockey players)," in *Psychology of Motor Behavior and Sport*, eds C. H. Nadeau, W. R. Halliwell, K. M. Newell, and G. C. Roberts (Champaign, IL: Human Kinetics), 643–649.

Thomas, J. R., Silverman, S., and Nelson, J. (2015). *Research Methods in Physical Activity, 7E*. Champaing, IL: Human Kinetics.

Villarejo, D., Ortega, E., Gómez, M. Á., and Palao, J. M. (2014). Design, validation, and reliability of an observational instrument for ball possessions in rugby union. *Int. J. Perf. Anal. Sport* 14, 955–967. doi: 10.1080/24748668.2014.11868771

Wiersma, L. D. (2001). Conceptualization and development of the sources of enjoyment in youth sport questionnaire. *Meas. Phys. Educ. Exerc. Sci.* 5, 153–177. doi: 10.1207/s15327841mpee0503_3

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Fitness, Technical, and Kinanthropometrical Profile of Youth Lithuanian Basketball Players Aged 7–17 Years Old

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Optimizing basketball performance during the stages of long-term athlete development require to identify the trainability and variation of specific technical skills, when adjusting for anthropometric changes. The aim of this study was to describe differences in height, body mass, arm span, and technical-related fitness (movement, dribbling, shooting) along the long-term development of 7–17 years Lithuanian basketball players. This cross-sectional analysis involved a total of 1051 basketball players from the Sabonis Basketball Center in Lithuania. Testing sessions were performed during 1 day of the competition period in an indoor court. The participants performed technical-related fitness tests to assess dribbling (control dribble, 20 m dribble, two balls of 20 m dribble, Illinois agility dribble), shooting (30 free-throw shoots, 1 min shooting, modified medium and long-range shots, close range shots) and defensive movements. The dribbling skills had substantial improvements (7 to 8-years-old: 20 m sprint with dribbling, effect size = 1.86; control dribble effect size = 2.18; 9 to 10-year-old: 20 m sprint with dribbling, effect size = 1.85; Illinois agility test with dribbling effect size = 1.82). Changes in defensive movement occurred mostly at the 14–15-age period. The best periods to develop dribbling and shooting skills were between 7–10 and 12–13 years, whereas defensive movements can be trained in later adolescent years. Current results and consequent normative profiles, presented as percentile tables, allow to accurately follow the players' development.

Keywords: basketball, technical testing, fitness testing, long-term development, physical profile

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INTRODUCTION

The Long-term Athlete Development model outlines an appropriate training, competition and recovery program in relation to the developmental age of the individual (Balyi and Hamilton, 2004; Stafford, 2005; Balyi et al., 2009). In fact, it takes 8–12 years of training for a talented player to reach elite levels of performance and this has been elsewhere described as the 10-year or 10,000-hour rule, which translates to approximately more than 3 h of daily practice for a period of 10 years (Bloom and Sosniak, 1985; Ericsson et al., 1993; Ericsson and Charness, 1994; Salmela et al., 1998; Balyi and Hamilton, 2004). It seems clear that a specific and carefully planned training process, as well as an adequate competition and recovery regime can ensure the optimum development throughout an athlete's career (Balyi and Hamilton, 2004). It is focused on training to optimize performance at long-term and considers sensitive developmental periods known as "windows of opportunity" (Ford et al., 2011). Developmental pathways in sport seem to be non-linear and athletes pass through discrete, but idiosyncratic stages as they develop from novices to experts (Cote and Hay, 2002; Abbott and Collins, 2004; Vaeyens et al., 2008). In basketball, although there is available research focused on the players' pathways (Leite and Sampaio, 2010, 2012), it remains unclear when the specific skills are most sensitive to certain areas of training during their development.

Individual and collective success in basketball are well related to anthropometric and fitness characteristics (Hoare, 2000; Angyan et al., 2003). For example, anthropometric and fitness tests accounted for ∼40% in the variance of playing performance (Hoare, 2000). In fact, findings that body size and fitness are key determinants of performance in basketball are intuitive to the basketball coaching community (Drinkwater et al., 2008).

The most frequent physical and technical demands in basketball include sprints (from a few strides to over a total of 20 m), abrupt stops, fast dribbling, quick changes of movement direction, different vertical jumps, acceleration, different shots, and passes (Johnson and Nelson, 1986; Ben Abdelkrim et al., 2007; Klusemann et al., 2013). For example, differences in motor abilities of European top-quality young female basketball players were already addressed. The results showed that the body height and the technically most demanding movements performed with the ball (e.g., 20 m sprint dribble) were the most potential descriptive variables (Erculj et al., 2009, 2010). In addition, Garcia-Gil et al. (2018) used a multiple regression analysis to identify that combined age, height, contracted arm perimeter, fat skinfold thickness, and time in T-Drill test yielded a strong predictor of a performance index per time played. More recently, Ramos et al. (2019) showed the importance of maturation derived variables to achieve playing opportunities and recommended to avoid premature talent identification, providing players with opportunities to progress through the talent pathway, at least until U-16 age category. In a similar way, Guimaraes et al. (2019) showed that top players were taller, had greater fat-free mass, greater strength, power, and agility, and were technically more skillful compared with lower level players, when controlling for training experience and maturation. Also, it has been shown that performance in tests such as control dribble, speed dribble, high intensity shuttle run and dribble shuttle run, are well correlated with elite young basketball players' power output (Apostolidis et al., 2004). In youth rugby players, a strong evaluation in performing change of direction occurs between 15 and 17 years old, because the older players seem able to perform the more advantageous "sharp" movement, instead of a "rounded" one, probably due to the positive development of basic arm and leg movements, timing and rhythmic-related abilities (Condello et al., 2013). Despite these results, research is still quite unclear about the evolution of these performance indicators across the different age groups. Therefore, the aim of this study was to identify the differences in height, body mass, arm span and technical fitness (movement, dribbling, shooting) in 7–17 years old basketball players. The outcomes may allow the establishment of normative player's characteristic across different development stages. This information may be used as guidelines to optimize the youth players' long-term athlete development by identifying windows of trainability and variation of specific technical skills.

MATERIALS AND METHODS

Participants

The participants detailed profiles are presented in **Table 1**. They were randomly selected from the Sabonis Basketball Center youth basketball players (aged 7–17 years, $n = 1051$, between 40 and 172 in each age group).

The typical weekly workloads planned and accomplished by these young basketball players aged constantly increased for the different age groups. The number of training sessions and practice time gradually increased during each year of training (**Table 2**). A written informed consent was obtained from the local university institutional review board, the school principal, the subjects and their parents.

Testing Procedures

The testing sessions were performed during the competitive period, and all players in the same age group were tested in an indoor court during 2 days. The players refrained from strenuous exercise for at least 48 h before the testing session. Each session was carried between 16.00 and 18.00 h by the same research team. Testing for each age group was performed in a 2 day period and during the beginning of the competitive period between October and November. In the first testing was measured the anthropometric and 20 m sprint dribble, two balls of 20 m sprint dribble and Illinois agility dribble test (around 90–110 min). The second day was dedicated to the measurement of control dribble, 30 free-throws shooting, 1 min shooting, defensive movement, close range shots, modified medium, and long range shots test of the subjects (around 90–110 min).

Anthropometry

The subject's body mass (to the nearest 0.1 kg, Tanita, Tanita Corporation), height without shoes (to the nearest 0.1 cm, Martin, GPM SiberHegner) and arm span using a ruler held vertically to the tape measure to record total arm span (to the nearest 0.1 cm), were measured before the participants performed a standardized warm-up for a total of 15 min. The warm up consisted of a controlled stretching routine and performing low intensity sport-specific activities using the ball, such as slow dribbling exercises.

Technical Testing

The participants performed technical tests to assess dribbling (Control dribble, 20 m dribble, Two balls of 20 m dribble, Illinois agility dribble), shooting (30 Free-throw shooting, 1 min shooting, Modified medium and long range shots, Close range shots) and defensive movement. The participants received verbal

TABLE 1 | Structure of loads for the young Lithuanian basketball players aged 7–17 years.

Indicators of loads		Age (years)										
		7	8	9	10	11	12	13	14	15	16	17
Training per week (min)	Preparatory				4 × 90	5 × 90	5 × 90	5 × 90	5 × 90	5 × 90	5 × 90	5 × 90
	Competitive	3 × 60	3 × 90	4 × 90	5 × 90	6 × 90	6 × 90	6 × 90	6 × 90	6 × 90	7 × 90	7 × 90
	Post-Competitive				4 × 90	5 × 90	5 × 90	5 × 90	5 × 90	5 × 90	5 × 90	5 × 90
Number of training days		117	117	172	212	257	257	257	257	267	299	299
Number of training hours		117	175.5	258	318	385.5	385.5	385.5	385.5	400.5	448.5	448.5
Matches per year		0	17	36	56	63	65	65	65	66	70	72

TABLE 2 | Number of subjects in youth basketball aged 7–17 years.

Measured Variables	Subjects age (years)											Total
	7	8	9	10	11	12	13	14	15	16	17	
Anthropometric indicators (n)												
Height (cm)	41	46	44	90	111	83	116	138	80	61	56	857
Body mass (kg)	41	46	44	49	47	47	48	50	42	44	45	503
Arm span (cm)	41	46	44	90	96	83	116	138	80	70	56	860
Technical fitness test (n)												
Control dribble	41	42	44	73	123	105	138	135	94	55	59	909
Defensive movement	n.a.	42	44	73	93	78	105	107	71	55	59	727
20 m sprint dribble	41	45	44	46	43	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	219
Two balls of 20 m sprint dribble	n.a.	n.a.	n.a.	n.a.	n.a.	47	46	58	40	44	56	291
Illinois agility dribble	n.a.	45	44	44	43	40	46	49	41	44	45	441
30 Free-throw shooting	n.a.	n.a.	44	84	139	124	172	167	115	77	65	987
1 min shooting	n.a.	n.a.	n.a.	84	139	123	145	139	115	73	65	883
Modified medium and long-range shots	n.a.	n.a.	n.a.	n.a.	43	47	48	50	42	43	44	317
Close range shots	n.a.	42	44	49	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	135

feedback about their performance after each test and were encouraged to perform maximally in each test.

Control Dribble Test (Johnson and Nelson, 1986)

Test objective: measure ball-handling skills while moving. Six cones are set up in the free-throw lane of a basketball court to provide obstacles (**Figure 1A**). On the signal "Ready, go," the performer starts dribbling with the non-dominant hand from the non-dominant hand side of stand A to the non-dominant hand side of stand B (left-handed dribble). Three timed trials are given. Recovery between trials was 5 min. The best result was used for analysis.

Defensive Movement Test (Johnson and Nelson, 1986)

Test objective: measure basic defensive movements. The test boundaries are the free-throw line behind the basket, and the rebound lane lines. The middle-rebound lane markers serve as targets C and F for the test (**Figure 1B**). Additional spots outside the four corners of the rectangular area should be marked by tape (points A, B, D, and E in **Figure 1B**). The athlete starts at A facing away from the basket. On the signal "Ready, go," the performer slides to the left (without crossing the feet) to marker B, touches the floor outside the lane with the left hand, performs a dropstep, and slides to point C and touches the floor outside the lane with the right hand. The athlete continues the course as shown in **Figure 1B** until both feet cross the finish line. Three timed trials were given. Recovery between trials was 5 min. The best performance was selected for analysis.

20 m Sprint Dribbling Test

Test objective: establish and assess the speed of players while dribbling a ball. At the beginning and at the end of the 20 m distance, there were photo-electric cells connected to an electronic timer (Powertimer Testing System, NewTest, Tampere, Finland). The starting position was 70 cm from the first photo-cell. Two trials were performed with a recovery of approximately 3 min in between. The best running time was used for analysis.

20 m Sprint Dribbling Two Balls

The same time recording system as in the previous 20 m sprint test was used. Each participant had one trial. If the participant lost the ball, the test was repeated up to three times. The best result was used for analysis.

Illinois Test With Dribbling the Ball (Getchell et al., 1998)

The same time recording system as in the 20 m sprint run was used (**Figure 1C**). Each participant had one trial. If the participant

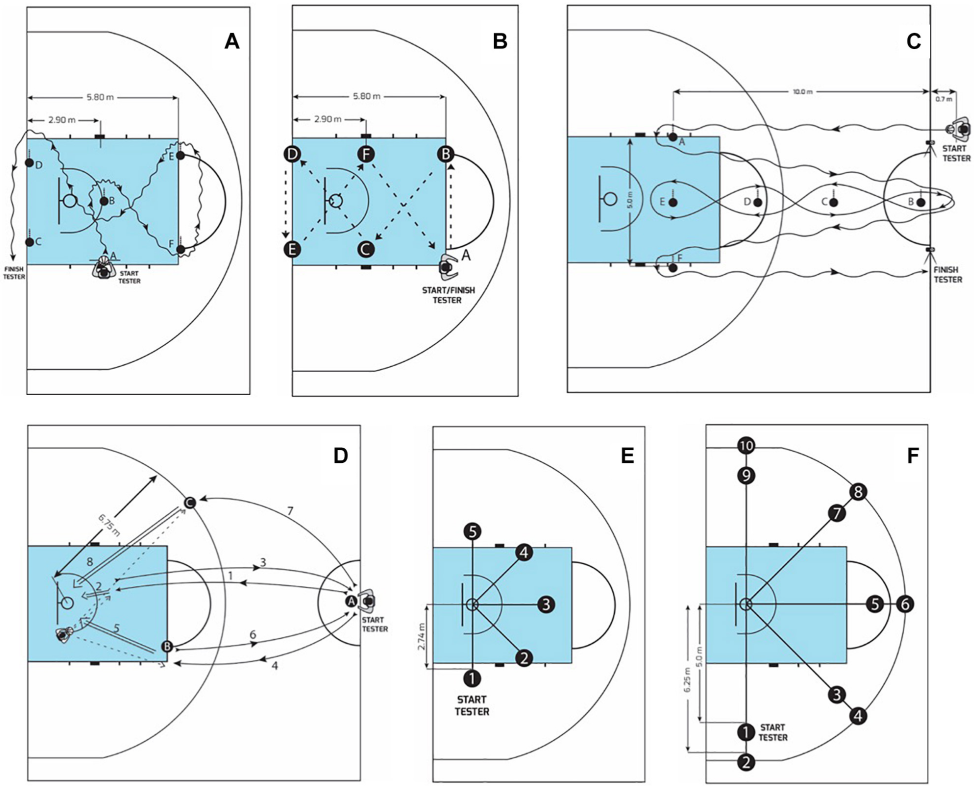

FIGURE 1 | Testing protocols used: **(A)** Control dribble test; **(B)** Defensive movement test; **(C)** Illinois test with dribbling the ball; **(D)** 1 min shooting test; **(E)** Modified medium and long range shots test; **(F)** Speed spot shooting test.

lost the ball, the test was repeated up to three times. The best result was used for analysis.

30 Free-Throw Shooting Test (Stonkus, 2002)

Test objective: measuring the accuracy and stability skills in free-throw shooting. The subject executes a free-throw; for the first and the second shots the ball is given to a partner, after the third shot the subject takes the ball himself, dribbles it to the free-throw line and throws again. This process is repeated until 30 free-throws are taken. The test is performed once. Test result: scores the number of throws. The subject has to shoot the ball into the basket in 5 s from the moment his partner passes him the ball or he takes the ball himself and stands at the free-throw line.

One Minute Shooting Test (Balciunas, 2005)

Test objective: the rates of this test estimate the sensorimotor capabilities of the player, the stability of shooting along with the ability to adapt to game situations (given the quite intensive physical load and the manifestation of certain fatigue). For 1 min, the subjects were shooting from the three points distance A, B, C (close distance, middle, and long distance). On the signal "Ready, go," the performer ran and shot from zone A, B, and C, and after each attempt the performer ran backward (**Figure 1D**) to the center line and the ball was passed to the shooter by another player standing under the basket. Two timed trials were given and two were recorded. Recovery between trials was 10–12 min. The best result was used for analysis.

Modified Medium and Long Range Shots Test (Stonkus, 1985)

Test objective: establish and measure shooting accuracy in condition of physical load. The court is marked with 10 points from which the players make shots: 1, 3, 5, 7, 9 are on the projection at 5 m distance from the center of the basketball hoop, and 2, 4, 6, 8, 10 points are at a distance of 6 m (**Figure 1E**). The subject stands at the first point with a ball, makes a shot, runs close to the basket, catches the scored or rebound ball, dribbles it to the second point, makes another shot, runs close to the basket and catches the ball, etc., The test includes two sets – 2 × 10 throws. The sum of throws over the limited time was registered. The duration of the test is different for young basketball players of different ages: 11–12 years – up to 145 s; 13–14 years – up to 135 s; 15–17 years – up to 130 s. For each inaccurate throw, the player gets one point if the ball falls on the hoop from above. The test was performed once.

Speed Spot Shooting Test (Johnson and Nelson, 1986)

Test objective: to measure skill in shooting rapidly from different positions and, to some extent, agility and ball handling. The floor markers are placed on the floor at the different spots from which the athletes must shoot. The distance of the spots from the basket is 9 foot (2.74 m). The distances for spots B, C, and D (**Figure 1F**) are measured from the center of the backboard: those for spots A and E are measured from the center of the basket. The athlete starts from behind any of the five markers. On the signal "Ready, go," the person shoots, retrieves the ball and dribbles to and shoots from another spot. A maximum of four lay-up shots may be attempted, but no more than two consecutivelly. The athlete must attempt one shot from each of the five spots. Three trials of 60 s are given: the first is a practice trial, and the next two are recorded. The tester records the spots at which the shots are taken as well as the number of lay-ups attempted. Two points are given for each shot made. One point is given for any unsuccessful shot that hits the rim (from above) either initially or after bouncing from the backboard. The total points for each legal shot for each of the two trials is the score. Recovery between trials was 10–12 min. The best result was used for analysis.

A test-retest procedure was performed to assess the reliability of each test and the reliability scores are given in **Table 3**.

Statistical Analysis

Descriptive data are presented graphically as means ± standard deviation. Test-retest reliability scores were obtained using intraclass correlation coefficients (ICC, two-way random effects model single measure reliability). Commercially available statistical software was used to obtain normative scores (percentile ranks) of anthropometric and technical-related fitness indicators (SPSS Inc., Version 17.0, Chicago, IL, United States). The statistical comparisons between trials were assessed using one-way repeated measures ANOVA. The magnitude from differences between age groups was assessed using standard effect sizes (Cohen, 1998; Hopkins, 2006) using previously established scales: <0.20 = trivial, 0.20–0.59 = small, 0.60–1.19 = moderate, 1.20–2.0 = large, and >2.0 = very large (Hopkins, 2002). The Pearson's correlation coefficients were calculated to determine the relationships between the variables within each age group. Correlation coefficients with values above 0.5 were considered as representing large correlations, 0.3 to 0.5 – moderate, 0.1 to 0.3 – small and <0.1 – trivial (Cohen, 1998). The alpha level for statistical significance was set at $P < 0.05$.

RESULTS

Anthropometric Indicators

Figure 2 and **Table 4** present the descriptive and inferential analysis for all considered variables. Results showed that for 12 and 15-year-old basketball players, the measures that increased most were height (ES = 0.72–1.18, $P < 0.001$), body mass (ES = 0.51–0.80, $P < 0.001$) and arm span (ES = 0.82–1.40, $P < 0.01$). Anthropometric indicators from the subjects at the age of 16 and 17 did not change much (ES = 0.08–0.48).

The correlations between height and control dribble test were large in three age groups (8 and 16–17 years, r = 0.55–0.84; $P < 0.001$) and moderate in another three groups (10 and 14–15 years, r = 0.47–0.49; $P < 0.001$). Height was strongly correlated with the defensive movement test in 14–15 and 17 years (r = 0.50–0.72; $P < 0.001$) and moderately in the 9 and 16-year age groups (r = 0.33–0.42; $P < 0.001$).

Very large correlations were identified between arm span and the control dribble test (r = 0.57–0.69; $P < 0.001$) in 8, 10 and 15–17 year olds. The arm span correlated with the defensive movement test in 15–17 years (r = 0.52–0.68; $P < 0.001$) and with the Illinois agility test in terms of dribbling (r = 0.52–0.87; $P < 0.001$) in the 15 and 17 year age groups. The arm span also had large correlations with the 20 m sprint dribbling two balls test in 16 and 17 years' age groups (r = 0.58–0.61; $P < 0.001$).

Technical Fitness Determination and Assessment

In the first 4 years of training (between 7 and 10) the most notable improvement was observed in the ball dribbling skills. During the initial years of training (7–10 years old) the dribbling skills had substantial improvements (7–8 years – 20 m sprint with dribbling test ES = 2.176, $P < 0.001$; control dribble test ES = 1.862, $P < 0.001$; Illinois agility test with dribbling – 9 to 10-year-old ES = 1.823, $P < 0.001$). The second phase of ball dribbling skill development was at 12 and 13 years of age (ES = 0.91 and ES = 1.38, respectively, $P < 0.001$). Depending on age, the indices of shooting from close, middle and long distances changed differently. For 9 and 10 years' ($P < 0.001$) basketball players, improvements in shooting a ball from close positions improved substantially. The greatest improvements

TABLE 3 | Technical fitness test reliability.

Test	Subjects age (years)										
	7	8	9	10	11	12	13	14	15	16	17
Control dribble	0.871	0.828	0.867	0.898	0.869	0.916	0.892	0.920	0.919	0.939	0.913
Defensive movement	n.a.	0.854	0.773	0.810	0.907	0.806	0.907	0.899	0.930	0.794	0.949
20 m sprint dribble	0.857	0.732	0.857	0.963	0.954	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Two balls of 20 m sprint dribble	n.a.	n.a.	n.a.	n.a.	n.a.	0.405	0.452	0.478	0.510	0.635	0.671
Illinois agility dribble	n.a.	0.802	0.831	0.866	0.913	0.953	0.942	0.947	0.950	0.919	0.953
30 Free-throw shooting	n.a.	n.a.	0.485	0.617	0.669	0.798	0.805	0.815	0.854	0.867	0.873
1 min shooting	n.a.	n.a.	n.a.	0.542	0.651	0.687	0.704	0.732	0.712	0.743	0.751
Modified medium and long-range shots	n.a.	n.a.	n.a.	n.a.	0.480	0.560	0.582	0.574	0.596	0.613	0.654
Close range shots	n.a.	0.765	0.572	0.653	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

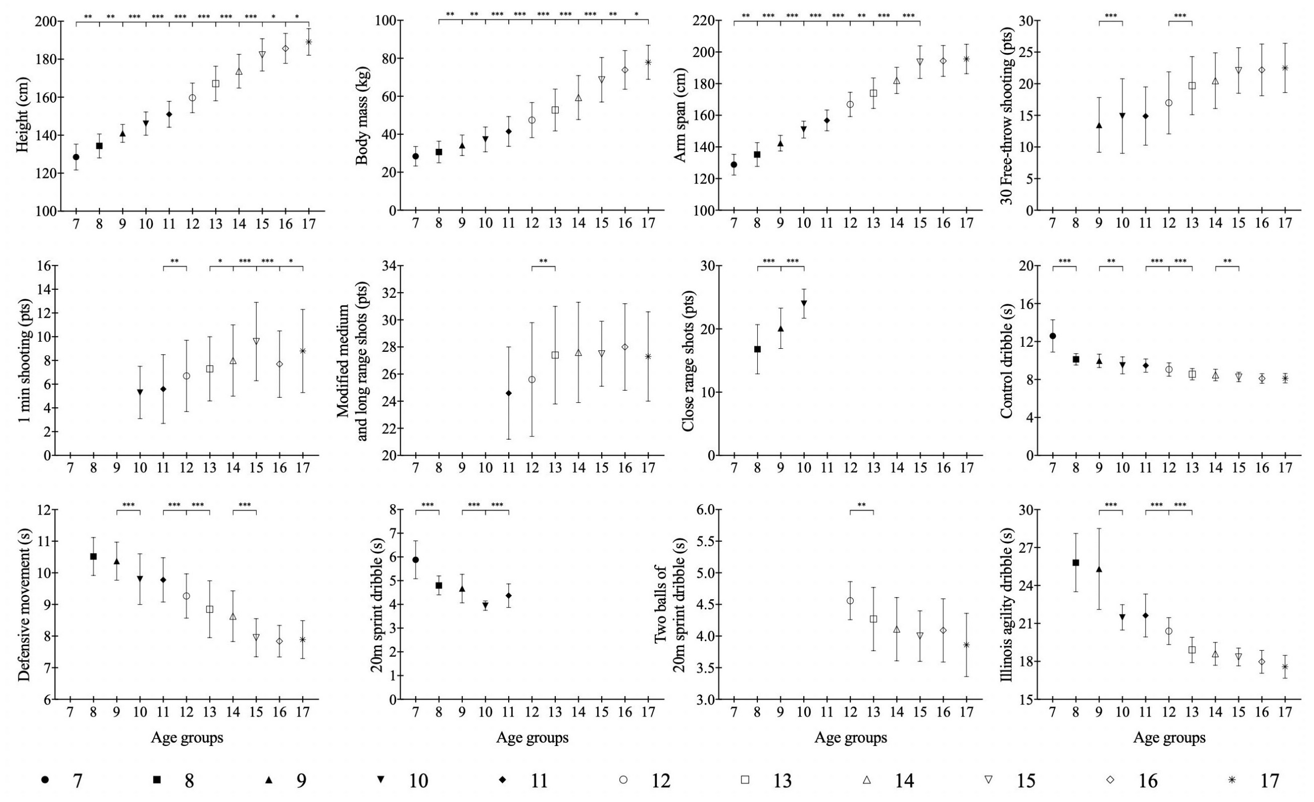

FIGURE 2 | Descriptive characteristics of Lithuanian basketball players aged 7–17 years. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

in free throws as well as shots from medium and long range distances was between 11 and 13 years of age (**Table 3**). The greatest improvements in defensive movements were identified between 14 and 15 years of age ($P < 0.001$). According to the results, it can be seen that players acquired and learned dribbling skills at quickest rates, whereas shooting skills are learned later.

DISCUSSION

The aim of this cross-sectional analysis involving 1051 basketball players was to identify differences in height, body mass, arm span, and technical-related fitness (movement, dribbling, shooting) along the long-term development of 7–17 years basketball players.

Body Size and Arm Span

The differences in players' height between the ages of 7–17 years seem in line with previous findings (Norton and Olds, 2001; Ostojic et al., 2006). Cross sectional analysis of the growth spurt of Sabonis Basketball Center players showed different trends in other variables. The peak height velocity per year was identified at the age of 12 (8.66 cm) and 15 years (8.57 cm). This value is within the range of already estimated values for samples of European boys [i.e., 13.8–14.2 years (Malina et al., 2004)].

Body mass also showed a well-defined adolescent spurt, during the interval of maximum growth in weight at about 13–15 years (Malina et al., 2004). The same tendency of peak height velocity of body mass as in height was seen in basketball players at the age of 12 (6.00 kg) and 15 years (9.37 kg).

The average height and body mass of Lithuanian, American children and European boys was similar, but the body size from the subjects of current sample was higher. Correlation coefficients between height and arm span (r = 0.44–0.87), and between height and body mass (r = 0.88–0.92) were large for all players.

Technical Fitness

In regard to the long-term basketball development, the aim of this study was to contribute to optimizing (Abbott and Collins, 2004; Bailey and Morley, 2006; Drinkwater et al., 2007) by using performance tests, indicators of change and the requirements of players at different age groups (Leonardo et al., 2002).

The technical-related fitness tests used in this study (Johnson and Nelson, 1986; Bouchard et al., 1997; Stonkus, 2002) are likely replicating the skills required in basketball games (Stonkus, 1985, 2002; Apostolidis et al., 2004). In the discussion on technical preparation it should be remembered that the manifestation of these abilities is related to the level of motor abilities (Stonkus, 1985; Karpowicz, 2006). Results for the dribble and defensive movement tests also depend on anaerobic capacity. The dribble and defensive movement indices of youth basketball players aged 7–17 years are consistent with good or very good level of

TABLE 4 | Inferential analysis for the characteristics of Lithuanian basketball players aged 7–17 years (absolute mean differences, percentage of variation and effect size).

Variables	Subjects age (years)									
	7 vs. 8	**8 vs. 9**	**9 vs. 10**	**10 vs. 11**	**11 vs. 12**	**12 vs. 13**	**13 vs. 14**	**14 vs. 15**	**15 vs. 16**	**16 vs. 17**
Anthropometric indicators										
Height (cm)	5.9 *cm*	6.6 *cm*	5.2 *cm*	4.9 *cm*	8.7 *cm*	7.5 *cm*	6.5 *cm*	8.6 *cm*	3.4 *cm*	3.5 *cm*
	4.38%	4.67%	3.53%	3.26%	5.42%	4.49%	3.74%	4.7%	1.83%	1.84%
	0.90(*M*)	1.20(*L*)	0.95(*M*)	0.76(*M*)	1.18(*M*)	0.89(*M*)	0.72(*M*)	0.98(*M*)	0.41(*S*)	0.46(*S*)
Body mass (kg)	2.3 *kg*	3.5 *kg*	3.1 *kg*	4.2 *kg*	6 kg	5.2 *kg*	6.5 *kg*	9.4 *kg*	5.2 *kg*	4 kg
	7.43%	10.29%	8.34%	10.14%	12.62%	9.88%	11.03%	13.65%	7.13%	5.08%
	0.42(*S*)	0.63(*M*)	0.52(*S*)	0.59(*S*)	0.70(*M*)	0.51(*S*)	0.58(*S*)	0.80(*M*)	0.48(*S*)	0.41(*S*)
Arm span (cm)	6.4 *cm*	7.2 *cm*	8.6 *cm*	5.8 *cm*	10.1 *cm*	7.1 *cm*	8.1 *cm*	11.5 *cm*	0.8 *cm*	1.2 *cm*
	4.73%	5.06%	5.72%	3.7%	6.02%	4.08%	4.45%	5.94%	0.4%	0.64%
	0.90(*M*)	1.16(*M*)	1.69(*L*)	0.98(*L*)	1.40(*L*)	0.82(*M*)	0.89(*M*)	1.24(*L*)	0.08(*T*)	0.13(*T*)
Technical fitness test										
Control dribble (s)	2.47*s*	0.15 *s*	0.48 *s*	0.03 *s*	0.41 *s*	0.5 *s*	0.08 *s*	0.21 *s*	0.16*s*	−0.18 *s*
	24.38%	1.5%	5.05%	0.32%	4.53%	5.84%	0.94%	2.54%	1.97%	−0.37%
	2.18(*VL*)	0.23(*S*)	0.60(*M*)	0.04(*T*)	0.58(*S*)	0.81(*M*)	0.14(*T*)	0.40(*S*)	0.31(*S*)	0.35(*S*)
Defensive movement (s)	*n.a.*	0.15 *s*	0.57 *s*	0.02 *s*	0.51 *s*	0.42 *s*	0.22 *s*	0.68 *s*	0.11 *s*	−0.05 *s*
		1.45%	5.82%	0.2%	5.5%	4.75%	2.55%	8.55%	1.4%	0.63%
		0.27(*S*)	0.86(*M*)	0.03(*T*)	0.76(*M*)	0.53(*S*)	0.26(*S*)	0.98(*M*)	0.21(*S*)	0.53(*S*)
20 m sprint dribble (s)	1.08 *s*	0.13 *s*	0.72 *s*	−0.42 *s*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
	22.5%	2.78%	18.23%	−9.61%						
	1.86(*L*)	0.28(*S*)	1.85(*L*)	1.25(*L*)						
Two balls of 20 m sprint dribble (s)	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	0.29 *s*	0.16 *s*	0.11 *s*	−0.09 *s*	0.23 *s*
						6.79%	3.89%	2.75%	2.2%	5.96%
						0.73(*M*)	0.35(*S*)	0.25(*S*)	0.20(*T*)	0.46(*S*)
Illinois agility dribble (s)	*n.a.*	0.5*s*	3.8 *s*	−0.15 *s*	1.27 *s*	1.45 *s*	0.31 *s*	0.25 *s*	0.38 *s*	0.39 *s*
		1.98%	17.83%	−0.69%	6.24%	7.67%	1.67%	1.36%	2.11%	2.22%
		0.18(*T*)	1.82(*L*)	0.11(*T*)	0.91(*M*)	1.38(*L*)	0.33(*S*)	0.31(*S*)	0.45(*S*)	0.43(*S*)
30 Free-throw shooting (pts)	*n.a.*	*n.a.*	1.4 *pts*	0.0 *pts*	2.1 *pts*	2.7 *pts*	0.8 *pts*	1.6 *pts*	0.1 *pts*	0.3 *pts*
			9.4%	0.0%	12.35%	13.71%	3.9%	7.24%	0.45%	1.33%
			0.27(*S*)	0.0(*T*)	0.44(*S*)	0.57(*S*)	0.18(*T*)	0.4(*S*)	0.03(*T*)	0.07(*T*)
1 min shooting (pts)	*n.a.*	*n.a.*	*n.a.*	0.3 *pts*	1.1 *pts*	0.6 *pts*	0.7 *pts*	1.6 *pts*	−1.9 *pts*	1.1 *pts*
				5.36%	16.42%	8.22%	8.75%	16.67%	24.68%	12.5%
				0.12(*T*)	0.37(*S*)	0.21(*S*)	0.25(*S*)	0.50(*S*)	0.62(*M*)	0.35(*S*)
Modified medium and long-range shots (pts)	*n.a.*	*n.a.*	*n.a.*	*n.a.*	1 pts	1.8 *pts*	0.2 *pts*	−0.1 *pts*	0.5 *pts*	−0.7 *pts*
					3.91%	6.57%	0.72%	−0.36%	1.79%	−2.56%
					0.26(*S*)	0.47(*S*)	0.05(*T*)	0.03(*T*)	0.18(*T*)	0.22(*S*)
Close range shots (pts)	*n.a.*	3.3 *pts*	3.9 *pts*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
		16.42%	16.25%							
		0.92(*M*)	1.41(*L*)							

technical-related fitness (Johnson and Nelson, 1986). In addition, the shooting skills showed the largest changes in the age groups of 9, 12–13, and 15 years.

The current youth basketball players have two “windows of opportunity” to improve their technical basketball skills. These periods are related to chronological age and occur at approximately 7–10 years, and 12–13 years and occur in accordance with the boys’ period of accelerated adaptation in sprint speeds, between the ages of 5 and 9 years (Borms, 1986; Viru et al., 1999). A second period of accelerated adaptation has been reported at around the age of 12 and 15 years (Borms, 1986). Additionally, the window for optimal skill training occurs between the ages of 9 and 12 years (Balyi and Hamilton, 2004; Dick, 2007).

The improvement in the technical qualifications of indicators of youth basketball players could be caused by the training program (Karpowicz, 2006; Drinkwater et al., 2007), biological maturity (Balyi and Hamilton, 2004) or genetic peculiarities (Bouchard et al., 1997). To identify and evaluate youth basketball players’ technical fitness levels at different ages it is important to establish a fitness ranking scale (Johnson and Nelson, 1986; Trninic et al., 1999; Drinkwater et al., 2008).

This study might be limited by the usage of the testing procedures also in load condition, having no possibility to account for these parameters. Further research might include the usage of session-RPE as a way to control the quality of data (see Lupo et al., 2017). Nevertheless, this study used a large sample size to identify the development in anthropometric measures and technical fitness test scores in elite Lithuanian youth players. For peak height velocity, the two most significant periods were at the ages of 12 and 15 years. The results also indicated that the best periods to develop technical skills, including dribbling and shooting, were at the ages of 7–10 years and 12–13 years, while defensive movements can be developed during 14–15 years of age. The overall results enable the establishment of normative player’s characteristic across different development stages (**Supplementary Tables S1–S9**), which can greatly assist coaches and researchers to design appropriate age-group strategies for training and development. This way, coaching staffs can fast and easily evaluate the players’ characteristics and their performance outputs across the developmental aging groups.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript/**Supplementary Files.**

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee from the Lithuanian Sport University. Written informed consent to participate in this study was provided by the participants’ legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

KM, AS, and JS conceived the study. KM, AS, CA, and JS designed the methodology of the work. KM, BG, and JS analyzed the data. KM and AS drafted the manuscript. All authors reviewed and edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01677/full#supplementary-material

REFERENCES

Abbott, A., and Collins, D. (2004). Eliminating the dichotomy between theory and practice in talent identification and development: considering the role of psychology. *J. Sports Sci.* 22, 395–408. doi: 10.1080/02640410410001675324

Angyan, L., Teczely, T., Zalay, Z., and Karsai, I. (2003). Relationship of anthropometrical, physiological and motor attributes to sport-specific skills. *Acta Physiol. Hung.* 90, 225–231. doi: 10.1556/APhysiol.90.2003.3.5

Apostolidis, N., Nassis, G. P., Bolatoglou, T., and Geladas, N. D. (2004). Physiological and technical characteristics of elite young basketball players. *J. Sports Med. Phys. Fitness* 44, 157–163.

Bailey, R., and Morley, D. (2006). Towards a model of talent development in physical education. *Sport Educ. Soc.* 11, 211–230. doi: 10.1080/13573320600813366

Balciunas, M. (2005). *Efficiency of Applying Optimum Physical Loads to Young Basketball Players.* Ph. D thesis, Lithuanian Sports University, Kaunas.

Balyi, I., and Hamilton, A. (2004). Long-term athlete development: trainability in childhood and adolescence. *Olympic Coach* 16, 4–9.

Balyi, I., ltad, U. K., and Williams, C. (2009). *Coaching the Young Developing Performer: Tracking Physical Growth and Development to Inform Coaching Programmes*. Chelsea: Coachwise.

Ben Abdelkrim, N., El Fazaa, S., and El Ati, J. (2007). Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br. J. Sports Med.* 41, 69–75; discussion 75. doi: 10.1136/bjsm.2006.032318

Bloom, B. S., and Sosniak, L. A. (1985). *Developing Talent in Young People*. New York, NY: Ballantine Books.

Borms, J. (1986). The child and exercise: an overview. *J. Sports Sci.* 4, 3–20. doi: 10.1080/02640418608732093

Bouchard, C., Malina, R. M., and Pérusse, L. (1997). *Genetics of Fitness and Physical Performance*. Champaign, IL: Human Kinetics.

Condello, G., Minganti, C., Lupo, C., and Benvenuti, C. (2013). Evaluation of change-of-direction movements in young rugby players. *Int. J. Sports Physiol. Perform.* 8, 52–56. doi: 10.1123/ijspp.8.1.52

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. 2nd Edn. New Jersey, NJ: Lawrence Erlbaum.

Cote, J., and Hay, J. (2002). "Children's involvement in sport: a developmental perspective," in *Psychological Foundations of Sport*, eds J. M. Silva and D. E. Stevens (Boston: MA: Allyn & Bacon), 484–502.

Dick, F. W. (2007). *Sports Training Principles*. London: A&C Black.

Drinkwater, E. J., Hopkins, W. G., McKenna, M. J., Hunt, P. H., and Pyne, D. B. (2007). Modelling age and secular differences in fitness between basketball players. *J. Sports Sci.* 25, 869–878. doi: 10.1080/02640410600907870

Drinkwater, E. J., Pyne, D. B., and McKenna, M. J. (2008). Design and interpretation of anthropometric and fitness testing of basketball players. *Sports Med.* 38, 565–578. doi: 10.2165/00007256-200838070-00004

Erculj, F., Blas, M., and Bracic, M. (2010). Physical demands on young elite European female basketball players with special reference to speed, agility, explosive strength, and take-off power. *J. Strength Cond. Res.* 24, 2970–2978. doi: 10.1519/JSC.0b013e3181e38107

Erculj, F., Blas, M., Coh, M., and Bracic, M. (2009). Differences in motor abilities of various types of european young elite female basketball players. *Kinesiology* 41, 203–211.

Ericsson, K. A., and Charness, N. (1994). Expert performance - its structure and acquisition. *Am. Psychol.* 49, 725–747. doi: 10.1037/0003-066x.49.8.725

Ericsson, K. A., Krampe, R. T., and Teschromer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychol. Rev.* 100, 363–406. doi: 10.1037/0033-295x.100.3.363

Ford, P., De Ste Croix, M., Lloyd, R., Meyers, R., Moosavi, M., Oliver, J., et al. (2011). The long-term athlete development model: physiological evidence and application. *J. Sports Sci.* 29, 389–402. doi: 10.1080/02640414.2010.536849

Garcia-Gil, M., Torres-Unda, J., Esain, I., Dunabeitia, I., Susana, M., Gil, J., et al. (2018). Anthropometric parameters, age, and agility as performance predictors in elite female basketball players. *J. Strength Cond. Res.* 32, 1723–1730. doi: 10.1519/JSC.0000000000002043

Getchell, B., Mikesky, A. E., and Mikesky, K. N. (1998). *Physical Fitness: A Way of Life*. Boston, MA: Allyn and Bacon.

Guimaraes, E., Baxter-Jones, A., Maia, J., Fonseca, P., Santos, A., Santos, E., et al. (2019). The roles of growth, maturation, physical fitness, and technical skills on selection for a portuguese Under-14 years basketball team. *Sports* 7:61. doi: 10.3390/sports7030061

Hoare, D. G. (2000). Predicting success in junior elite basketball players–the contribution of anthropometic and physiological attributes. *J. Sci. Med. Sport* 3, 391–405. doi: 10.1016/s1440-2440(00)80006-7

Hopkins, W. (2002). Probabilities of clinical or practical significance. *Sports Sci.* 6.

Hopkins, W. (2006). Spreadsheets for analysis of controlled trials, with adjustment for a subject characteristic. *Sports Sci.* 10, 46–50.

Johnson, B. L., and Nelson, J. K. (1986). *Practical Measurements for Evaluation in Physical Education*. California, CA: Burgess Pub.

Karpowicz, K. (2006). Interrelation of selected factors determining the effectiveness of training in young basketball players. *Hum. Mov.* 7, 130–146.

Klusemann, M. J., Pyne, D. B., Hopkins, W. G., and Drinkwater, E. J. (2013). Activity profiles and demands of seasonal and tournament basketball competition. *Int. J. Sports Physiol. Perform.* 8, 623–629. doi: 10.1123/ijspp.8.6.623

Leite, N., and Sampaio, J. (2010). Early sport involvement in young portuguese basketball players. *Percept. Mot. Skills* 111, 669–680. doi: 10.2466/05.10.PMS.111.6.669-680

Leite, N., and Sampaio, J. (2012). Long-term athletic development across different age groups and gender from portuguese basketball players. *Int. J. Sports Sci. Coach.* 7, 285–300. doi: 10.1260/1747-9541.7.2.285

Leonardo, A., Teodora, P., and Adriana, A. (2002). The Modeling of Physical Preparation's Content in Basketball Game (Juniors). *Paper Presented at the 7th Annual Congress of the European College of Sport Science*, Athens.

Lupo, C., Tessitore, A., Gasperi, L., and Gomez, M. A. R. (2017). Session-RPE for quantifying the load of different youth basketball training sessions. *Biol. Sport* 34, 11–17. doi: 10.5114/biolsport.2017.63381

Malina, R. M., Bouchard, C., and Bar-Or, O. (2004). *Growth, Maturation and Physical Activity*, 2nd Edn. Champaign, IL: Human Kinetics.

Norton, K., and Olds, T. (2001). Morphological evolution of athletes over the twentieth century: causes and consequences. *Sports Med.* 31, 763–783. doi: 10.2165/00007256-200131110-00001

Ostojic, S. M., Mazic, S., and Dikic, N. (2006). Profiling in basketball: physical and physiological characteristics of elite players. *J. Strength Cond. Res.* 20, 740–744. doi: 10.1519/00124278-200611000-00003

Ramos, S., Vollossovich, A., Ferreira, A., Fragoso, I., and Massuça, L. (2019). Differences in maturity, morphological and physical attributes between players selected to the primary and secondary teams of a Portuguese Basketball elite academy. *J. Sports Sci.* 37, 1681–1689. doi: 10.1080/02640414.2019.1585410

Salmela, J. H., Young, B. W., and Kallio, J. (1998). "Within-career transition of the athlete-coach triad," in *Career Transitions in Sport*, eds P. Wylleman and D. Lavallee (Morgantown, VA: Fit Publications).

Stafford, I. (2005). *Coaching for Long-Term Athlete Development: To Improve Participation and Performance in Sport*. Leeds: The National Coaching Foundation.

Stonkus, S. (1985). *Krepšinis*. Vilnius: Mokslas.

Stonkus, S. (2002). *Krepšinio Testai*. Kaunas: LKKA.

Trninic, S., Perica, A., and Dizdar, D. (1999). Set of criteria for the actual quality evaluation of the elite basketball players. *Coll. Antropol.* 23, 707–721.

Vaeyens, R., Lenoir, M., Williams, A. M., and Philippaerts, R. M. (2008). Talent identification and development programmes in sport - current models and future directions. *Sports Med.* 38, 703–714. doi: 10.2165/00007256-200838090-00001

Viru, A., Loko, J., Harro, M., Volver, A., Laaneots, L., and Viru, M. (1999). Critical periods in the development of performance capacity during childhood and adolescence. *Eur. J. Phys. Educ.* 4, 75–119. doi: 10.1080/1740898990040106

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Modeling the Quality of Player Passing Decisions in Australian Rules Football Relative to Risk, Reward, and Commitment

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The value of player decisions has typically been measured by changes in possession expectations, rather than relative to the value of a player's alternative options. This study presents a mathematical approach to the measurement of passing decisions of Australian Rules footballers that considers the risk and reward of passing options. A new method for quantifying a player's spatial influence is demonstrated through a process called commitment modeling, in which the bounds and density of a player's motion model are fit on empirical commitment to contests, producing a continuous representation of a team's spatial ownership. This process involves combining the probability density functions of contests that a player committed to, and those they did not. Spatiotemporal player tracking data was collected for AFL matches played at a single stadium in the 2017 and 2018 seasons. It was discovered that the probability of a player committing to a contest decreases as a function of their velocity and of the ball's time-to-point. Furthermore, the peak density of player commitment probabilities is at a greater distance in front of a player the faster they are moving, while their ability to participate in contests requiring re-orientation diminishes at higher velocities. Analysis of passing decisions revealed that, for passes resulting in a mark, opposition pressure is bimodal, with peaks at spatial dominance equivalent to no pressure and to a one-on-one contest. Density of passing distance peaks at 17.3 m, marginally longer than the minimum distance of a legal mark (15 m). Conversely, the model presented in this study identifies long-range options as have higher associated decision-making values, however a lack of passes in these ranges may be indicative of differing tactical behavior or a difficulty in identifying long-range options.

Keywords: motion models, spatiotemporal, decision-making, team sports, Australian Rules football, player tracking

INTRODUCTION

Team sport athletes are consistently presented with situations in which their decisions effect the immediate state of a game. These consist of overt on-ball decisions relating to passing or shooting, however also include off-ball actions such as occupation of a given space. Whilst previous works have quantified the impact of a decision on some measure of possession expectation (Cervone et al., 2014, 2016; Jackson, 2016) or on measures of spatial control (Fernandez and Bornn, 2018), their value has typically been measured by the change in some metric or relative to a contextual mean. We believe the value of a player's decision should be quantified relative to the alternative options that were available. Although a pass may yield a positive increase in a team's scoring chance by *x*, the decision is by definition sub-optimal if alternatives exist that increase it by greater than *x*. By measuring a player's decision relative to their options, we can quantitatively attribute value to a player's decision-making abilities, further decoupling components of a player's performance.

The expected possession value (EPV) metric considers spatiotemporal data, match phase and player behaviors to quantify possession outcomes in basketball (Cervone et al., 2014, 2016). Computing the change in EPV between possessions assigns a value to player possession contributions. A player's decision is valued relative to the tendencies of other players in the same situation, producing a player's EPVA (EPV-added over replacement) as the sum of a player's EPV-added ($EPV_{end} - EPV_{start}$) across all possessions. In Jackson (2016), Australian Rules footballers ranking points are the sum of their possession contributions, valued relative to the event and location, an extension of the measure of field equity developed in O'Shaughnessy (2006). Similar to Cervone et al. (2014), player contributions are measured relative to mean outcomes and a player is deemed to be a good decision maker if their involvement improved their team's field equity, a measurement of scoring chance relative to match phase and possession location. In Horton et al. (2015), football passes were labeled qualitatively using machine learning algorithms with quantitative inputs, learnt from manual labeling of passing quality by sporting professionals. The inclusion of player dominant regions, a method of bounding a player's spatial ownership via consideration of player momentum, suggests the quality of a pass has some dependence on a team's spatial control.

Common amongst these studies is the valuation of player decisions with respect to some change in possession expectation. Another approach would be to value decisions relative to alternative options, however, modeling this problem presents unique challenges. While quantifying a decision after the fact can be done by measuring the change in a given objective, each option available to a player has an accompanying probability of success. Multiple studies have measured the risk of passes in football. In Szczepański and McHale (2016), the success of a pass depended upon the skill of a player and their teammates, field position of the pass location and destination, and pressure. The latter was approximated dependent on a player's typical playing positions and time between passes, rather than consideration of opponent locations due to an absence of player tracking data. Power et al. (2017) measured the risk and reward of passing options using spatiotemporal tracking data, where the risk of a pass considers player velocity, defender proximity and momentum, and possession statistics and the reward of a pass is the probability that the pass will result in a shot on goal. From their measure of risk, the risk tendencies and completion rates of players were analyzed. Our recent work in AFL produced measures of risk and reward via discrete player motion models and measures of future possession expectations respectively (Spencer et al., 2018). Passing networks have been used to describe the passing behaviors of athletes (e.g., Fewell et al., 2012; Pena and Touchette, 2012), but have not included quantitative measurements of the quality of links in these networks.

In this study we value a player's passing decisions through consideration of the risk and reward of their options. We measure the risk of a pass through modeling of individual and team spatial control, and reward via a measure of field equity detailed in Jackson (2016). We present a new method for modeling spatial control via probabilistic modeling of player commitment to contests with consideration of their momentum. This process, referred to as commitment modeling, produces player motion models that more realistically represent player behavior based on their proximity to important events. We use the resultant decision-making model to analyze characteristics of player decision-making, its predictability, and distributions of risk taking within teams.

Related Work

Motion Models

There exist many methods for representing a player's spatial occupancy. One common approach, particularly in football, is that of Voronoi tessellations which bound a player's owned space as the space in which they could occupy before any other player. Simple applications of this approach do not consider player orientation, velocity, or individual physical capabilities (e.g., Fonseca et al., 2012). Taki and Hasegawa (2000) produced variations incorporating a player's orientation, velocity, but assumed consistent acceleration. Fujimura and Sugihara (2005) proposed an alternative motion equation, adding a resistive force that decreases velocity. This approach involved a generalized formula that more realistically represented a player's inability to cover negative space if moving at speed. Gudmundsson and Wolle (2014) individualized these models, fitting a player's dominant region from observed tracking data.

Underlying these models is an assumption that spatial ownership is binary. That is, each location on the field is owned completely by a single player, determined by the time it would take them to reach said location, henceforth referred to as their time-to-point. Through observations of contests, we propose that ownership of space is continuous. For a given location, if the time-to-point of the ball is greater than the time-to-point of at least two players, then no single player owns the space completely. This distinction is important if we wish to quantify spatial occupancy (and its creation) relative to the ball, given its time-to-point, as we need to account for changes in field formations that could occur between possessions.

Recent papers have addressed this. The density of playing groups was explored with Gaussian mixture models in Spencer et al. (2017). Spencer et al. (2018) produced a smoothed representation of a team's control using non-probabilistic player motion models fit on observed tracking data. While a team's ownership was expressed on a continuous scale, the use of motion models with discrete bounds may result in unrealistic estimations of a player's influence (Brefeld et al., 2018). Fernandez and Bornn (2018) measured a player's influence area using bivariate normal distributions that considered a player's location, velocity, and distance to the ball. The result is a smoothed surface of control in which a team's influence over a region is continuous, however the size of a player's influence is within a selected range, rather than learnt from observed movements. Recently, Brefeld et al. (2018) fit player motion models on the distribution of observed player movements, utilizing these probabilistic models to produce more realistic Voronoi-like regions of control. In the interest of computing time, two-dimensional models were produced for different speed and time bands, hence the resultant models are not continuous in all dimensions.

Given its contested and dynamic nature, a continuous representation of space control is preferable (e.g., Fernandez and Bornn, 2018; Spencer et al., 2018). Furthermore, a player logically exhibits greater control over space in which they are closer, hence we develop probabilistic motion models in this paper. When probabilistic models are fit on the entirety of a player's movements (as in Brefeld et al., 2018), we find that the probability of player reorientation is underestimated. In decision-making modeling, our interest is in measuring the contest of space that would occur if the ball were kicked to said space. Hence to represent this realistically, it is important to fit the distribution of player movements observed under similar circumstances. We model a player's behavior when within proximity of contests. We achieve this via a procedure we call *commitment modeling*, where we fit the distribution of player commitment to contests in four dimensions (velocity, time, and x- and y- field position). The result is a realistic representation of player behaviors when presented with the opportunity to participate in a contest.

MATERIALS AND METHODS

Data and Pre-processing

Spatiotemporal player tracking data was collected from the 2017 and 2018 AFL seasons. Data were collected by local positioning system (LPS) wearable Catapult Clearsky devices (Catapult Sports, Melbourne, VIC, Australia), situated in a pouch positioned between the players' shoulder blades. Positional data in the form of Cartesian coordinates was recorded at a frequency of 10 Hz for all 44 players. To ensure consistent tracking and field dimensions, analyzed matches were limited to those played at Docklands Stadium, Melbourne, VIC, Australia. Play-by-play transactional data (i.e., match events such as kicks, marks, and spoils, and their associated meta-data) were manually collected by Champion Data (Champion Data, Pty Ltd., Melbourne, VIC, Australia). These events are henceforth referred to as transactions. Consolidation of transaction and tracking data was used to infer ball position from possession, as ball tracking data is not available in Australian Rules football. Datasets were joined via unix timestamps present in both datasets. Transactions were recorded to the nearest second, hence it was assumed they occurred at the beginning of a second when matched to 10 Hz tracking data. If the location of one or more players was lost during a passage of play, said passage was omitted from the analysis. In total, data from 60 matches was used in this study. A total of 2236 passes across 60 matches were analyzed in this study.

A player's velocity and displacement direction were calculated from raw positional data. Displacement direction was extracted from consecutive tracking samples (i.e., a player's displacement direction was recorded as the angle formed by consecutive tracking samples, relative to the positive y-axis). A player's change in displacement direction was considered as the angle between two vectors, $\vec{AB}$ and $\vec{BC}$, where A, B, and C are the player's three most recent positions, and the angle describes the change in displacement direction between positions B and C (Eq. 1). The same process was used to calculate the location of an event relative to a player (where A and B are a player's previous and current position, and C is the location of interest). Velocity, recorded in meters/second, was calculated as the Euclidean distance between a player's current position and their position, 1 s prior.

$$\theta = \cos^{-1}\left(\frac{\vec{AB} \cdot \vec{BC}}{||\vec{AB}|| \cdot ||\vec{BC}||}\right) \quad (1)$$

In this study, only player decisions following a mark were included, given that a mark provides the player with time to make an informed decision. In Australian Rules football, a mark is a kick greater than 15 m that is received by a player on the full (i.e., without bouncing). To locate the destination of a player's kick following their mark, the next transaction must also be a mark. If the next possession following a kick is not a mark, we are unable to reliably locate the intended target, given a reliance on transactions to infer ball position.

Commitment Modeling

For analysis purposes, a contest was defined as a transaction following a pass in which at least one player from each team was involved and the ball location (for both the preceding kick and the receive) could be inferred from the consolidated datasets. In this study, the contest transaction types were spoils and contested marks. The former is an attempted pass that was physically prevented by the opposition and the latter is a mark in which multiple players attempted to receive the ball. For each contest, interest related to two moments – the pass that preceded the contest and the contest itself. For each moment, the time (t_p and t_c respectively) and field formation (position, displacement direction, and velocity of all on-field players) were recorded. A player was considered as having committed to a contest if their Euclidean distance from the location of the contest was less than 2 m at t_c. Using a player's position at t_p and their commitment (recorded as a binary value), a model was developed that quantified the probability a player would commit to a contest across a continuous space within their vicinity.

For each contest, we record player's velocity, displacement direction, and position, and define the time between t_p and t_c

as the ball's time-to-point. For each player, compute the relative location of the contest to player displacement direction and position. If the Euclidean distance between said player's position at time t_c and the contest location is ≤ 2 m, set their commitment to 1, else commitment is set to 0 if the distance is > 2 m. A player's velocity, commitment, the ball's time-to-point, and the relative x- and y- co-ordinates of the contest are recorded. Given that options are only considered in a 60 m radius of the kicker, the maximum repositioning time available to a player never exceeds 4 s, hence it is unlikely that a player can relocate more than 30 m in this period. In the interest of computation time, player commitment behavior is only recorded for players within 35 m of the contest locations.

The data was separated by the binary commitment variable, and kernel density estimation (KDE) used to estimate their probability density functions (PDFs). KDE is a form of data smoothing in which the PDF of a dataset is estimated, the form of which depends on the chosen kernel function and bandwidth inputs (Silverman, 1986). KDE has previously been used in motion model studies by Brefeld et al. (2018) who produced motion models on the distribution of a player's observed movements, regardless of context. In this study Gaussian kernel functions were used and bandwidth was set to 1.5, chosen after experimentation of different values. Datasets were four-dimensional, containing player velocity (m/s), ball time-to-point (s), and the relative x- and y- co-ordinate of the contest (m).

Individually, these distributions represent the density of the data-sets in four dimensions. If a player's positional information and the ball location is known, the probability they will commit to a contest at location x is as follows:

$$\Pr(x) = \frac{wf_{c=1}}{wf_{c=1} + (1-w)f_{c=0}} \tag{2}$$

where w is a weighting factor equal to the size of the commitment dataset divided by the total number of samples, and $f_{c=1}$ and $f_{c=0}$ are the PDFs for the datasets where commitment = 1 and commitment = 0 respectively. A player's commitment probability ($\Pr(x)$) considers their position relative to x, their velocity, and the ball's time-to-point. Ball time-to-point to a location is equal to the distance between the ball and the location, divided by ball velocity. Ball velocity was estimated as 18.5 m/s after manually timing kicks from two quarters of a single AFL match and taking the average, however we note that this is a rough estimation as distances were estimated from manually recorded transactions. This represents a novel method for combining the distributions of two datasets of unequal sample size, where the resulting metric quantifies the probability that a new point belongs to each distribution. The combination of these distributions in a 2D space is illustrated in **Figure 1**. The resultant distributions can be calculated for a player's position, providing a distribution of the likelihood of their repositioning to each location, such that we derive a representation of their spatial influence comparable to that of traditional motion models.

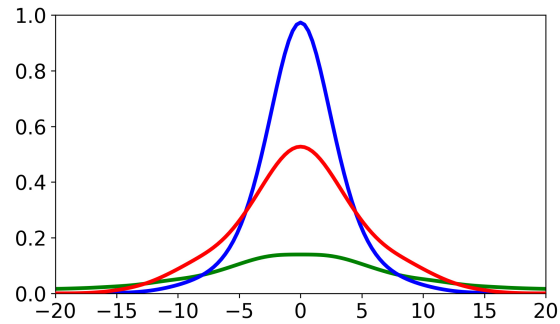

FIGURE 1 | Two-dimensional representation of the commitment modeling process. The blue line represents the distribution for commitment values of 1 ($f_{c=1}$), and the green line represents the distribution for commitment values of 0 ($f_{c=0}$). The red line represents player influence ($P_r(x)$), derived from the combined commitment distributions (see Eq. 2). This exemplar represents a player's commitment probability across relative x- co-ordinates for a y-displacement of 1 m, velocity = 4 m/s, and time = 2 s. All co-ordinates are relative to player displacement direction.

Decision-Making Model

Following a pass, the ball can be received on the full, resulting in a mark, or can be received after a bounce, in which case a mark is not awarded. Hence, each of a player's passing options has four possible outcomes – successful passes in which a teammate receives the ball before (A) or after (B) it bounces, and unsuccessful passes in which an opponent does the same (C and D respectively). For each option, we calculate the probability (p) and value (e) of each event (Eq. 3). As we consider players to be moving objects who exhibit spatial influence over locations not at their present position, the player with the ball could theoretically kick to any location within a radius equal to their maximum kicking distance. The typical maximum range of elite footballers has been found to be between 55 and 63 m (Ball, 2008c), hence the kicking radius in this study is set to 60 m. While some locations are likely sub-optimal choices, we calculate the expected outcome (EO) of each location within said radius. The EO for a location, x, is as follows:

$$EO(x) = p_A(x)e_a(x) + p_B(x)e_a(x) - p_C(x)e_o(x) - p_D(x)e_o(x) \tag{3}$$

where e_a and e_o are the field equity values for the attacking team and their opponent respectively. Derivation of field equity in AFL has been the focus of previous studies (O'Shaughnessy, 2006; Jackson, 2016).

From the EO of a pass, we calculate the value of a decision (referred to as the decision value or DV) as the EO of the pass that was executed, divided by the maximum EO contained in a player's kicking range (EO_{opt}):

$$DV(x) = \frac{EO(x)}{EO_{opt}} \tag{4}$$

The EO of a pass will be negative if the equity at its target location is negative. For a decision with negative EO, the associated DV will likewise be negative. For a DV < -1, we set DV to -1.

Outcome Probabilities

For a given location, a team's spatial influence (INF) is the sum of the influence of its players:

$$INF(x) = \sum_{i=1}^{18} \Pr_i(x) \quad (5)$$

where $\Pr_i$ is the commitment probability array for player i, from Eq. 2. An attacking team's influence is a measure of the commitment of its players. From the influence of each team, we calculate the attacking team's spatial dominance (DOM) as:

$$DOM_a(x) = \frac{INF_a(x)}{INF_a(x) + INF_o(x)} \quad (6)$$

where $INF_a(x)$ and $INF_o(x)$ are the influence of the attacking team and their opponent at x.

The attacking team's dominance at x is the proportion of space they own. Logically, greater spatial dominance translates to a higher chance of a successful pass. Given that dominance is a relative measure, it is possible for a team to have high dominance over a location where influence is low. In such a case, while the probability of a successful pass is high due to their dominance, the probability that their players will reach the location is low, hence such a location is likely a poor passing location. To account for this, we calculate the probability of a successful mark ($p_A$and p_C from Eq. 3) as a team's dominance multiplied by their influence.

$$p(x) = DOM(x) \times INF(x) \quad (7)$$

Given that a team's desired outcome is a successful pass resulting in a mark, this probability (Eq. 7) is of particular importance when analyzing a pass. We refer to p_A as the *risk* of a pass, where higher values indicate a safer passing option.

If a pass does not result in a mark, the probability that either team would win the ball is simply equal to their dominance ($p_B$and p_D from Eq. 3).

Kicking Variance

Given imperfect accuracy of kicks, there is a chance that a kick will not reach its intended target. To incorporate this variance, we represent the likely target of a kick using a 2D Gaussian distribution with covariance equal to 5% of the kicking distance. The modified EO of a kick is equal to the summed product of the kicking Gaussian's PDF and the raw EO values contained in its radius:

$$EO_{mod}(x) = \sum_{i \in S} EO(i)f(i) \quad (8)$$

where S is the set of integer co-ordinates in a radius around x equal to 5% of the Euclidean distance between the ball and x.

Statistical Analysis

For each analyzed event, the optimal pass is identified as the pass to a teammate within a 60 m radius of the kicker whose EO is highest. The characteristics of the pass that was made and the pass identified as being optimal were extracted for all kicks that were preceded and resulted in a mark across the analyzed matches (see **Table 1** for a list of variables and definitions). We refer to the pass that was made as the *decision* and the pass identified as the optimal option as the *alternative* (note that if the decision was optimal it will be equal to the alternative). Descriptive statistics (mean ± SD) were produced for all metrics. Spearman's correlation coefficient (ρ) was used to measure the correlation of decision-making metrics with location. KDE was used to fit the distribution of analyzed variables, finding that the decision-making metrics are not normally distributed. The Mann–Whitney U-test was used to assess differences between the characteristics of decisions and alternatives (Mann and Whitney, 1947).

We explore team level trends in decision-making by comparing two teams. Teams were selected by taking the teams with the highest samples who fit the following criteria – one team who finished in the top 8 (*Team A*) in both the 2017 and 2018 regular AFL playing seasons, and one team who finished in the bottom 10 in the same seasons (*Team B*). Participation in the play-off finals in AFL is between the top 8 teams, hence the choice of cut-off criteria ensured one team who participated in the finals, and one non-finalist team. Furthermore, the distribution of team samples is heavily skewed, hence importance was placed on selecting teams with adequate sample sizes. This skew in team samples is due to this study's focus on matches played at a single stadium, hence teams who played more matches at this stadium appear more frequently in the dataset. Differences between team-level statistics were measured using the Mann–Whitney U-test. Within-team decision-making is analyzed for both teams. We fit the distribution of mean decision-making characteristics for each player on the team. All analyses were carried out in the Python programing language, using SciPy (Jones et al., 2014) and the Scikit-learn (Pedregosa et al., 2011) packages.

TABLE 1 | Definitions of decision-making variables.

Variable	Definition
Dominance	The proportion of space owned by a team (see Eq. 6)
Influence	A measure of spatial occupancy irrespective of opposition locations, equal to the summed commitment probabilities of a team's players (see Eq. 5)
Risk	The likelihood of a successful pass resulting in a mark (see Eq. 7)
Decision value (DV)	The value of a player's passing decision, measured relative to the optimal decision available at the time of the pass (see Eq. 4)
Expected outcome (EO)	A numerical value describing the expected value of passing to a field position that considers the risk and reward of said pass (see Eq. 3)
Distance	The Euclidean distance between two points. For a kick, distance is the Euclidean distance between the location of the kicker and of the receiver

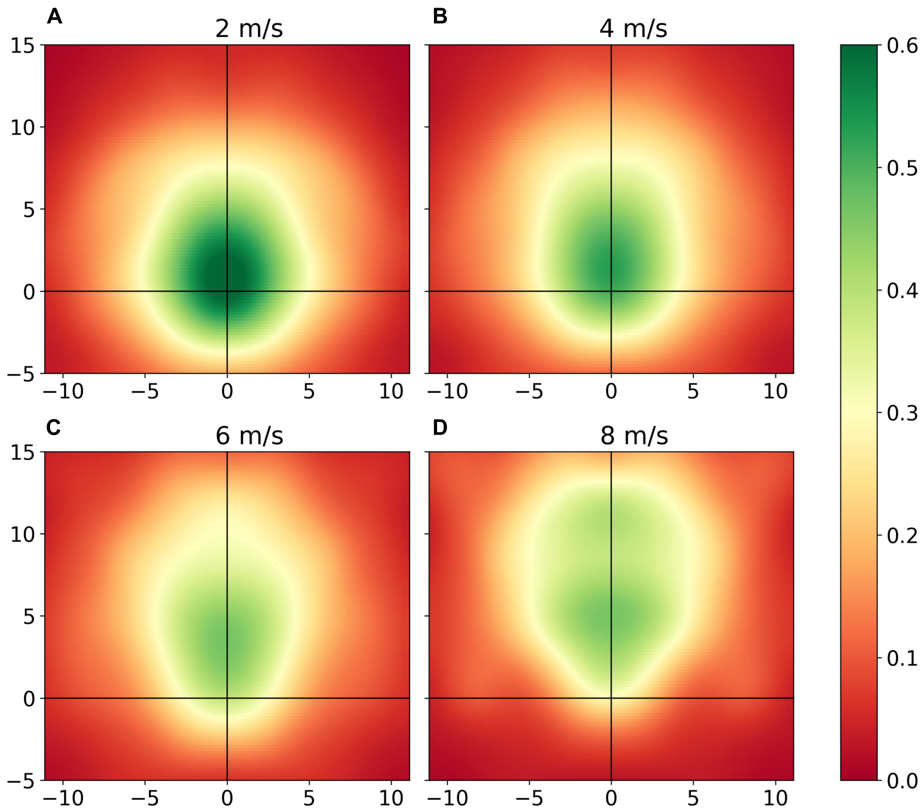

FIGURE 2 | Motion models representing a player's area of influence when moving at **(A)** 2 m/s, **(B)** 4 m/s, **(C)** 6 m/s, and **(D)** 8 m/s for ball time-to-point of 2 s. Heatmap intensity is equivalent to the probability that a player (at the point of origin) would participate in a contest at relative x-, y-co-ordinates, as quantified by observed commitment behaviors.

RESULTS

Motion Models

Motion models were produced from 46220 instances of player commitment. Within the dataset there were 6392 instances of player commitment (Commitment = 1), and 39828 instances of no commitment (Commitment = 0), producing a weighting coefficient (w) of 0.14. Resultant motion models for four different player velocities for ball time-to-point of 2 s are visualized in **Figure 2**. Peak commitment probabilities occurred at 0.8 m for a velocity of 2 m/s (**Figure 2A**), 1.6 m for 4 m/s (**Figure 2B**), 3.7 m for 6 m/s (**Figure 2C**), and 5.3 m for 8 m/s (**Figure 2D**). While density peaks at further distances as velocity increases, a negative correlation is revealed between player velocity (integers from 1 to 8 m/s) and peak commitment probabilities ($\rho = -0.80$ for $t = 2$ s), and between ball time-to-point (whole second integers from 1 to 4 s) and peak commitment probabilities ($\rho = -1$ for velocity = 4 m/s). At higher velocities, the probability that a player will commit to a contest decreases as the relative angle increases. For a velocity of 8 m/s or greater, player's exhibit minimal influence on space in the negative y-axis (i.e., behind their direction of displacement direction). As velocity increases, we also note that the shape of a player's commitment inverts.

Decisions and Alternatives

A total of 2935 passes matched the selection criteria across 60 matches (48.9 ± 14.7 kicks per match). An example decision-making output is visualized in **Figure 3**. In this example, the kicker passes to a teammate positioned toward the boundary line in the defensive 50 m region, while the model identified three higher value passes to teammates positioned toward the center of the field. **Figure 4** presents the components that constitute EO calculations. Summarized characteristics of decisions and alternatives are presented in **Table 2**. The mean of all analyzed variables was lower for decisions compared to alternatives and all differences were statistically significant (refer to **Table 2**).

A very weak correlation was noted between vertical displacement from center and DV of decisions ($\rho = 0.06$). Horizontal displacement from the attacking team's goal is positively correlated with DV ($\rho = 0.56$).

The distributions of decision-making characteristics are presented in **Figure 5**. The distribution of dominance (**Figure 5A**) is bimodal, with peak density for decisions at DOM = 0.54 and a local maximum at DOM = 1.0. This global peak at 0.54 represents a contest between two teams that slightly favors the attacker, while the local maximum at 1.0 represents a kick to an area of absolute dominance. The distribution of alternatives is similarly bimodal, with a greater negative

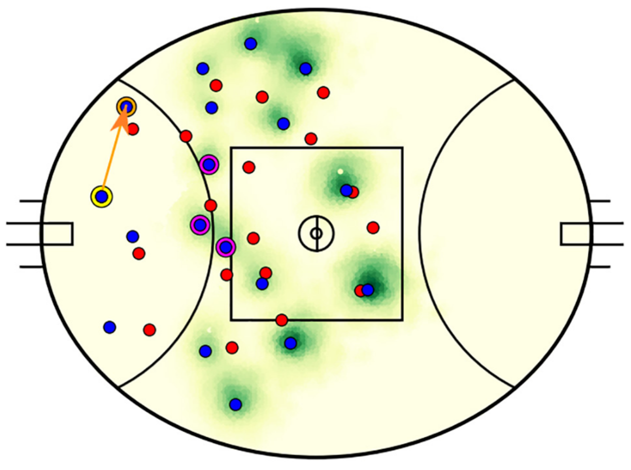

FIGURE 3 | An example output of the decision-making model. The attacking team players are plotted in blue and their opponents in red. The kicker (circled in yellow) executed a pass along the orange line to the receiver (circled in orange). The model identified three higher valued passes (to players circled in magenta) toward the middle of the field that are within a 60 m radius of the kicker. The intensity of green correlates to the expected outcome of passes to each field position.

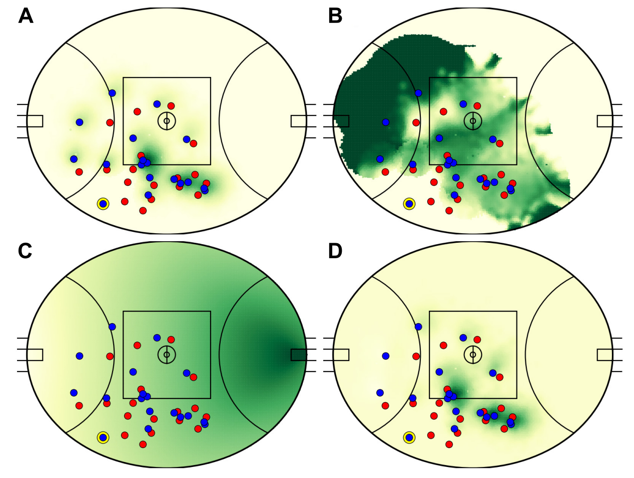

FIGURE 4 | Team influence **(A)**, dominance **(B)**, field equity **(C)**, and resultant expected outcomes **(D)** relative to the player in possession (circled in yellow, toward the lower boundary). High value space is represented as darker green regions. Team influence measures the spatial influence of the attacking team (whose players are in blue), while dominance measures their spatial ownership relative to the opposition (whose players are in red). All values are calculated relative to the player in possession. When complete, the model presented in this paper identifies two high value areas toward the center square, both viable passing options (see **D**).

skew and density around absolute dominance. Influence of decisions (**Figure 5B**) reveals peak density at INF = 0.43, which is comparable to the average peak density of player commitment models (**Figure 2**). Density for risk peaks at 0.25 (**Figure 5C**). The shape of the distributions of EO for decisions and alternatives are different, with decisions exhibiting peak density at EO = 0.14 (**Figure 5D**), and minimal density is noted at EO > 2, while alternatives are noted as having a greater range of EO values, with no notable density peak. DV follows a relatively normal distribution for decisions (**Figure 5E**) and distributions of kicking distance (**Figure 5F**) exhibit opposite skews (decisions are positively skewed, while alternatives negatively). Density of kicking distance for decisions is highest at 17.3 m, marginally longer than the 15 m minimum distance required for a legal mark. Small density peaks at 0.0 are observed for the dominance, influence, and risk of alternatives.

Team-Level Characteristics

The distributions of passing characteristics for two teams are presented in **Figure 6** and the summary statistics in **Table 3**. There was minimal difference in the dominance, influence, risk, and distance of decisions between the two teams. The mean EO and DV for Team B are higher than those of Team A, however no differences were found to be statistically significant. While the shape of variable distributions is similar for both teams, it is noted that Team B exhibits a greater negative skew for EO, DV, and distance variables. Distributions of mean decision-making characteristics for players amongst both teams were found to be similar (**Figure 7**). While the differences between player-level standard deviations were not found to be statistically significant, the distributions for dominance and distance variance display visual differences.

TABLE 2 | Mean values for decision-making variables between decisions and alternatives.

Variable	Decisions	Alternatives
Dominance	0.66 ± 0.23	0.75 ± 0.23
Influence	0.51 ± 0.27	0.63 ± 0.31
Risk	0.33 ± 0.19	0.47 ± 0.21
Expected outcome	0.34 ± 0.46	2.11 ± 1.41
Decision value	0.13 ± 0.42	0.78 ± 0.24
Distance	25.0 ± 11.8	42.7 ± 17.8

Values are presented as Mean ± SD and all differences are statistically significant.

DISCUSSION

This study demonstrates a method for measuring characteristics of player pass decision-making in invasion team sports. Previous studies of player decisions have measured decisions relative to some current measure of possession expectation (e.g., Cervone et al., 2014), rather than relative to the value of alternative passes that were presented. While the former approach assigns value to a specific kick, relative measures of decision-making assign value to individual decisions. Similar to the distinction between player accuracy and shot difficulty (e.g., Chang et al., 2014), assigning value to player decision-making presents greater insights into individual player performance. The adoption of decision-making evaluation in combination with measurements of accuracy and risk would allow for targeted coaching and recruitment, as well as defining categories of player tactical behavior.

The methodology presented in this study has practical applications in performance analysis. Understanding the

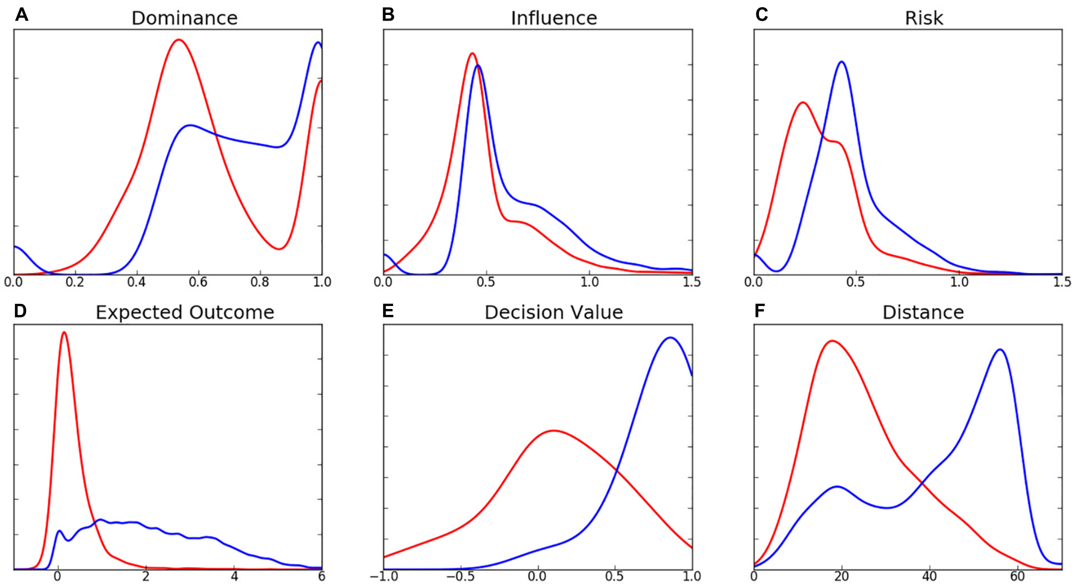

FIGURE 5 | Distribution of **(A)** Dominance, **(B)** Influence, **(C)** Risk, **(D)** Expected Outcome, **(E)** Decision Value, and **(F)** Distance (m) for decisions (red) and alternatives (blue).

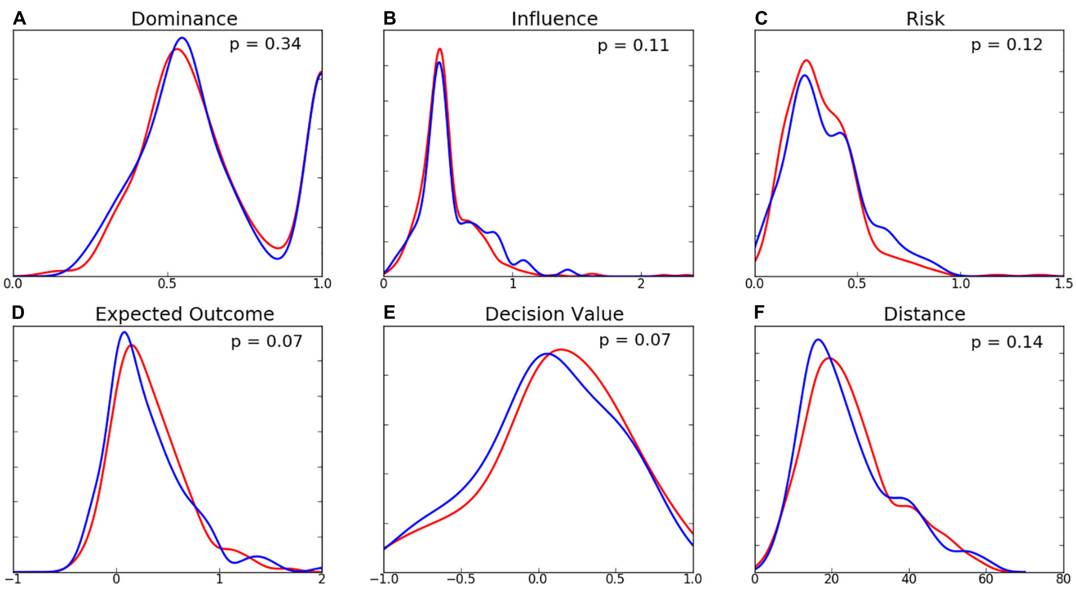

FIGURE 6 | Distribution of team-level **(A)** Dominance, **(B)** Influence, **(C)** Risk, **(D)** Expected Outcome, **(E)** Decision Value, and **(F)** Distance (m) for Team A (blue) and Team B (red). Associated *p*-values (computed using the Mann-Whitney *U*-test) are presented for each variable.

components of player behavior that contribute to their overall performance can be used by sporting teams to target coaching or recruitment practices. For example, understanding if a player has poor execution but good decision-making, or vice versa, provides meaningful insights into said players individual performance. This concept could be explored further in future work by analyzing player decisions in response to match events. It is likely that a player's decision-making abilities vary based on external stimulus such as opposition pressure. Understanding these components of player performance allows for more specific recruitment of player types. For example, should teams tend toward a style of decision-making (i.e., risk aversion), the quantification of player decisions would allow for more informed recruitment.

A major component of the decision-making modeling were player motion models, fit on the weighted distributions of player commitment to contests. While previous studies have developed probabilistic motion models with arbitrary bounds

TABLE 3 | Mean values for decision-making variables between Team A and Team B. *p*-values for differences are presented in **Figure 5**.

Variable	Team A	Team B
Dominance	0.66 ± 0.23	0.66 ± 0.23
Influence	0.52 ± 0.24	0.49 ± 0.24
Risk	0.34 ± 0.19	0.32 ± 0.17
Expected outcome	0.29 ± 0.39	0.34 ± 0.42
Decision value	0.08 ± 0.42	0.13 ± 0.43
Distance	24.3 ± 12.0	24.9 ± 11.6

(Fernandez and Bornn, 2018) or from a player's observed displacements (Brefeld et al., 2018), the commitment modeling approach demonstrated in this study fits player behavior with consideration of movement context, representing a new approach to the measurement of a player's spatial influence. Furthermore, the models are parameterized through the fitting of density in four dimensions (with consideration of a player's velocity, time and x- and y- co-ordinates), presenting a continuous representation of player commitment. A notable finding of the motion models is that commitment peaks are of lower density for higher velocity and time values. That is, players are overall less likely to commit to an upcoming contest if the ball is further away (hence, a high time-to-point) or if they are moving at high velocities. This finding is logical and may be explained by a desire to simply corral an opponent or reposition for future involvements, rather than participate in the immediate transaction. As with alternative motion models, we found that a player's influence in the negative y-axis (i.e., behind them) degrades as their speed increases. While models fit on player commitments more realistically measure their likelihood to occupy future space, the models only consider a player's position and momentum, not teammate locations. A player's participation in a contest logically has some dependence on the position of their teammates, hence attempts to incorporate may produce more realistic models.

A key finding in this study are the novel insights into the decision-making and passing tendencies of Australian Rules footballers. Previous studies have identified the importance of kicking in the AFL (Stewart et al., 2007; Robertson et al., 2016) but there has been minimal work into describing the kicking landscape at elite levels at a transactional level (e.g., distance, level of pressure), despite studies on the biomechanics of kicking in Australian Rules football (e.g., Ball, 2008a,b). This study found that kicks resulting in a mark are most commonly short, with a density peak at 17.3 m (mean = 25 m), marginally longer than the minimum distance required for a legal mark. This could be the result of tactical behavior, or indicative of the ease in which close options can be identified due to lower visual obstruction. Furthermore, successful marks are most often to players in one on one contests or to players who are completely open (as suggested by the bimodal distribution of passing dominance and the density peaks of risk), which may be indicative of risk aversion, however more research is required to understand individual player behavior. These insights into the passing behavior of Australian footballers has practical applications in training practices. A recent study by Robertson et al. (2019) suggested analyzing passing constraints in the AFL to ensure training conditions represent those experienced in a match. The metrics developed in this study are continuous and measured from positional data, hence may provide more objective results than the manually collected passing constraints in Robertson et al. (2019). Understanding the spatial characteristics of passes may allow for coaching staff to prescribe training drills that reflect the spatial pressure experienced by players during match conditions.

In contrast to player decisions, the optimal alternative passes that were identified by the model presented in this study were long distance kicks, less frequently to unmarked individuals. While the distribution of dominance was similarly bimodal for alternatives, the peak at absolute dominance (DOM = 1.0) was less intense than for decisions. The higher density for passes to areas of dominance between 0.5 (a 50/50 contest) and 1.0 suggests kicks to areas in which multiple teammates have an opportunity to receive the ball. This is reinforced by the distribution of influence for alternatives (**Figure 5B**) where more density is noted for influence above 0.5 compared to decisions. Long-range passes having higher associated values (EO and DV) is logical due to the inclusion of AFL field equity, in which the value of space increases as the distance and angle to the goalposts decreases (Jackson, 2016; **Figure 4C**). The contrast in distances between decisions and alternatives (**Figure 5F**) could be due to several factors, such as a difficulty for players to identify long-range options (due to visual obstruction and lower decision-making time, for example) or an underestimation of kicking accuracy by the model. Due to the unavailability of precision ball tracking in AFL, this study used an arbitrary measurement of kicking accuracy. Should more detailed transactional data or LPS ball tracking become available, it is believed that kicking accuracy could be modeled from empirical data. The density peaks at values toward 0 for dominance, influence, and risk can be explained by situations in which all passing options are positioned in areas of negative field equity (e.g., field formations in the defensive 50 m area), resulting in an optimal decision being a kick to an area of no spatial dominance (hence, no negative associated equity). This is a common problem with models that use equity-based rewards, where moving the ball backwards is often associated with a reduction in equity. A further limitation of the equity component used in this study is its lack of consideration for teammate and opponent positions. This metric predates the widespread availability of player tracking information in the AFL, hence only considered possession location and source in its computation (O'Shaughnessy, 2006). An updated metric that considers player locations may improve the accuracy of this decision-making model.

Team level analysis revealed that the less successful team in the 2017/2018 season had higher average DV than the more successful team. Furthermore, while within-team distribution of player averages were similar, the player variance of DV was more positively skewed for the less successful team. Of particular interest is the finding that the less successful team executed passes of higher value, potentially suggestive of a difference in playing styles. Future research into player and team-level

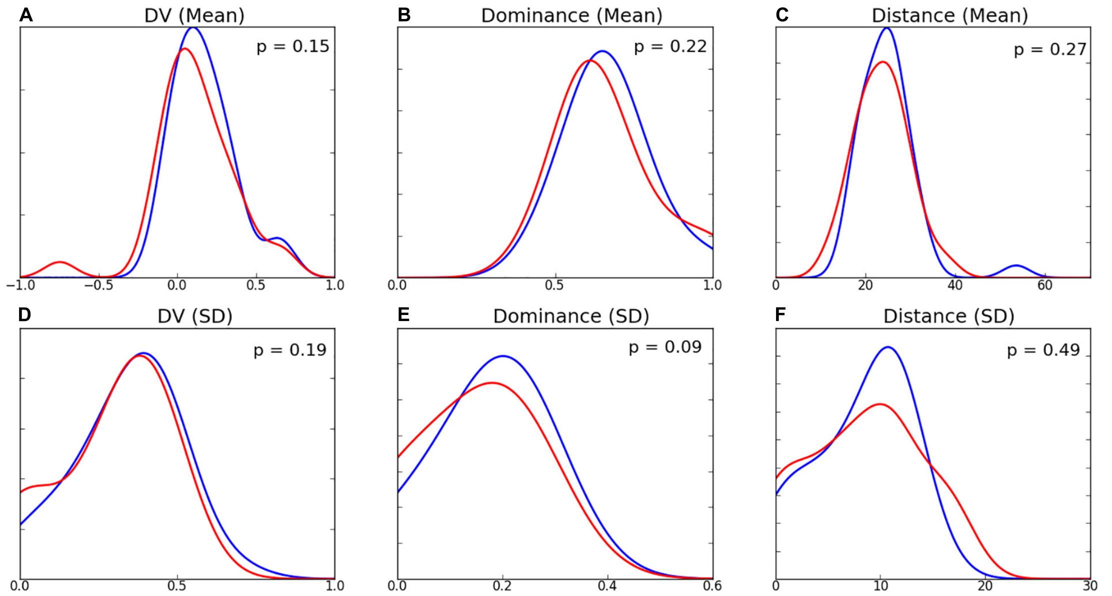

FIGURE 7 | Within-team distributions for decision-making for Team A (blue) and Team B (red). Top row are the distributions for the within-team player means of **(A)** Decision Value, **(B)** Dominance, and **(C)** Distance (m), and the bottom row are the within-team player standard deviations of **(D)** Decision Value, **(E)** Dominance, and **(F)** Distance (m).

decision-making, should consider contextual information such as match conditions, score deficits, and tactical styles.

The tactical behavior of teams has been explored via network behavior, in which the connectivity between players is quantified via the frequency of passing between them in soccer (for examples, see Pena and Touchette, 2012; Gonçalves et al., 2017) and basketball (Fewell et al., 2012). While some of these studies have utilized spatiotemporal datasets (e.g., Gonçalves et al., 2017), this has not been used to measure differences in the spatial characteristics of passes between players. Furthermore, it is possible that the decision-making of links in said passing networks varies – that is, do some players have a tendency to create passing links to teammates of quantitatively lower valued decisions? The quantitative measurement of these links (in terms of DV and EO) may yield insights into the tactical behaviors of teams, as well as the decision-making of individual players. This work could be used to measure a player's perceived skill based on their teammates willingness to execute lower valued or riskier passes to said player.

Despite these differences in the mean and standard deviation of team-level metrics, we note that the differences were not meaningfully different. Compared to the league-wide averages, the greatest differences experienced by either team were of Team A's DV and EO. Given that the decision-making model is developed from league-wide averages, this may suggest that Team A executes passes at a level above the league average. The reward component is fit on the average equity gain, given field location and pressure, hence it is possible that individual team equity gains may have significant variation. Future research into the decision-making of Australian footballers should consider differences in outcomes to identify if there is a difference in the execution of passes between teams. That is, do certain teams outperform the mathematical averages of this decision-making model? At an individual level, this analysis could be used to identify players who are executing passes above the average of their cohort.

CONCLUSION

This work represents the beginning of ongoing research into player decision-making in the AFL. The decoupling of player decision-making from overall player performance allows for a more precise understanding of player ability that has applications in coaching and scouting. Underlying the decision-making model is a player motion model fit on the combined distributions of relative contest locations that were committed to, and those that were not. The resulting motion model quantifies the probability that a player would commit to a contest, given their velocity, displacement direction, and past behaviors. It was found that player commitment decreases as a function of velocity and available time, offering insights into the commitment behavior of players. Analysis of passes revealed that players typically execute short kicks that are most commonly to teammates in one-on-one or unmarked situations, resulting in a bimodal distribution of passing dominance. Conversely, the mathematical model presented in this paper identifies long-range options as having higher expected value, given the inclusion of field equity which rewards possession closer to the goalposts. This mismatch indecisions could be due to the ease in which short-range options can be identified and executed compared to long-range options. Differences in decision-making variables between two analyzed teams suggests a need for expanded datasets and research into player decision-making with consideration of match context.

ETHICS STATEMENT

Players provided their data and written and informed consent to the commercial provider as part of their collective bargaining agreement. Ethical approval for this study was granted by Victoria University's Human Research Ethics Committee (VU HREC 24514).

AUTHOR CONTRIBUTIONS

BS, KJ, and SR: conceptualization. BS and KJ: methodology. TB: data extraction. BS and TB: data cleaning. BS: data analysis and visualization. BS and SR: writing. BS, SR, KJ, and TB: drafting.

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REFERENCES

Ball, K. (2008a). Biomechanical considerations of distance kicking in Australian rules football. *Sports Biomech.* 7, 10–23. doi: 10.1080/14763140701683015

Ball, K. (2008b). "Foot interaction during kicking in Australian rules football," in *Science and Football VI*, eds T. Reilly and F. Korkusuz (Abingdon: Routledge), 62–66.

Ball, K. (2008c). "Use of weighted balls for improving kicking for distance," in *Science and Football VI*, eds T. Reilly, F. Korkusuz (Abington: Routledge), 285.

Brefeld, U., Lasek, J., and Mair, S. (2018). Probabilistic movement models and zones of control. *Mach. Learn.* 108, 127–147. doi: 10.1007/s10994-018-5725-1

Cervone, D., D'Amour, A., Bornn, L., and Goldsberry, K. (2014). "POINTWISE: predicting points and valuing decisions in real time with NBA optical tracking data," in *Proceedings of the 8th MIT Sloan Sports Analytics Conference*, Vol. 28, (Boston, MA), 3.

Cervone, D., D'Amour, A., Bornn, L., and Goldsberry, K. (2016). A multiresolution stochastic process model for predicting basketball possession outcomes. *J. Am. Statist. Assoc.* 111, 585–599. doi: 10.1080/01621459.2016.1141685

Chang, Y. H., Maheswaran, R., Su, J., Kwok, S., Levy, T., Wexler, A., et al. (2014). "Quantifying shot quality in the NBA," in *Proceedings of the 8th Annual MIT Sloan Sports Analytics Conference*, (Boston, MA: MIT).

Fernandez, J., and Bornn, L. (2018). "Wide open spaces: a statistical technique for measuring space creation in professional soccer," in *Proceedings of the Sloan Sports Analytics Conference*, (Boston, MA).

Fewell, J. H., Armbruster, D., Ingraham, J., Petersen, A., and Waters, J. S. (2012). Basketball teams as strategic networks. *PLoS One* 7:e47445. doi: 10.1371/journal.pone.0047445

Fonseca, S., Milho, J., Travassos, B., and Araújo, D. (2012). Spatial dynamics of team sports exposed by voronoi diagrams. *Hum. Mov. Sci.* 31, 1652–1659. doi: 10.1016/j.humov.2012.04.006

Fujimura, A., and Sugihara, K. (2005). Geometric analysis and quantitative evaluation of sport teamwork. *Syst. Comput. Jpn.* 36, 49–58. doi: 10.1002/scj.20254

Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jiménez, S., and Sampaio, J. (2017). Exploring team passing networks and player movement dynamics in youth association football. *PLoS One* 12:e0171156. doi: 10.1371/journal.pone.0171156

Gudmundsson, J., and Wolle, T. (2014). Football analysis using spatio-temporal tools. *Comput. Environ. Urban Syst.* 47, 16–27. doi: 10.1016/j.compenvurbsys.2013.09.004

Horton, M., Gudmundsson, J., Chawla, S., and Estephan, J. (2015). "Automated classification of passing in football," in *Pacific-Asia Conference on Knowledge Discovery and Data Mining*, eds T. Cao, et al. (Cham: Springer), 319–330. doi: 10.1007/978-3-319-18032-8_25

Jackson, K. (2016). *Assessing Player Performance in Australian Football Using Spatial Data*. Melbourne: Swinburne University of Technology.

Jones, E., Oliphant, T., and Peterson, P. (2014). *{SciPy}: Open Source Scientific Tools for {Python}*. Available at: http://www.scipy.org/ [accessed July 19, 2019]

Mann, H. B., and Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Stat.* 18, 50–60. doi: 10.1214/aoms/1177730491

O'Shaughnessy, D. M. (2006). Possession versus position: strategic evaluation in AFL. *J. Sports Sci. Med.* 5, 533–540.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., and Thirion, B. (2011). Scikit-learn: machine learning in python. *J. Mach. Learn. Res.* 12, 2825–2830.

Pena, J. L., and Touchette, H. (2012). A network theory analysis of football strategies. *arXiv*

Power, P., Ruiz, H., Wei, X., and Lucey, P. (2017). "Not all passes are created equal: Objectively measuring the risk and reward of passes in soccer from tracking data," in *Proceedings of the 23rd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, (New York, NY: ACM).

Robertson, S., Back, N., and Bartlett, J. D. (2016). Explaining match outcome in elite Australian rules football using team performance indicators. *J. Sports Sci.* 34, 637–644. doi: 10.1080/02640414.2015.1066026

Robertson, S., Spencer, B., Back, N., and Farrow, D. (2019). A rule induction framework for the determination of representative learning design in skilled performance. *J. Sports Sci.* 37, 1280–1285. doi: 10.1080/02640414.2018.1555905

Silverman, B. W. (1986). *Density Estimation for Statistics and Data Analysis*. London: Chapman & Hall.

Spencer, B., Bedin, T., Farrow, D., and Jackson, K. (2018). "A method for evaluating player decision-making in the Australian football league," in *Proceedings of 14th Australasian Conference on Mathematics and Computers in Sport*, (Sippy Downs, QLD: University of the Sunshine Coast), 7–12.

Spencer, B., Morgan, S., Zeleznikow, J., and Robertson, S. (2017). "Measuring player density in australian rules football using gaussian mixture models," in *Proceedings of the Complex Systems in Sport, International Congress Linking Theory and Practice*, 172–174.

Stewart, M., Mitchell, H., and Stavros, C. (2007). Moneyball applied: econometrics and the identification and recruitment of elite Australian footballers. *Int. J. Sports Financ.* 2, 231–248.

Szczepański, Ł, and McHale, I. (2016). Beyond completion rate: evaluating the passing ability of footballers. *J. Royal Stats. Soc.* 179, 513–533. doi: 10.1111/rssa.12115

Taki, T., and Hasegawa, J. I. (2000). "Visualization of dominant region in team games and its application to teamwork analysis," in *Proceedings Computer Graphics International 2000*, (Geneva: IEEE), 227.

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ORIGINAL RESEARCH
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Effects of Temporary Numerical Imbalances on Collective Exploratory Behavior of Young and Professional Football Players

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The aim of this study was to explore how the use of temporary numerical imbalances during small-sided Game SSGs affects team's exploratory behaviors (i.e., variety and quantity of responses given in an ever-changing game context and its rate of change) in different age groups. Two different age groups (under−15 and under−23) of football players participated in the study. For each age group, three teams of five players played six small-sided games of 5 min duration in different conditions: (i) numerical balance (GK + 4 vs. 4 + GK); (ii) temporary numerical imbalance, which consisted of a numerical change of teammates and opponents every one minute. Latitude and longitude GPS coordinates were used to determine the positioning-derived variables. The dynamic overlap (i.e. the measure of average similarity of the game patterns that take place in increasingly larger time intervals) was used to provide information of the rate and breadth of exploratory behavior. The results revealed that the long-term exploratory breadth increased for the under−23 age group. Non-clear effects were found for the short-term rate of exploration, but with an increasing trend. In the under−15 group, the exploratory behavior was more likely to increase in the long term. The increase for the short-term rate of exploration was unclear, but it follows an increasing trend. These results suggest that the use of temporary numerical imbalances could offer coaches more dynamic training situations and different adaptive training environments similar to matches.

Keywords: tactical behavior, small-sided games, dynamic overlap, complex systems, state space

INTRODUCTION

During a game of a team sport, different dynamic interpersonal coordination movements arise between the players and the environment. These team coordination movements can be captured from positioning-derived variables (i.e., from GPS/LPS or optical technology) that describe the coordinative patterns of a team in response to the set of game constraints (Ric et al., 2016). The most frequent team-related variables, resulting from the dynamic player's positional data, used to reveal the tactical pattern of a football team and to define its tactical behavior and exploratory behavior are: player's positioning in sectors and corridors of the field (Travassos et al., 2014), geometrical center of the team (Duarte et al., 2012), geometrical center of the team's sectors (Gonçalves et al., 2013), team width and length (Frencken et al., 2011; Folgado et al., 2012) and spread rate, that is, the speed of change of the stretch index (STI) (Bourbousson et al., 2010). The STI is a tactical metric related to the spaces of play, which tries to understand the defensive principle of contraction (concentration of players) and the offensive principle of expansion (width and length), in the longitudinal and lateral axes that take place during a match or small-sided Game (SSG) due to the collective tactical behavior of the players of a team (Bourbousson et al., 2010; Clemente et al., 2013). These positioning-derived variables can be used to reveal the effect of relevant constraints on collective tactical behaviors during full and SSGs (Duarte et al., 2013; Gonçalves et al., 2016b).

A major aspect for the observation of game play is the configuration of play approach and its ever-changing shape, particularly via periods of contraction and expansion, and its dynamical position on the field (Gréhaigne and Godbout, 2014; Gonçalves et al., 2018). These game situations seem to be in symbiosis and one succeeds the other. It can help players to elucidate and anticipate the movement in the game and take right decisions (Gréhaigne and Godbout, 2014). In this sense, it seems reasonable to think that as found by Bourbousson et al. (2010) the STI of each team will present a bi-stable attraction in the longitudinal direction (while one team is in open space play in the opponent field the opponent team is in retreat close to their goal). The combination of two or more of these team variables would allow us to depict the state space of a team, where the high values define unstable coordinative states while the minimum values define highly stable coordinative states (Ric et al., 2017). For example, the STI and the distance of the centroid to the own goal (DCG) determine a pattern of interaction between two confronted teams (Gréhaigne and Godbout, 2014).

Exploratory behavior has been defined as a "subsequent realization of a large number of movement configurations which reveals the hierarchical action landscape under specific constraints of each performer" (Hristovski et al., 2011, p. 187) or team. Exploratory practice of unusual training environments may promote a varied and flexible behavior, so that performers learn to be more adaptive and, at the same time, more creative (Santos et al., 2018). Consequently, exploratory behavior seems to be important in collective sports because they are based on the improvisation and interaction between performers within the changing environment (Hristovski et al., 2012) and because it offers discovery of perception action solutions to the emergent tasks. There are some actions that are more likely to be repeated than others under the players/team and environmental interaction. In football, for example, this could be achieved by manipulating key tasks to direct the search of the apprentices so that they find effective coordination solutions (Davids et al., 2005), whether individual or collective. Thanks to the manipulation of tasks by the coach, the performers are encouraged to discover the answer to a task for themselves, without the need for the performer to receive instructions, orders or an exact list of those things that must be done (Hristovski et al., 2011).

In recent years, many studies have shown how the manipulation of constraints in SSGs can cause changes in individual and collective tactical behavior (Ometto et al., 2018). SSGs are specific format training tasks with the goal of reducing interactions and increasing the proportion of players who participate in the decision-making process, but keeping basic variability properties from the game (Aguiar et al., 2012; Davids et al., 2013). They are often adopted as a training drill used by coaches of different team sports, but the research into SSGs has focused particularly on football (Folgado et al., 2018; Coutinho et al., 2019), and to a lesser extent on basketball (Sansone et al., 2018), rugby (Vaz et al., 2019), futsal (Assunção et al., 2019) and handball (Iacono et al., 2015). These kind of games often simulate sub-phases of full-sided games preserving their unstable, dynamic and unpredictable nature (Hristovski et al., 2013; Gonçalves et al., 2016a; Ric et al., 2016) and they often reproduce the physical, technical and tactical (Bach Padilha et al., 2017) requirements of real match play (Aguiar et al., 2012). In order to replicate these demands in practice, various task constraints are manipulated by coaches, such as the pitch size and shape, the encouragement of the coach, the number of players involved in each team (Silva et al., 2014), the specific rules of the game, the duration of the game and rest periods, the available balls or the method by which players can score points (Hill-Haas et al., 2011). To describe the movements made by athletes during competition (Castellano and Casamichana, 2014) or to monitor different training tasks (Aughey, 2011), collective sports have applied the use of GPS technology (Castellano and Casamichana, 2014). Positional data has also allowed it to be demonstrated that during a football match, local and temporary numerical imbalances appear (Vilar et al., 2013). The numerical imbalances have been widely studied in recent years (Sampaio et al., 2014; Gonçalves et al., 2016b; Torrents et al., 2016). However, no research has evaluated the effects of the temporary manipulation of constraints during training. To train this kind of situation, coaches make use of numerical imbalances or joker players in SSGs (Ric et al., 2015), which are extra players placed internally or externally to the playing space, who can be fixed during the whole of the training drill or temporary. Their role is important insofar as it constrains the game by forcing the other players to adapt to the new game contexts (Ric et al., 2015).

To our knowledge, no research has evaluated the effects of temporary numerical imbalances on team exploratory behavior, as suggested by Ric et al. (2015, 2016). Thus, the aim of this study was to explore how the use of temporary numerical imbalances in SSGs affects the exploratory breadth of a team in different age categories.

MATERIALS AND METHODS

Participants

The participants in the study were 30 male football players, of which 15 of them were under the age of 23 years old (age: 19.9 ± 1.6 years) and the other 15 were under the age of 15 years old (age: 13.8 ± 0.4 years). Each age groups were homogenous because they played in the same team and category (Under 23 group: Spanish 3rd division; under 15 group: División de Honor, top level of the Spanish football league system of that age). An informed and written consent was obtained from all adult participants and from the parents/legal guardians of all non-adult participants, before the beginning of the study. All participants were notified that they could withdraw from the study at any time. The investigation was approved by the local institutional Research Ethics Committee (CEIC Hospital Universitari Arnau de Vilanova) and it conformed to the recommendations of the Declaration of Helsinki.

Procedure

For each age group, three teams (A, B and C) of five football players (four outfielders and a goalkeeper) played six SSGs games against each other (first, A vs. B; secondly A vs. C; and finally B vs. C) in two different SSG formats: balanced and imbalanced. Balanced SSG consisted of a fixed number of opponents (GK + 4 vs. 4 + GK) during the whole 5 min game. Imbalanced SSG consisted of numerical change of opponents and teammates every minute after the first minute, as follows: minute one: 4 vs. 4; minute two: 5 vs. 4; minute three: 4 vs. 5; minute four: 6 vs. 4; and minute five: 4 vs. 6. The three teams were distributed taking into account several factors according to the coach's criteria, to ensure that the team's performances were comparable (Aguiar et al., 2013). To ensure an equal distribution of players based on the team positions, teams and the changes of players were made under the coach criteria. All SSG were played on a natural pitch measuring 40 × 45 m, and in accordance with the official rules of soccer, with three exceptions to allow continuous spontaneous interactions between teammates and opponents (Davids et al., 2013; Torrents et al., 2016): first, there was no off-side; second, when a team scored, the same team kept the ball and restarted the game with a goal kick; third, when a ball was thrown out of the field limits, the game was restarted with a goal kick by the goalkeeper of the opposing team. These three actions were taken because they are usual in football training and to increase the effective playing time. In order to maintain the rhythm of play and avoid the influence of fatigue, each game involved 5-min periods of play separated by 3-min of passive rest (**Table 1**). The current study should acknowledge the limitation that no data related to fatigue was collected. To increase the effective playing time, the non-playing footballers and coaches were placed next to the goal to supply a ball whenever the game needed to be restarted.

TABLE 1 | Data analysis for the SSG scenarios (Balanced and Imbalanced SSG) considering the variation in the number of opponents and teammates in the Temporary Numerical Imbalanced SSG.

Time	Min 1	Min 2	Min 3	Min 4	Min 5
Numerical balance	4 vs. 4	4 vs. 4	4 vs. 4	4 vs. 4	4 vs. 4
Temporary numerical imbalance	4 vs. 4	5 vs. 4	4 vs. 5	6 vs. 4	4 vs. 6

Data Collection

Data were gathered through the use of a 5 Hz non-differential global positioning system (SPI ProX, GPSports, Canberra, ACT, Australia). The team-related variables used were: location of team geometrical centroid in the sectors and corridors of the field, the centroid speed, the team length and width, and the spread rate (**Table 2**). To define the field sectors and corridors we divided the field in six parts, from back to front and from right to left, respectively (Fradua et al., 2013). The team length is the distance between the most backward and the most forward player (*x*-coordinate) and the team width is the distance between the most lateral players on each side of the field (*y*-coordinate) (Frencken et al., 2011; Folgado et al., 2014; Frias and Duarte, 2015; Castellano et al., 2016). The spread rate is the velocity of contraction or expansion and was calculated by differentiating each STI data point of the time series to the following one. All these variables were determined using latitude and longitude coordinates exported from the GPS units and computed using dedicated routines in Matlab®(MathWorks, Inc., MA, United States) (see the guidelines suggested by Folgado et al., 2014).

A two-step cluster analysis was performed to determine the boundary values of each positioning-derived variable (Ric et al., 2016). The data collected for each team produced configuration states derived from the 36 categories belonging to the six variables named above. Teams changed their states during the 5-min game, so in total each game gathered 1500 vectors of data. Every vector was defined as a 36-component binary vector representing the full configuration state, attributing a value of 1 for active categories and 0 for the inactive ones. This enabled the formation of a 36 × 1500 multivariate binary (Boolean) matrix.

Two other variables, the STI and the distance from the centroid to the goal, allowed us to depict the potential landscape of team behavior. The STI was calculated by computing the mean distance of each team member from the spatial center for that team (Bourbousson et al., 2010; Frias and Duarte, 2015). The centroid is the geometric center of the average positions of the outfield players from a team (Frencken et al., 2011, 2012; Clemente et al., 2013; Folgado et al., 2014; Aguiar et al., 2015; Rein and Memmert, 2016). These two variables were used to capture and provide relevant information about collective organization of teams.

Data Analysis

The dynamic overlap was computed to determine the dynamic properties of the game by defining these dynamics of either short or long-term exploration of player's movement patterns (Ric et al., 2016). Therefore, it informs about the rate and breadth of the exploratory behavior during the game at different time-scales (Torrents et al., 2015). The dynamic overlap $< q_d(t) >$ was calculated as an average cosine auto-similarity between configurations for increasing time lag (Hristovski et al., 2013).

TABLE 2 | Data collected to assess the tactical pattern of each team, formed by 36 categories.

VARIABLE	CATEGORIES
Sector (from right – 1 to left – 6)	0–7.5 m
	7.5–15 m
	15–22.5 m
	22.5–30 m
	30–37.5 m
	37.5–45 m
Corridor (from back – 1 to front – 6)	0–6.66 m
	6.66–13.33 m
	13.33–20 m
	20–26.66 m
	26.66–33.33 m
	33.33–40 m
Centroid Speed (m/s)	<−2
	−2 to −1
	−1 to 0
	0 to 1
	1 to 2
	>2
Team Length (m)	<4
	4 to 8
	8 to 12
	12 to 16
	16 to 20
	>20
Team Width (m)	<12
	12 to 16
	16 to 20
	20 to 24
	24 to 28
	>28
Speed of Spread Rate (m/s)	<−1
	−1 to −0.5
	0.5 to 0
	0 to 0.5
	0.5 to 1
	>1

The mean dynamic overlap was fitted by the following equation, which is derived for systems with an intricate hierarchical structure (Sibani and Dall, 2003):

$$\langle q_d(t)\rangle = (1-q_{stat})\, t^{-\alpha} + q_{stat}$$

Where $< q_d(t) >$ is the known mean dynamic overlap, q_{stat} is the asymptotic value of the dynamic overlap (horizontal line of the curve which tends to infinity), t is the time lag, and α is the dynamic exponent (slope of the curve). q_{stat} detects the exploratory breadth of the team, and α the rate of exploration. Hence, the average dynamic overlap $< q_d(t) >$, captures both the short- and long-term exploratory behavior of teams through the values of parameters α and q_{stat}, respectively.

The combination of the distance from the team geometrical centroid to the own goal and the STI allowed us to define the state space of the teams for each condition and age group. Time series of both variables were divided in twenty clusters each allowing us to define a total of 400 configuration states. To determine each configuration state, the time series were clustered from the minimum distance from the centroid to the own goal (<8 m) to the maximum (>34 m) with a range of two meters, and one meter for the stretch index, from the minimum value (<4 m) to the maximum (>12 m). Probabilities of each configuration state were calculated by dividing the frequency of occurrence of each configuration (n_i) by the total frequencies ($\rho_i = n_i/N$). The potential of each configuration state was calculated by the following equation (Balescu, 1975):

$$V_i = Qln\left(\rho_i/_N\right)$$

Where Q is the standardized variance of the system assuming that noise is constant ($Q = 1$), and N is the total number of configurations.

Statistical Analysis

Magnitude-based inferences and precision of estimation were applied to the inferential analysis due to the low sample (Batterham and Hopkins, 2006). Before the comparison of conditions (numerical balanced vs. temporary numerical imbalanced), all processed variables were log-transformed to reduce the bias from no uniformity of error. The variables used for the comparisons were the sector and corridor where the centroid was located (both from one to six), the speed of the centroid (m/s), the team length (m) and width (m), and the speed of spread rate (m/s). A descriptive analysis was performed using mean and standard deviations for each variable. Differences in means between scenarios were expressed in percentage units with 90% confidence limits (CL). The effect was reported as unclear if the CL overlapped the thresholds for smallest worthwhile changes, which were computed from the standardized units multiplied by 0.2. Magnitudes of clear effects were described according to the following scale: 25–75%, possibly; 75–95%, likely; 95–99%, very likely; > 99%, most likely (Hopkins et al., 2009). Also, the within-scenarios comparisons were assessed via standardized Cohen differences and respective 90% CL. Thresholds for effect sizes statistics were: 0.2, trivial; 0.6, small; 1.2, moderate; 2.0, large; > 2.0, very large (Hopkins et al., 2009).

RESULTS

Table 3 shows the results of α and q_{stat} values for numerical balanced and temporary numerical imbalanced conditions for each group of age and SSG condition. For the under−23 age group, the average value of q_{stat} most likely decreased (difference in means,%; ± 90% CL: −12.8; ± 2.7%) by using temporary numerical imbalances (0.24 ± 0.01). The effect size was very large (−2.32; ± 0.52) confirming the increase in the exploratory breadth. The rate of exploration (α) showed unclear effects for both situations. For the under−15 age group, the average value of q_{stat} unclearly decreased (−7.3; ± 14,8%) by using temporary numerical imbalances from a balanced situation. The rate of exploration (α) reported that its average value would be likely

TABLE 3 | Results of q_{stat} and α values for numerical balanced and temporary numerical imbalanced conditions for each age group.

Age group	Variable	Numerical Balance	Temporary Numerical Imbalance	Difference in means (%; ± 90%CL)	Chances for smaller/similar/ greater	Uncertainty in the true differences	Standardized Cohen's d (%; ± 90%CL)
U23 (n = 6)	q_{stat}	0.275 ± 0.013	0.239 ± 0.013	−12.8; ± 2.7	100/0/0	most likely ↓	−2.32; ± 0.52
	α	0.109 ± 0.011	0.106 ± 0.007	−2.3; ± 11.4	54/21/25	unclear	−0.22; ± 1.10
U15 (n = 6)	q_{stat}	0.285 ± 0.048	0.264 ± 0.037	−7.3; ± 14.8	71/16/12	unclear	−0.45; ± 0.95
	α	0.109 ± 0.018	0.101 ± 0.013	−6.4; ± 4.8	88/11/1	likely ↓	−0.35; ± 0.27

U, Under; CL, confidence limits; ↑, increase; ↓, decrease.

reduced (−6.4; ± 4.8%) from a numerical balanced situation to a temporary numerical imbalanced situation, with a small effect size (−0.35; ± 0.27).

The relationship between the STI and the DCG is represented in **Figure 1**. The green shaded areas represent the attractive tactical behavior when relating STI and DCG, corresponding to the probability of their occurrence. The darker areas depicted in red are areas that can only be reached when the system is heavily destabilized. The pattern of a team will change depending on both the age of the players and the use of temporary numerical imbalances.

In accordance with these results, potential landscapes of both age categories showed that the use of extra players each minute create a wider basin of attraction allowing them to explore a greater number of tactical behaviors (**Figure 1**).

Related to a specific team behavior, these potential landscapes inform of the mid-field, which is closer to its own goal in the under−15 age group than in the under−23 age group. In other words, it seems that the under−23 players are able to keep their opponents further from their own goal. On the opponent's mid-field, the same occurs in both age categories: the under−23 players cannot get as close to the opponent's goal as the under−15 players.

DISCUSSION

This study shows that the manipulation of the number of teammates and opponents at 1-min intervals promoted, in the under−15 years of age category, a slight increase in the exploratory behavior in both short- and long-term exploration breadth; while in the under−23 years of age category, the same constraint promoted an unclear increase in the short-term exploration, and a very large increase in the long-term.

By using extra players that enter and leave a game over 60 s, new environments (training tasks) were created over shorter timescales allowing teams to quickly explore all their available state space (i.e., whole set of possible configuration of play). In that sense, it has been demonstrated that teams are able to adapt their behavior to perturbations of the environment (McGarry et al., 2002). Specifically, to real changing-game constraints in terms of local (interaction of few players) and temporary (manipulation of numerical task conditions on a shorter timescale) constraints (Vilar et al., 2013). Although in the present study the results did not show clear effects for the under−15 age group, professional teams increased their collective exploration.

According to these results, and in line with the suggestions of Ric et al. (2016), the use of temporary numerical imbalances in SSG seems to be justified if the objective of the coach is to promote a quick exploration of the whole variety of team behaviors. However, one must keep in mind that the age of the players can affect the exploration of the whole possibilities of action of the team (Almeida et al., 2016). Torrents et al. (2016) suggested that the easier a game situation is, the more regular and less varied play is promoted, and vice versa, the more difficult a scenario is, the more possible it is for the players to explore tactical actions to perform until a limit (too difficult scenarios would also promote a regular and less varied play). In line with this comment, we can consider that the temporary numerical imbalance situation carried out in the present study is a more difficult scenario for the players than a stable one, in terms of perception of the environment and when relating with varying numbers of teammates and opponents. It would explain why the exploratory behaviors are enhanced. In line with this, Vilar et al. (2014) concluded in a study where they examined the effects of the variation of the number of players involved in football SSGs on different individual actions, that these variabilities in the number of teammates and opponents are learning environments that will allow players a major transferability from one situation (training) to another (real match), and help them to perceive better the information sources and perform better according to their capabilities. Furthermore, these imbalances may promote different collective actions such as the reduction of the team area of play when in inferiority or less commitment in maintaining a pre-structured strategical behavior when playing in superiority conditions (Sampaio et al., 2014), offering the coaches an applicable approach to regulate the players perception under certain conditions (Vilar et al., 2014).

Taking into account the results of the potential landscapes, in which seems to exist a pressure exerted by the teams in order not to allow the opponent to get close to their own goal, we generated an hypothesis from the results of Bourbousson et al. (2010) which consisted of finding two main configurations of play, one of these configurations consisted of a compact team when located in its own mid-field, while the other configuration consisted of an expanded team in the opponent's mid-field. Although our results do not concur with the Bourbousson et al. (2010) results, they are closer to the Moura et al. (2016) findings, which detected that when one team expands, the other team also does so, and vice versa.

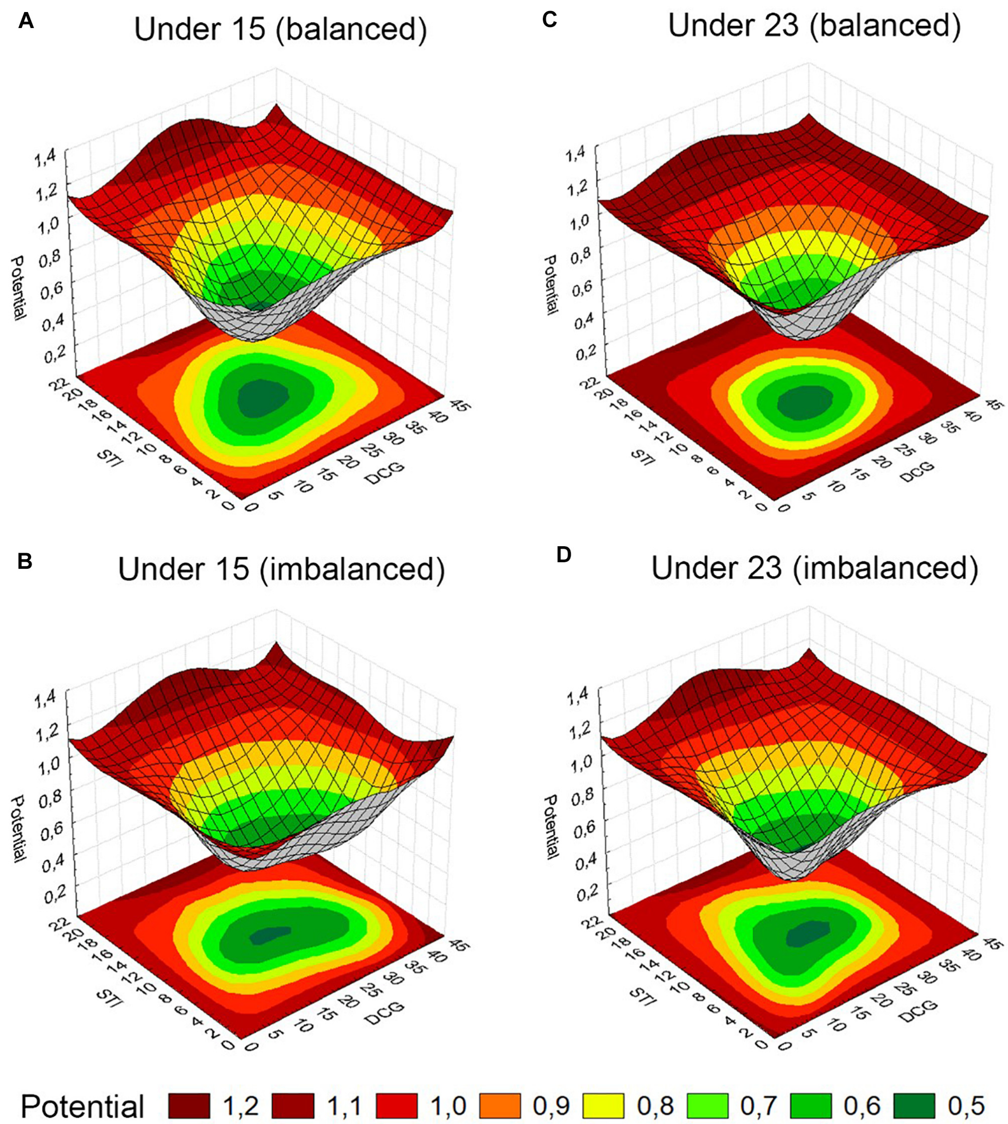

FIGURE 1 | Attractiveness regions for team stretch index-distance from the centroid to the own goal under **(A)** under–15 years old balanced game, **(B)** under–15 years old in temporary numerical imbalanced game, **(C)** under–23 years old balanced game, **(D)** under–23 years old in temporary numerical imbalanced game. The 3D deeper wells correspond to 2D-projected more attractive (i.e., more probable) areas.

Therefore, the use of this type of task constraint implies on the one hand changing the patterns of tactical behavior and the exploratory dynamics of the players by experiencing dynamic training situations that simulate the intrinsic variability of the competitive environment (Pinder et al., 2012; Davids et al., 2013; Ric et al., 2015; Torrents et al., 2015) and, therefore, allow the player to better solve those imbalanced situations that locally take place during a real game (Vilar et al., 2013). On the other hand, it reveals the differentiated decision-making abilities that performers are constrained to develop under varying conditions (Ric et al., 2016).

It would be interesting to carry out future research that continues to investigate the use of temporary numerical imbalances during SSGs to see how they affect the exploratory behavior of athletes in general and football players in particular and, if possible, comparing different age groups in order to help as many coaches as possible to create new training tasks that help them improve both the performance of their teams and their players. A concrete proposal is to perform different balanced and dynamic imbalanced training tasks in different age categories, but varying not only the number of players but also the field size to see how it modifies the tactical structure and the exploratory behavior of a team with the aim of elucidating which tasks are more prone to favor these two given variables. By creating tasks and generating different sub-tasks with different time constraints, these sub-tasks could be compared in different age categories to verify when the stationary state is achieved for each group of age. This would help coaches to choose more suitable tasks to favor the exploratory behavior of a team. Another future proposal is to compare how these time, size or numerical imbalance constraints affect different teams with different skill levels.

CONCLUSION

The use of temporary numerical imbalances at 1-min intervals promotes the exploratory behavior of football players. However, it occurs differently depending on the age of the players. Accordingly, higher values were found in the short-term exploratory breadth in the under−15 years of age category, while in the long-term exploratory breadth happened the opposite. Considering that imbalances appear in different zones of the field at different moments, we suggest to create and implement such training tasks for its representativeness of real game. Moreover, taking into account that it is a task that both, promotes the exploratory behavior and it's representative of what happens in a real match, it would be interesting to carry out this kind of activity in a learning context to guide learners to experience more game contexts that can later happen in the game. Thus, the findings of this study suggest that the use of temporary numerical imbalances will be useful for football players to perform more varied situations similar to real game. In this sense, we propose to perform future research in which other age categories and inter-team number imbalances are taken into account. Additionally, it would be of interest to know as to whether throughout the 1-min time epochs, there were varying expressions of the six variables investigated at different time periods (i.e., did a period of adjustment exist as players re-familiarized with having a numerical advantage or disadvantage?) by considering the variables as time series.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

All participants were informed about the research procedures; players under the age of 23 years old provided prior informed consent, while for the players under the age of 15 the prior informed consent was provided by a parent or a legally authorized representative. The local Institutional Research Ethics Committee approved the study, which also conformed to the recommendations of the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

AC worked on the design of the study, collection, analysis, and interpretation of the data, and drafting of the manuscript. CT participated in the conceptualization and design of the study, and reviewed the content of the manuscript. AR participated in the conceptualization and design of the study, data collection, and reviewed the content of the manuscript. BG worked on the data collection and reviewed the content of the manuscript. JS reviewed the content of the manuscript. RH conceived the approach to data analysis, data interpretation, and drafting of the manuscript. All authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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REFERENCES

Aguiar, M., Botelho, G., Gonçalves, B., and Sampaio, J. (2013). Physiological responses and activity profiles of football small-sided games. *J. Strength Cond. Res.* 27, 1287–1294. doi: 10.1519/JSC.0b013e318267a35c

Aguiar, M., Botelho, G., Lago, C., Maças, V., and Sampaio, J. (2012). A review on the effects of soccer small-sided games. *J. Hum. Kinet.* 33, 103–113. doi: 10.2478/v10078-012-0049-x

Aguiar, M., Gonçalves, B., Botelho, G., Lemmink, K., and Sampaio, J. (2015). Footballers' movement behaviour during 2-, 3-, 4- and 5-a-side small-sided games. *J. Sports Sci.* 33, 1259–1266. doi: 10.1080/02640414.2015.1022571

Almeida, C. H., Duarte, R., Volossovitch, A., and Ferreira, A. P. (2016). Scoring mode and age-related effects on youth soccer teams' defensive performance during small-sided games. *J. Sports Sci.* 34, 1355–1362. doi: 10.1080/02640414.2016.1150602

Assunção, J. A., Coutinho, D., and Travassos, B. (2019). Pitch-size constraint in futsal learning. *Motricidade* 15, 140–140.

Aughey, R. J. (2011). Applications of GPS technologies to field sports. *Int. J. Sports Physiol. Perform.* 6, 295–310. doi: 10.1123/ijspp.6.3.295

Bach Padilha, M., Guilherme, J., Serra-Olivares, J., Roca, A., and Teoldo, I. (2017). The influence of floaters on players' tactical behaviour in small-sided and conditioned soccer games. *Int. J. Perform. Anal. Sport* 17, 721–736. doi: 10.1080/24748668.2017.1390723

Balescu, R. (1975). *Equilibrium and Nonequilibrium Statistical Mechanics*. New York, NY: John Wiley & Sons.

Batterham, A. M., and Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *Int. J. Sports Physiol. Perform.* 1, 50–57. doi: 10.1123/ijspp.1.1.50

Bourbousson, J., Sève, C., and McGarry, T. (2010). Space-time coordination dynamics in basketball: part 2. The interaction between the two teams. *J. Sports Sci.* 28, 349–358. doi: 10.1080/02640410903503640

Castellano, J., and Casamichana, D. (2014). Deporte con dispositivos de posicionamiento global (GPS): aplicaciones y limitaciones. *Revista de Psicologia Del Deporte* 23, 355–364.

Castellano, J., Silva, P., Usabiaga, O., and Barreira, D. (2016). The influence of scoring targets and outer-floaters on attacking and defending team dispersion, shape and creation of space during small-sided soccer games. *J. Hum. Kinet.* 51, 153–163. doi: 10.1515/hukin-2015-0178

Clemente, F. M., Couceiro, M. S., Martins, F. M. L., and Mendes, R. (2013). An online tactical metrics applied to football game. *Res. J. Appl. Sci. Eng. Technol.* 5, 1700–1719. doi: 10.19026/rjaset.5.4926

Coutinho, D., Gonçalves, B., Travassos, B., Abade, E., Wong, D. P., and Sampaio, J. (2019). Effects of pitch spatial references on players' positioning and physical performances during football small-sided games. *J. Sports Sci.* 37, 741–747. doi: 10.1080/02640414.2018.1523671

Davids, K., Araújo, D., Correia, V., and Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exerc. Sport Sci. Rev.* 41, 154–161. doi: 10.1097/jes.0b013e318292f3ec

Davids, K., Araujo, D., and Shuttleworth, R. (2005). "Applications of dynamical systems theory to football," in *Proceedings of the 5 th World Congress on Science and Football*, (London), 537–550.

Duarte, R., Araújo, D., Folgado, H., Esteves, P., Marques, P., and Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *J. Syst. Sci. Complex.* 26, 62–72. doi: 10.1007/s11424-013-2290-3

Duarte, R., Araújo, D., Freire, L., Folgado, H., Fernandes, O., and Davids, K. (2012). Intra- and inter-group coordination patterns reveal collective behaviors of football players near the scoring zone. *Hum. Mov. Sci.* 31, 1639–1651. doi: 10.1016/j.humov.2012.03.001 doi: 10.1016/j.humov.2012.03.001

Folgado, H., Bravo, J., Pereira, P., and Sampaio, J. (2018). Towards the use of multidimensional performance indicators in football small-sided games: the effects of pitch orientation. *J. Sports Sci.* 37, 1064–1071. doi: 10.1080/02640414.2018.1543834

Folgado, H., Duarte, R., Fernandes, O., and Sampaio, J. (2014). Competing with lower level opponents decreases intra-team movement synchronization and time-motion demands during pre-season soccer matches. *PLoS one* 9:e97145. doi: 10.1371/journal.pone.0097145

Folgado, H., Lemmink, K. A. P. M., Frencken, W., and Sampaio, J. (2012). Length, width and centroid distance as measures of teams tactical performance in youth football. *Eur. J. Sport Sci.* 14, S487–S492. doi: 10.1080/17461391.2012.730060

Fradua, L., Zubillaga, A., Caro, Ó, Iván Fernández-García, Á, Ruiz-Ruiz, C., and Tenga, A. (2013). Designing small-sided games for training tactical aspects in soccer: extrapolating pitch sizes from full-size professional matches. *J. Sports Sci.* 31, 573–581. doi: 10.1080/02640414.2012.746722

Frencken, W., de Poel, H., Visscher, C., and Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *J. Sports Sci.* 30, 1207–1213. doi: 10.1080/02640414.2012.703783

Frencken, W., Lemmink, K., Delleman, N., and Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *Eur. J. Sport Sci.* 11, 215–223. doi: 10.1080/17461391.2010.499967

Frias, T., and Duarte, R. (2015). Man-to-man or zone defense? Measuring team dispersion behaviors in small-sided soccer games. *Trends Sport Sci.* 3, 135–144.

Gonçalves, B., Esteves, P., Folgado, H., Ric, A., Torrents, C., and Sampaio, J. (2016a). Effects of pitch area-restrictions on tactical behavior, physical, and physiological performances in soccer large-sided games. *J. Strength Cond. Res.* 31, 2398–2408. doi: 10.1519/jsc.0000000000001700

Gonçalves, B., Marcelino, R., Torres-Ronda, L., Torrents, C., and Sampaio, J. (2016b). Effects of emphasising opposition and cooperation on collective movement behaviour during football small-sided games. *J. Sports Sci.* 34, 1346–1354. doi: 10.1080/02640414.2016.1143111

Gonçalves, B., Figueira, B., Maçãs, V., and Sampaio, J. (2013). Effect of player position on movement behaviour, physical and physiological performances during an 11- a-side football game. *J. Sports Sci.* 32, 191–199. doi: 10.1080/02640414.2013.816761

Gonçalves, B., Folgado, H., Coutinho, D., Marcelino, R., Wong, D., Leite, N., et al. (2018). Changes in effective playing space when considering sub-groups of 3 to 10 players in professional soccer matches. *J. Hum. Kinet.* 62, 145–155. doi: 10.1515/hukin-2017-0166

Gréhaigne, J.-F., and Godbout, P. (2014). Dynamic systems theory and team sport coaching. *Quest* 66, 96–116. doi: 10.1080/00336297.2013.814577

Hill-Haas, S. V., Dawson, B., Impellizzeri, F. M., and Coutts, A. J. (2011). Physiology of small-sided games training in football. *Sports Med.* 41, 199–220. doi: 10.2165/11539740-000000000-00000

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–12. doi: 10.1249/mss.0b013e31818cb278

Hristovski, R., Davids, K., Araújo, D., and Passos, P. (2011). Constraints-induced emergence of functional novelty in complex neurobiological systems: a basis for creativity in sport. *Nonlinear Dynamics Psychol. Life Sci.* 15, 175–206.

Hristovski, R., Davids, K., Araújo, D., Passos, P., Torrents, C., Aceski, A., et al. (2013). "Creativity in sport and dance: ecological dynamics on a hierarchically soft-assembled perception-action landscape," in *Complex Systems in Sport*, eds K. Davids, R. Hristovski, D. Araújo, N. Balagué Serre, C. Button, and P. Passos (London: Routledge), 261–274.

Hristovski, R., Davids, K., Passos, P., and Araújo, D. (2012). Sport performance as a domain of creative problem solving for self-organizing performer-environment systems. *Open Sports Sci. J.* 5, 26–35. doi: 10.2174/1875399x01205010026

Iacono, A. D., Eliakim, A., and Meckel, Y. (2015). Improving fitness of elite handball players: small-sided games vs. high-intensity intermittent training. *J. Strength Cond. Res.* 29, 835–843. doi: 10.1519/jsc.0000000000000686

McGarry, T., Anderson, D. I., Wallace, S. A., Hughes, M. D., and Franks, I. M. (2002). Sport competition as a dynamical self-organizing system. *J. Sports Sci.* 20, 771–781. doi: 10.1080/026404102320675620

Moura, F. A., van Emmerik, R. E. A., Santana, J. E., Martins, L. E. B., de Barros, R. M. L., and Cunha, S. A. (2016). Coordination analysis of players' distribution in football using cross-correlation and vector coding techniques. *J. Sports Sci.* 34, 2224–2232. doi: 10.1080/02640414.2016.1173222

Ometto, L., Vasconcellos, F. V. A., Cunha, F. A., Teoldo, I., Souza, C. R. B., Dutra, M. B., et al. (2018). How manipulating task constraints in small-sided and conditioned games shapes emergence of individual and collective tactical behaviours in football: a systematic review. *Int. J. Sports Sci. Coach.* 13, 1200–1214. doi: 10.1177/1747954118769183

Pinder, R. A., Davids, K., and Renshaw, I. (2012). Metastability and emergent performance of dynamic interceptive actions. *J. Sci. Med. Sport* 15, 437–443. doi: 10.1016/j.jsams.2012.01.002

Rein, R., and Memmert, D. (2016). Big data and tactical analysis in elite soccer: future challenges and opportunities for sports science. *SpringerPlus* 5:1410. doi: 10.1186/s40064-016-3108-2

Ric, A., Hristovski, R., Gonçalves, B., Torres, L., Sampaio, J., and Torrents, C. (2016). Timescales for exploratory tactical behaviour in football small-sided games. *J Sports Sci.* 34, 1723–1730. doi: 10.1080/02640414.2015.1136068

Ric, A., Hristovski, R., and Torrents, C. (2015). Can joker players favor the exploratoy behaviour in football small-sided games. *Res. Phys. Educ. Sport Health* 4, 35–39.

Ric, A., Torrents, C., Gonçalves, B., Torres-Ronda, L., Sampaio, J., and Hristovski, R. (2017). Dynamics of tactical behaviour in association football when manipulating players' space of interaction. *PLoS One* 12:e0180773. doi: 10.1371/journal.pone.0180773

Sampaio, J., Lago, C., Gonçalves, B., Maçãs, V., and Leite, N. (2014). Effects of pacing, status and unbalance in time motion variables, heart rate and tactical behaviour when playing 5-a-side football small-sided games. *J. Sci. Med. Sport* 17, 229–233. doi: 10.1016/j.jsams.2013.04.005

Sansone, P., Tessitore, A., Paulauskas, H., Lukonaitiene, I., Tschan, H., Pliauga, V., et al. (2018). Physical and physiological demands and hormonal responses in basketball small-sided games with different tactical tasks and training regimes. *J. Sci. Med. Sport* 22, 602–606. doi: 10.1016/j.jsams.2018.11.017

Santos, S., Coutinho, D., Gonçalves, B., Schöllhorn, W., Sampaio, J., and Leite, N. (2018). Differential learning as a key training approach to improve creative and tactical behavior in soccer. *Res. Q. Exerc. Sport* 89, 11–24. doi: 10.1080/02701367.2017.1412063

Sibani, P., and Dall, J. (2003). Log-poisson statistics and full aging in glassy systems. *Europhys. Lett.* 64, 8–14. doi: 10.1209/epl/i2003-00109-0

Silva, P., Travassos, B., Vilar, L., Aguiar, P., Davids, K., Araújo, D., et al. (2014). Numerical relations and skill level constrain Co- adaptive behaviors of agents in sports teams. *PLoS One* 9:e107112. doi: 10.1371/journal.pone.0107112

Torrents, C., Ric, A., and Hristovski, R. (2015). Creativity and emergence of specific dance movements using instructional constraints. *Psychol. Aesthet. Creat. Arts* 9, 65–74. doi: 10.1037/a0038706

Torrents, C., Ric, A., Hristovski, R., Torres-Ronda, L., Vicente, E., and Sampaio, J. (2016). Emergence of exploratory, technical and tactical behavior in small-sided soccer games when manipulating the number of teammates and opponents. *PLoS One* 11:e0168866. doi: 10.1371/journal.pone.0168866

Travassos, B., Gonçalves, B., Marcelino, R., Monteiro, R., and Sampaio, J. (2014). How perceiving additional targets modifies teams' tactical behavior during football small-sided games. *Hum. Mov. Sci.* 38, 241–250. doi: 10.1016/j.humov.2014.10.005

Vaz, L., João, P. V., Gomes, I., Gaspar, P., and Figueira, B. (2019). Effects of rugby specific small-sided games in rugby union players. *Motricidade* 15, 142–142.

Vilar, L., Araújo, D., Davids, K., and Bar-Yam, Y. (2013). Science of winning soccer: emergent pattern-forming dynamics in association football. *J. Syst. Sci. Complex.* 26, 73–84. doi: 10.1007/s11424-013-2286-z

Vilar, L., Esteves, P. T., Travassos, B., Passos, P., Lago-peñas, C., and Davids, K. (2014). Varying numbers of players in small-sided soccer games modifies action opportunities during training. *Int. J. Sports Sci. Coach.* 9, 1007–1018. doi: 10.1260/1747-9541.9.5.1007

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Validity and Reliability of a Commercially Available Indoor Tracking System to Assess Distance and Time in Court-Based Sports

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The aim of this study was to evaluate the validity and reliability of a commercially available local position measurement (LPM) tracking system when assessing distance and running time at different speeds. Fifteen male healthy athletes performed 15 m displacements at walking, running and sprinting speed. Data recorded by the LPM system were compared to those from the reference equipment, consisting of measuring tape and electronic timing gates placed at 0, 5, 10, and 15 m. Mean error, mean absolute error (MAE), standard deviation (SD) of the measurement error, maximum measurement error and root mean square error (RMSE) were calculated to determine the validity for distance and the running time variables. Product-moment correlation and intraclass correlation coefficient (ICC) were also used for the running time. Finally, the reliability of the distance was carried out comparing data from the three repetitions with the standard tape measure using a linear mixed model and the typical error as mean coefficient of variation (CV) (%). MAE shows errors under 0.18 m for the distance variable at all speeds and under 0.08 s for the running time variable at all speeds, except from 15 m at walking. Product-moment correlations were high to nearly perfect for running time (range: 0.60–0.99), ICC varied between high (0.75–0.90) and extremely high (>0.99) for most measures, and coefficients of variation remained almost invariable as speed increased (walking: 2.16; running: 2.52; sprinting: 2.20). The tested LPM system represents a valid and reliable method for monitoring distance during different constant speeds over a straight line, as long as there is no signal loss. However, the running time errors could be too large for performance tests that require acute precision.

Keywords: team sports, player tracking, indoor tracking, training load, match analysis

INTRODUCTION

Accurate assessment of athletes' movement profile during training and match play in team sports presents useful information that could assist coaches and trainers in the development of specific conditioning activities and recovery strategies (Duffield et al., 2010). Initially, computer-based tracking systems were used for assessing players at constant running speeds such as distance covered and time spent during sports-specific tasks (Edgecomb and Norton, 2006). However, this analysis technique required large amounts of time and was overall difficult to implement when simultaneously assessing large groups of athletes or entire teams. In the last few years, advancements in technology have led to the introduction and rapid proliferation of sophisticated systems such as multiple camera semi-automatic systems, global positioning systems (GPS) and local position measurement (LPM) systems. These technologies are capable of quickly recording and processing the players' physical exertions throughout an entire match or training session (Carling et al., 2008).

The development of these technologies has mostly been linked with outdoor sports such as football which has seen the rapid evolution of multiple camera and GPS systems, bringing forth a significant improvement in sport performance and player management, thereby contributing to the emergence of a whole new industry. The main contribution of these technologies is that they allow the concurrent analysis of running speeds of numerous players to be completed on a routine basis with affordable expenses (Buchheit et al., 2014).

Computerized analysis using multiple camera, semi-automatic, video match-analysis systems has proved to be a valid and reliable tool to measure player movements and actions, and to classify the game events in professional competitions (Di Salvo et al., 2007, 2008; Carling et al., 2008). However, installing and using this technology generally requires a large investment in economic terms that represents a limitation in most sports.

Global positioning systems devices have also been widely assessed for their validity and reliability in measuring distance, time, speed and acceleration during different sporting actions over the last decade (Edgecomb and Norton, 2006; Barbero-Alvarez et al., 2010; Coutts and Duffield, 2010; Coutts and Duffield, 2010; Gray et al., 2010; Jennings et al., 2010; Waldron et al., 2011; Varley et al., 2012; Vickery et al., 2014), and it has led to GPS being the preferred technology used in player tracking. However, the main limitation of GPS technology is that it requires an "open" sky without obstructions above athletes that ensures clear space for positional data acquisition from satellites. This constraint prevents GPS devices from being used in indoor sports such as basketball or handball. Thus, other technologies such as LPM have been used for the assessment of athletes' movement profile indoors.

The LPM technology has seen moderate improvements over the last few years, resulting in better stability and precision. The declared relative position measurement accuracy of some of these systems is around 3 cm which can be measured up to 1 kHz (Buchheit et al., 2014). This technology consists of radio systems based on a Bluetooth Low Energy (BLE) radio signals which provide location information through a network of antennas (base stations) and transponders. These base stations are positioned around the playing area to be measured while the transponders are worn by the athletes.

There is limited information regarding the validity and reliability of commercially available indoor tracking systems using LPM technology for assessing constant running speeds during indoor team sports (Frencken et al., 2010; Siegle et al., 2013; Link et al., 2018; Linke et al., 2018). Although LPM systems have been reported to offer higher validity for measuring athletes' position compared to video and GPS technology (Linke et al., 2018), they still have the highest deviations when measuring distance, which might also cause relevant limitations for the assessment of sprint performance especially over short distances (Link et al., 2018). In the past few years, this type of positioning system has experienced an increasing commercialization, and some of them are currently being used by different basketball teams of the highest category in Spain. The present work aims to assess the validity and reliability of distance and running time measured by means of an LPM system at different speeds, providing an initial contribution for the assessment of this technology.

MATERIALS AND METHODS

Experimental Approach to the Problem

Participants performed repeated straight-line displacements at different speeds while distance and time were assessed using the LPM system and compared to the reference values. Actual distance was measured using a calibrated tape measure and time was measured using four pairs of dual-beam photocells (Witty, Microgate, Bolzano, Italy) placed at the starting line and every 5 m. This technology has been previously considered as a reference tool in the measurement of distances and time (Buchheit et al., 2014) and is the recommended technology to register accurate and reliable short sprint results in scientific research (Haugen and Buchheit, 2016). The tests were conducted in an indoor sport facility with parquet surface, normally used by a basketball team of the ACB (first division of Spanish basketball).

Subjects

Fifteen trained male athletes (age: 26 ± 3 years; height: 1.85 ± 0.06 m; weight: 79 ± 3 kg) were randomly chosen from a population of basketball players that volunteered to participate in the study. Participants were informed about the experimental procedures and the potential risks and benefits resulting from participating in the study, and they all signed an institutionally approved informed consent document, as outlined in the Declaration of Helsinki. The study protocol was approved by the Local Ethics Committee.

Procedures

Each participant completed nine 15-m displacements on a straight line separated by 1 min of passive recovery, following procedures mentioned previously (Jennings et al., 2010). The first three displacements were made at a comfortable walking speed; displacements 4 to 6 were performed running at gentle pace; and the last three displacements were performed sprinting at maximum speed. To expand the scope of the study at different speeds and distances, timing gates were placed at 0, 5, 10, and 15 m. Total time (0–15 m) and times of each of the three 5-m splits (0–5, 5–10, and 10–15 m) were recorded.

For the calculation of the distances traveled in a specific time, the LPM system considered the start time of each displacement as that when the first movement occurred (i.e., the first increase on the velocity curve above zero (Petersen et al., 2009; Jennings et al., 2010). This starting time was associated with the moment that the athlete went through the timing gate placed at 0 m mark. Then, the time from the timing gates was used to indicate the end of the movement for each known distance. Thus, for a time interval determined by two successive cuts of timing gates, distance measured with the LPM system was compared to the current distance between both timing gates.

In addition, the time taken to complete the distance of 15 m (according to the LPM system) was recorded. This data was compared to the time recorded by the timing gates for the same distance. Therefore, distances and times recorded by the LPM system in each test were compared to the taped distances and the times obtained from the timing gates, respectively. Only trials where an accurate measurement was made by both the timing gates (trials discarded for timing gate measurement error: walking = 2, jogging = 4, sprinting = 19) and the LPM system (trials discarded due to momentary drop in signal: walking = 5, jogging = 3, and sprinting = 12) were considered for analysis.

LPM System

The system used in this study is commercially known as NBN23 (Nothing But Net, Valencia, Spain) and is composed of two different elements. First, the system hardware was created by the Finnish company Quuppa (Nokia Corporation, 2014). This technology consists of locators and the devices that the players carry (tags) which were placed on the waist, at the back of the trousers at the height of the sacrum. This position represents the approximate position of the center of mass of the subject and avoids a possible shielding of the signal with the participant's own body. Tags are emission devices, and the system works by triangulating the signal they emit. The frequency at which they send information can be varied between 9, 17, 33, and 50 Hz. The frequency band is 2.4 GHz, the system delay is 100 ms with a capacity of 400 information packets per second. In this study, eight locators (firmware v9.047) placed in two groups of four at a height of 13.51 m (**Figure 1**) were used along with eight different tags at a frequency of 17 Hz (Nokia Technologies Oy, 2014).

Secondly, the specific software for the LPM system was used (Nothingbutnet v1.1.3, Spain, 2016). This software adds a Kalman filter to the position coordinates (given in terms of *X* and *Y*) provided by Quuppa to reduce noise and measurement error with a cut-off frequency of 3 Hz. The distance traveled was calculated through the position changes on the *X* and *Y* axes. To carry out the tests, the participant started from a static position on the free throw line.

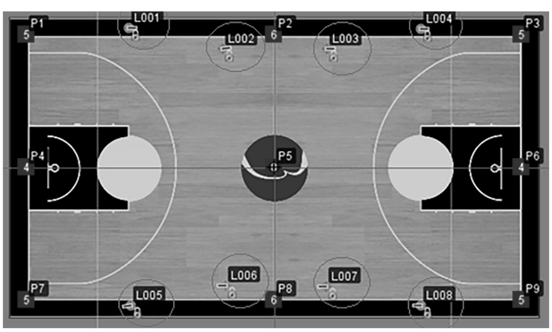

FIGURE 1 | The positioning of the locaters (L) and reference points (P) of the NBN system.

Statistical Analyses

Mean error, mean absolute error (MAE), standard deviation (SD) of the measurement error, maximum measurement error and root mean square error (RMSE) were determined for assessing validity of the distance variable, considering the tape measurement as the standard. A plot with the difference between criterion and LPM distance in each speed and 5-m split (0–5, 5–10, and 10–15 m) was also added.

Validity of the running time variable was performed between the times recorded using the LPM system and the interval times recorded by the timing gates for equal distances. Product-moment correlation (r), intraclass correlation coefficient (ICC), absolute agreement with 95% confidence intervals (Field, 2013) and Bland–Altman plots were used. Moreover, similar to the distance measures, MAE, SD of the measurement error, maximum measurement error and RMSE were determined taking the timing gates data as the standard. Product-moment correlation results were evaluated as trivial (<0.10), small (0.10–0.30), moderate (0.30–0.50), large (0.50–0.70), very large (0.70–0.90), nearly perfect (0.90–1.00) scores (Johnston et al., 2014). ICC were evaluated as very low (<0.20), low (0.20–0.50), moderate (0.50–0.75), high (0.75–0.90), very high (0.90–0.99), and extremely high (>0.99) scores (Buchheit et al., 2014).

The reliability of the distance was carried out comparing data from the three repetitions with the standard tape measure using a linear mixed model. For this model, the repetition was considered as the fixed factor, and the participant was the random factor. Furthermore, typical error as mean coefficient of variation (CV) (%) was calculated by the Hopkins reliability spreadsheet (Hopkins, 2015), and used among the three trials for each velocity (walking, running, and sprinting). Once CV was established, it was divided into criterion categories, being rated as good (CV < 5%), moderate (CV 5 to 10%) or poor (CV > 10%) (Atkinson and Nevill, 1998; Duthie et al., 2003; Johnston et al., 2014).

Normality and homogeneity of the variance were previously tested and assumed by the Kolmogorov Smirnov test and the Levene's statistical analysis. The level of significance was established at $p < 0.05$. Data were analyzed using SPSS version 21.0 (SPSS Inc., Chicago, IL, United States) and SAS University Edition (SAS Institute Inc., 2015, Cary, NC, United States).

RESULTS

Tables 1, **2** show the errors measured between the LPS system and the gold standard measurement: the fixed taped distance and the timing gates. The mean error, and the MAE show values under 0.18 m for the distance variable at all speeds, which is lower than 5% of the actual measured value (**Figures 2**, **3**). In case of the time

TABLE 1 | Validity and agreement of the distance variable.

	N	Mean error (m)	MAE (m)	SD of measurement error (m)	Max error (m)	RMSE (m)
Walking						
0–5 m	38	0.08	0.13	0.20	0.76	0.22
5–10 m	38	−0.08	0.10	0.11	0.37	0.14
10–15 m	38	0.03	0.11	0.15	0.34	0.15
0–10 m	38	0.01	0.13	0.19	0.70	0.19
0–15 m	38	0.03	0.12	0.16	0.45	0.16
Jogging						
0–5 m	38	0.05	0.13	0.18	0.52	0.19
5–10 m	38	−0.06	0.12	0.18	0.49	0.19
10–15 m	38	−0.02	0.13	0.19	0.56	0.19
0–10 m	38	0.01	0.16	0.21	0.54	0.19
0–15 m	38	−0.01	0.12	0.15	0.34	0.15
Running						
0–5 m	14	0.08	0.12	0.14	0.29	0.15
5–10 m	14	0.05	0.15	0.23	0.73	0.23
10–15 m	14	−0.13	0.18	0.24	0.68	0.26
0–10 m	14	0.13	0.15	0.25	0.91	0.27
0–15 m	14	0.00	0.17	0.26	0.70	0.26

N, number of trials; MAE, mean absolute error; SD, standard deviation; RMSE, root mean square error; Max error, maximum error; MAE and RMSE were determined with respect to the measured distance.

TABLE 2 | Validity and agreement of the time variable.

Variables	*N*	Mean error (s)	MAE (s)	SD of measured error (s)	Max error (s)	RMSE (s)	*r*	ICC
Walking								
0–5 m	38	−0.04	0.05	0.08	0.36	0.09	0.96	0.97
5–10 m	38	−0.02	0.03	0.02	0.10	0.04	0.99	0.99
10–15 m	38	−0.03	0.07	0.14	0.83	0.16	0.80	0.87
0–10 m	38	−0.06	0.07	0.07	0.38	0.10	0.99	0.99
0–15 m	38	−0.08	0.12	0.14	0.85	0.18	0.97	0.98
Running								
0–5 m	38	−0.02	0.03	0.02	0.08	0.03	0.99	0.99
5–10 m	38	−0.03	0.03	0.03	0.10	0.04	0.99	0.99
10–15 m	38	−0.00	0.05	0.07	0.29	0.09	0.88	0.94
0–10 m	38	−0.05	0.05	0.04	0.14	0.06	0.99	0.99
0–15 m	38	−0.05	0.08	0.06	0.29	0.10	0.98	0.99
Sprinting								
0–5 m	14	−0.02	0.02	0.02	0.05	0.03	0.97	0.96
5–10 m	14	−0.02	0.04	0.04	0.13	0.50	0.60	0.71
10–15 m	14	−0.03	0.04	0.03	0.11	0.06	0.64	0.59
0–10 m	14	−0.04	0.05	0.04	0.18	0.07	0.77	0.79
0–15 m	14	−0.07	0.08	0.04	0.15	0.09	0.89	0.83

MAE, mean absolute error; SD, standard deviation; Max error, maximum error; RMSE, root mean square error; r, product-moment correlation; ICC, intraclass correlation coefficient.

variable a slightly higher value of MAE was recorded at the longer distances. In this case, the ICC went from high to extremely high values at walking and running speeds, while at sprinting speed it presents moderate to very high correlation values. In spite of the lower coefficients at sprinting speed, correlations values are still above the threshold of moderate magnitude.

Table 3 shows the reliability results of distance data. In this case, all the values fit within the best criterion category (good). Unlike the previous cases, results show a great consistency in all speeds and distances, with mean CVs remaining below 3% for all speeds (walking: 2.16; running: 2.52; sprinting: 2.20).

Finally, **Table 4** shows the reliability of the differences in distances between the LPM system measurement and the taped measurement. The results show that the differences between the trials only varied for the 0–15 m distance at a walking speed, and inter-participant differences were observed for the 0–10 m walking distance.

DISCUSSION

This paper presents the validity and reliability of an LPM measuring system for distance and running time during different constant speeds over a straight line. The validity of the system, which consisted of a set of tags placed at the sacrum of the player, was measured against taped distances and timing gates.

When assessing distance validity, results show that the LPM system either over or underestimates the actual distance, but the MAE are well under 0.18 m (percentage of differences is less than 2%). The magnitude of this difference were over those declared by Frencken et al. (2010) when assessing accuracy and validity of an equivalent LPM device in smaller, straight line distances (0.2%), but under that declared for GPS devices when assessing distance at different speeds over a 200 m on a straight line (0.8–2.8%) (Gray et al., 2010). It is important to consider that some noise-inducing variables such as a slightly forward position of the device at the beginning or end of the trial, can cause these differences. Furthermore, the SD of measurement error varied from 0.11 to 0.26 m, but this issue was not discussed in these previous studies.

On the other hand, the results of the present study show that the LPM system offers a higher accuracy than that shown by GPS in other studies such as Coutts and Duffield (2010) (3.6–7.1%), Gray et al. (2010) (0.5–9.8%), Duffield et al. (2010) (4.0–30.0%) or Jennings et al. (2010) (9.0–32.4%), although some of those studies consisted of more complex validation protocols including turns and curved movement paths.

Possibly, one of the most frequent uses in these monitoring systems is the quantification of the load as accumulated distance at different speeds, as previous studies refer to these individual movements in team sports (Gray et al., 2010). Therefore, the LPM system analyzed can be used to quantify distances in simple movements with the same or greater precision than those obtained through a system like the GPS. However, more research is needed involving complex circuits and routes that mimic the movement patterns of sports such as basketball, handball or futsal.

When assessing running time spent to cover a certain distance, validity correlation ranged from very large to nearly perfect in walking and running speeds (0.80–0.99), in agreement to those described by Frencken et al. (2010). When assessing running

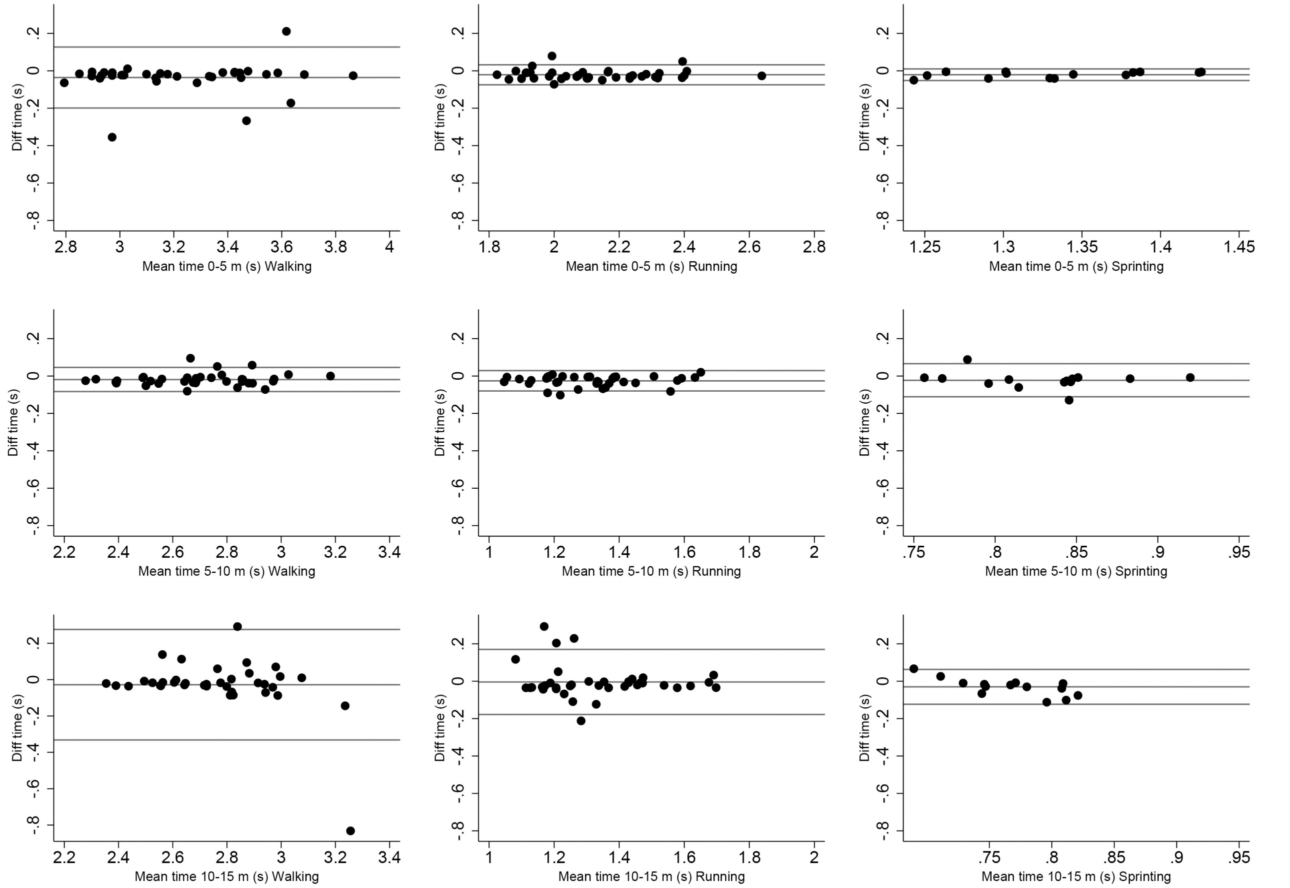

FIGURE 2 | Bland-Altman plots representing the differences between the time measured by the NBN system and the standard timing gates.

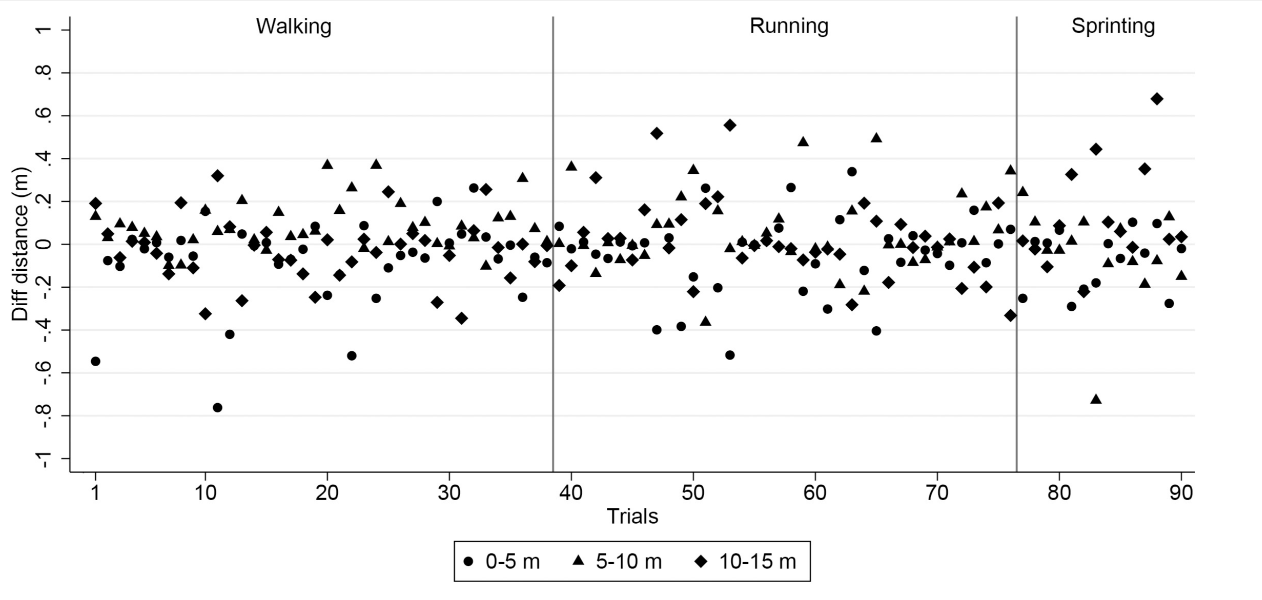

FIGURE 3 | Bland-Altman plots representing the differences between the distance measured by the NBN system and the taped distances.

TABLE 3 | Reliability of the distance variable (typical error presented as the mean CV).

Distance interval	CV walking (%)	CV running (%)	CV sprinting (%)
0–5 m	3.0	2.4	2.3
5–10 m	2.6	4.1	2.3
10–15 m	2.8	3.2	4.3
0–10 m	1.3	2.0	0.6
0–15 m	1.1	0.9	1.5

CV, coefficient of variation.

TABLE 4 | Reliability of the differences in distances between the taped distance and the distance measured by the local position measurement (LPM) system.

	Fixed effects				Random effects	
	F	df1	df2	*p*	Wald *Z*	*p*
Walking						
0–5 m	3.15	2	22.92	0.062	1.90	0.06
5–10 m	1.04	2	35.00	0.366	−1.46	0.14
10–15 m	0.05	2	23.53	0.952	0.57	0.57
0–10 m	2.61	2	22.65	0.096	2.03	0.04†
0–15 m	3.51	2	35.00	0.041*	−0.42	0.67
Jogging						
0–5 m	0.22	2	21.65	0.803	1.83	0.07
5–10 m	0.12	2	35.00	0.889	−1.88	0.06
10–15 m	0.78	2	35.00	0.468	−0.33	0.74
0–10 m	0.27	2	35.00	0.767	0.17	0.87
0–15 m	1.12	2	22.71	0.344	1.25	0.21
Running						
0–5 m	1.13	2	6.67	0.378	1.04	0.30
5–10 m	0.50	2	4.18	0.639	1.26	0.21
10–15 m	0.49	2	11.00	0.625	−0.18	0.86
0–10 m	0.38	2	4.89	0.701	1.65	0.10
0–15 m	0.98	2	6.98	0.422	0.44	0.66

*A linear mixed model was used with the repetition being the fixed effect and the athlete being the random effect. *Indicates a significant difference between the difference of the measures in the different repetitions. †Indicates a significant difference between participants in different repetitions. All tests were carried out with α = 0.05.*

time at sprinting speed the correlation values down to large (0.60–0.97). In relative terms, the percentage of difference varied between 0 and 2.48% at walking and running speeds and between 4.35 and 6.68% at sprinting speed. In addition, the ICC varied between a high (0.75–0.90) and extremely high (>0.99) except in two time-variables at sprinting speed, where it is still moderate (0.50–0.75). However, MAE remain similar in all speeds, which varied between 0.02 and 0.12. In agreement with previous research validating GPS devices, the accuracy of the LPM system decreased slightly as speed increased (Edgecomb and Norton, 2006; Coutts and Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010; Vickery et al., 2014). These differences are once more in line with those described by Frencken et al. (2010) (1.3–3.9%) and are lower than those generally described for speed in GPS devices as in Duffield et al. (2010) (10–30%). Furthermore, the LPM system provides better level of accuracy for measures of running time compared with other tracking devices such as GPS where ICC has been reported to vary from 0.10 to 0.70 (Duffield et al., 2010) or from 0.50 to 0.86 (Vickery et al., 2014).

The reliability of the LPM system when measuring distance traveled during each bout was good (CV < 5%), being this consistent as speed increases from walking to maximal sprint, and this was confirmed by the linear mixed model. The overall reliability of the LPM system data across all trials remains within the ranges that have been described for other LPM systems (0.4–2.0%) (Frencken et al., 2010) or other tracking devices. For example, regarding GPS systems, Barbero-Alvarez et al. (2010) reported CVs of between 1.2 and 1.7% for summated maximal speed and peak speed expressed during 15 and 30-m repeated sprint tests over seven trials. Others such as Coutts and Duffield (2010) reported good-to-moderate CVs for total distance (3.6–7.1%) and peak speed (2.3–5.8%) when assessing validity and reliability of different GPS devices. However, studies assessing reliability of other tracking devices generally report that the higher the speed, the greater the measurement error (Duffield et al., 2010; Gray et al., 2010; Vickery et al., 2014). Contrarily, in the present study better reliability was observed as intensity increases, with the lowest CVs corresponding to the highest speed.

The measurement can be considered as useful for precise measurements when the noise is at least equal to or lower than the smallest worthwhile change (SWC) (Haugen and Buchheit, 2016). The SWC could be defined as 0.2 multiplied by the between-subject SD (Hopkins et al., 2009; Ferioli et al., 2018). In this study the SWC is between 0.01 and 0.06 s in 5 m splits for the time measurement (between 0.8 and 2.75%). The SD of measurement errors were between 0.02 and 0.14 s in the 5 m splits, which could make the random error higher than the differences in performance between players, presenting a limitation of its use in performance tests carried out over short distances. Nevertheless, it can be a useful device in determining accumulated loads in training and games.

Another limitation of this study was that time and distance were only assessed over standard straight-line 15-m displacements and that true peak speed was not measured directly. Quite often, short sprints, changes of direction and brief maximal accelerations of >1 s are completed in team sports. Although previous methodologies were followed to match the start of timing gates and LPM measurement, there are still possible errors because the LPM system may start recording a few ms before the first timing light cut. There is also a spatial limitation since it was possible that in some specific points of the field (bands or corners) the LPM system could measure differently depending on the distance to the system receivers. Finally, this study also has its own measurement error associated with timing gates. Among them, the possible swinging of arms and legs, an error that can reach 0.02 s (Haugen et al., 2014) and errors associated with the height or distance of the photocells (Cronin and Templeton, 2008). Therefore, the scope of this work is limited, and it is possible that important data may be missed due to the protocol design. Future research should examine the efficacy of this system when assessing more complex protocols.

CONCLUSION

The tested LPM system represents a valid and reliable method for monitoring distance and running time during constant speeds over a straight line as long as there is no signal loss. Intensity appears to affect the LPM system running time accuracy, being this lower as speed increases. The typical error measured with CV (%) shows a great consistency regardless of speed and distance, with good reliability results. This implies that the LPM system provides similar consistency than other tracking devices such as GPS system and could be useful for training purposes and determinate external workload. However, the random part of measurement error is higher than the SWC, so the LPM could not be a good system to evaluate performance tests carried out at high speeds in short distances.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Institutional Research Board of the Universidad de Castilla–La Mancha, Toledo, Spain with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethics Committee of the Universidad de Castilla–La Mancha, Toledo, Spain.

AUTHOR CONTRIBUTIONS

EC coordinated the research, drafted the initial manuscript, and carried out the statistical analyses. JG-U, JF, and AN substantially contributed to the analysis and interpretation of the data. JS-S helped on the conceptualization and design of the study. JC-M, MC, and ML coordinated the data collection process. All authors contributed to the manuscript revision, read, and approved the submitted version.

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REFERENCES

Atkinson, G., and Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med.* 26, 217–238. doi: 10.2165/00007256-199826040-00002

Barbero-Alvarez, J. C., Coutts, A., Granda, J., Barbero-Alvarez, V., and Castagna, C. (2010). The validity and reliability of a global positioning satellite system device to assess speed and repeated sprint ability (RSA) in athletes. *J. Sci. Med. Sport* 13, 232–235. doi: 10.1016/j.jsams.2009.02.005

Buchheit, M., Allen, A., Poon, T. K., Modonutti, M., Gregson, W., and Di Salvo, V. (2014). Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies. *J. Sports Sci.* 32, 1844–1857. doi: 10.1080/02640414.2014.942687

Carling, C., Bloomfield, J., Nelsen, L., and Reilly, T. (2008). The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. *Sports Med.* 38, 839–862. doi: 10.2165/00007256-200838100-00004

Coutts, A. J., and Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *J. Sci. Med. Sport* 13, 133–135. doi: 10.1016/j.jsams.2008.09.015

Cronin, J. B., and Templeton, R. L. (2008). Timing light height affects sprint times. *J. Strength Cond. Res.* 22, 318–320. doi: 10.1519/JSC.0b013e31815fa3d3

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bachl, N., and Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *Int. J. Sports Med.* 28, 222–227. doi: 10.1055/s-2006-924294

Di Salvo, V., Benito, P. J., Calderon, F. J., Di Salvo, M., and Pigozzi, F. (2008). Activity profile of elite goalkeepers during football match-play. *J. Sports Med. Phys. Fitness* 48, 443–446.

Duffield, R., Reid, M., Baker, J., and Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *J. Sci. Med. Sport* 13, 523–525. doi: 10.1016/j.jsams.2009.07.003

Duthie, G., Pyne, D., and Hooper, S. (2003). The reliability of video based time motion analysis. *J. Hum. Mov. Stud.* 44, 259–271.

Edgecomb, S. J., and Norton, K. I. (2006). Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. *J. Sci. Med. Sport* 9, 25–32. doi: 10.1016/j.jsams.2006.01.003

Ferioli, D., Bosio, A., Bilsborough, J. C., La Torre, A., Tornaghi, M., and Rampinini, E. (2018). The preparation period in basketball: training load and neuromuscular adaptations. *Int. J. Sports Physiol. Perform.* 13, 991–999. doi: 10.1123/ijspp.2017-0434

Field, A. (2013). *Discovering Statistics Using IBM SPSS Statistics*, 3rd Edn. London: Sage.

Frencken, W. G., Lemmink, K. A., and Delleman, N. J. (2010). Soccer-specific accuracy and validity of the local position measurement (LPM) system. *J. Sci. Med. Sport* 13, 641–645. doi: 10.1016/j.jsams.2010.04.003

Gray, A. J., Jenkins, D., Andrews, M. H., Taaffe, D. R., and Glover, M. L. (2010). Validity and reliability of GPS for measuring distance travelled in field-based team sports. *J. Sports Sci.* 28, 1319–1325. doi: 10.1080/02640414.2010.504783

Haugen, T., and Buchheit, M. (2016). Sprint running performance monitoring: methodological and practical considerations. *Sports Med.* 46, 641–656. doi: 10.1007/s40279-015-0446-0

Haugen, T. A., Tønnessen, E., Svendsen, I. S., and Seiler, S. (2014). Sprint time differences between single-and dual-beam timing systems. *J. Strength Cond. Res.* 28, 2376–2379. doi: 10.1519/JSC.0000000000000415

Hopkins, W. G. (2015). Spreadsheets for analysis of validity and reliability. *Sportscience* 19, 36–42.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–13. doi: 10.1249/MSS.0b013e31818cb278

Jennings, D., Cormack, S., Coutts, A. J., Boyd, L., and Aughey, R. J. (2010). The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *Int. J. Sports Physiol. Perform.* 5, 328–341. doi: 10.1123/ijspp.5.3.328

Johnston, R. J., Watsford, M. L., Kelly, S. J., Pine, M. J., and Spurrs, R. W. (2014). Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J. Strength Cond. Res.* 28, 1649–1655. doi: 10.1519/JSC.0000000000000323

Link, D., Weber, M., Linke, D., and Lames, M. (2018). Can positioning systems replace timing gates for measuring sprint time in ice hockey? *Front. Physiol.* 9:1882. doi: 10.3389/fphys.2018.01882

Linke, D., Link, D., and Lames, M. (2018). Validation of electronic performance and tracking systems EPTS under field conditions. *PLoS One* 13:e0199519. doi: 10.1371/journal.pone.0199519

Petersen, C., Pyne, D., Portus, M., and Dawson, B. (2009). Validity and reliability of GPS units to monitor cricket-specific movement patterns. *Int. J. Sports Physiol. Perform.* 4, 381–393. doi: 10.1123/ijspp.4.3.381

Siegle, M., Stevens, T., and Lames, M. (2013). Design of an accuracy study for position detection in football. *J. Sports Sci.* 31, 166–172. doi: 10.1080/02640414.2012.723131

Varley, M. C., Fairweather, I. H., and Aughey, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *J. Sports Sci.* 30, 121–127. doi: 10.1080/02640414.2011.627941

Vickery, W. M., Dascombe, B. J., Baker, J. D., Higham, D. G., Spratford, W. A., and Duffield, R. (2014). Accuracy and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. *J. Strength Cond. Res.* 28, 1697–1705. doi: 10.1519/JSC.0000000000000285

Waldron, M., Worsfold, P., Twist, C., and Lamb, K. (2011). Concurrent validity and test-retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. *J. Sports Sci.* 29, 1613–1619. doi: 10.1080/02640414.2011.608703

Conflict of Interest Statement: JC-M was employed by company Nothingbutnet S.L.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Strategies for Maintaining the Coach–Analyst Relationship Within Professional Football Utilizing the COMPASS Model: The Performance Analyst's Perspective

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There is a considerable body of research by that has investigated the coach–athlete relationship in sport. However, given the multi-disciplinary nature of modern elite coaching, there is a scarcity of research focusing on the relationship between coaches and other members of the coaching and support team. This study examined the perceptions of six elite professional football analyst's relationships with their respective coaches. Semi structured interviews utilizing the COMPASS Framework were conducted focusing on Conflict, Openness, Motivation, Preventative Strategies, Assurance, Support, and Social Networks. The results verified that the COMPASS Model of relationship maintenance was applicable to this dyad. Content analysis indicated that there was 215 raw data units comprising of 16 higher order themes across the model which was further broken down into 29 lower order themes. All aspects of the model were found to contribute toward a positively maintained relationship. Having an open relationship underpinned by honesty and being able to provide an opinion was seen as the highest rated attribute that was closely followed by supporting the coach by understanding their requirements for successful coaching practice. Not meeting the coach's expectations was found to cause conflict and was further highlighted by an inductive analysis that revealed the existence of a relationship that is fundamentally dictated by the coach. Implications of this investigation are that professionals which support elite performers need to set out clear expectations of working practice and hierarchies in order to minimize the chance of internal conflict that can impact on the service levels received by the performer.

Keywords: sports performance analysis, relationship maintenance, elite sport, soccer, coach, analysts, power relationships

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INTRODUCTION

O'Donoghue (2010) showcased that performance analysis has become a validated support structure for coaches and athletes and although there is a body of research which investigates the role of the analyst (Bampouras et al., 2012; Wright et al., 2013) and the perceptions of performance analysis within the coaching process (Francis and Jones, 2014; Wright et al., 2016), there is a scarcity of information surrounding the way coaches create, interact and maintain working relationships with performance analysts (Wright et al., 2013). The relationship between the analyst and coach has however, been shown to be so important that coaches would attempt to recruit analysts that they have worked with in previous roles when they gain new employment (Reid et al., 2004; Butterworth and Turner, 2014; Huggan et al., 2015).

Whilst research has identified that elite coaches are supported by a large group of support staff, collaborating data and observations for the benefit of the athletes (Reid et al., 2004; Gustafsson et al., 2008; Bampouras et al., 2012; Clement and Arvinen-Barrow, 2013; Wagstaff et al., 2015), research investigating the relationships present within this group has focused primarily around the coach and athlete (Poczwardowski et al., 2002; Jowett, 2003; Lafrenière et al., 2008; Adie and Jowett, 2010). It has been shown that the emotions, cognitions and behaviors of the persons within this dyad have been shown to be central in developing meaningful relationships (Jowett and Ntoumanis, 2004). Research has also been conducted around the maintenance of relationships, including the conceptualization of the COMPASS Model and Coach–Athlete Relationship Maintenance Questionnaire (CARM-Q) validation process (Rhind and Jowett, 2010, 2012) which has provided valuable insights of coaches within typical dyads in sport.

Jowett and colleagues have employed a number of methodological approaches for the expansive array of research into the coach–athlete relationship. They have mainly centered around the use of questionnaires for model validation purposes (Jowett and Chaundy, 2004; Jowett and Clark-Carter, 2006; Lafrenière et al., 2008; Olympiou et al., 2008; Jowett, 2009; Adie and Jowett, 2010; Jowett et al., 2012b; Rhind and Jowett, 2012; Yang and Jowett, 2013) and interviews for exploratory investigations (Jowett and Meek, 2000; Jowett, 2003; Jowett and Cockerill, 2003; Rhind and Jowett, 2010; Jowett et al., 2012a; Jowett and Carpenter, 2015). All interviews adopted a semi structured format utilizing open ended questions and prompts where required to elicit deeper insight (Patton, 2002). This pattern was followed regardless of the sample size being small (n = 2) (Jowett, 2003) or large (n = 30) (Jowett and Carpenter, 2015). Of those studies to undertake interviews, the selection criteria for inclusion ranged from a minimum 6-month coach–athlete relationship (Jowett et al., 2012a; Jowett and Carpenter, 2015) to 4 years (Jowett and Cockerill, 2003). Jowett and Cockerill's (2003) research only interviewed athletes. This enabled free expression of the athletes, without worry of their coaches' involvement or retort (McKenna and Mutrie, 2003). Rhind and Jowett (2010) recruited unconnected coaches and athletes as previous studies had shown this amplified the range and scope of the data to make it more generalizable in the wider sporting context.

Whilst most interviews were conducted in person, Jowett et al. (2012a) utilized telephone interviews for data collection as the data had not been shown to produce significantly different data to interviews in person (Sweet, 2002). The authors did concede that the format may have limited the expression of experiences and impacted on the perception of the information. Content analysis (Weber, 1990) was used extensively (Jowett and Meek, 2000; Jowett, 2003; Jowett and Cockerill, 2003; Rhind and Jowett, 2010; Jowett et al., 2012a) to categorize the data points into a hierarchy of responses and determine a frequency analysis and is well documented as a common approach for sports psychology studies (Côté et al., 1993). This type of processing was found to highlight prominent themes across responses from all participants (Rhind and Jowett, 2010).

Jowett and Meek (2000) investigated the constructs of closeness, co-orientation and complementarity (3C's) when interviewing four atypical dyads (married couples who also held a coach–athlete relationship) and identified that the coach–athlete relationship was interdependent. Closeness referred to the emotions of the dyad and the affective elements of the coach–athlete relationship were reflected in mutual feelings of trust and respect. Co-orientation was reflective of the quality of the coach–athlete relationship that was highlighted through the thoughts and perspectives of the dyad where mutual empathetic feelings suggested a more effective relationship. Complementarity considered the interactions and co-operative behaviors of the coach and athlete. Where corresponding behaviors were elicited, an increase in the strength of the relationship was perceived. Interdependence is characterized in the coach–athlete dyad by the high levels of closeness, co-orientation and complementarity creating a mutually beneficial relationship at an affective, cognitive and behavioral level (Jowett et al., 2012a). Although the qualitative method provided a rich source of information, useful in advancing the scope of knowledge in the area, including the web of interactions that crossed the 3C's, the small sample size and use of atypical participants meant that there was a need for a more quantitative study using greater sample size to create generalizable results (Jowett and Meek, 2000). Further validation of the interactive aspects of the 3C's was explored via interviews with 12 elite Olympic medalists where connections between the C's were uncovered, although the causality could not be confirmed (Jowett and Cockerill, 2003). They did establish that the relationships contained attributes including, but not limited to, respect, trust, and clear roles. Inconsistencies in the data collection method (some interviews and some written responses to questions) may have impacted upon the validity of the results. The findings were however, suggested to be integral in the initial construct of the Coach–Athlete Relationship Questionnaire (CART-Q) (Jowett and Ntoumanis, 2004) where co-orientation (+1C) was validated as commitment and that has been used as the basis for various empirical research (Jowett, 2009; Rhind and Jowett, 2010; Yang and Jowett, 2013). The conceptualization of the 3+1C's model (Jowett, 2007) to include co-orientation which measured how accurately the coach/athlete was able to understand how the other was feeling, thinking and behaving. This led to the requirement for better understanding of how these relationships use strategies including conflict management and socializing to keep a dyad in a specific way (Dindia and Canary, 1993).

Keeping a relationship in a stable state using effective maintenance strategies, facilitated long term, satisfying relationships (Canary and Stafford, 1994, p. 4). Rhind and Jowett (2010) investigated how coaches and athletes used such approaches to preserve a steady coach–athlete environment. The authors based the categorization of themes for their research on previous work into romantic relationship maintenance (Stafford and Canary, 1991; Canary and Stafford, 1994) and led to the conceptualization of the COMPASS model. The original categories were: Conflict management (proactive and reactive), openness (discussing feelings), motivation (effort, motivate the other, fun and demonstrations), positivity (adaptability, fairness and external pressure), advice (sport focused, reward feedback and constructive criticism), support (assurance, Sport specific, personal), and social networks (socializing and shared networks).

The "COMPASS" model complemented the 3+1C's model and was proposed as a method to understand and manage the complex dynamics of the coach–athlete dyad. The authors also identified the potential for the COMPASS model to be transferable to other interpersonal sporting relationships (Rhind and Jowett, 2010). This body of work was further validated by Rhind and Jowett (2012) with the development of the CARM-Q. The authors found some inconsistencies of the COMPASS model after an exploratory factor analysis had identified highly related subscales (Stafford et al., 2000). Positivity was replaced by Preventative Strategies as positivity was found across various subscales of other categories and Advice was replaced by Assurance to differentiate between support and openness which was validated by Study 2 in the paper.

Research within sport has investigated the domineering power exerted by coaches over their athletes (Johns and Johns, 2000; Cushion and Jones, 2006; Rylander, 2016). A number of theories have contributed to a large body of research on power within social psychology that have often been influenced by the seminal work of French and Raven (1959). Their 5 stage model of interpersonal influence depicted the bases of power which were identified as expert, referent, legitimate, coercive and reward. Rylander (2016) interpreted these for research within the coach–athlete setting and defined expert power as the coaches knowledge which the athlete requires or values. Referent power was based around the coach being identified as a role model or somebody that they could relate to creating reciprocal behavioral and actions. Legitimate power was shown as the recognition within society that the athlete was expected to be comply with their direction. Coercive and reward power were seen as the ability of the coach to discipline or reward athlete behavior based on conformity or outcome. This model has undergone several amendments (Raven, 1965, 1992, 1999) over time and have come under some scrutiny (Patchen, 1974; Carson et al., 1993; Yukl, 2006) although the original model is still considered to be applicable for contemporary research (Groom et al., 2012). Cushion and Jones (2006) found that players within a professional football academy were hegemonized by the historical culture which had existed within the industry for years. The social control elicited by a coach has been further investigated (Purdy et al., 2008; Purdy and Jones, 2011) in adult sport and is perceived to be more transient with the idea of power being negotiable between the coach and athlete depending on the circumstance (Poczwardowski et al., 2002; Cushion et al., 2003; Purdy et al., 2008). Jones (2006) also argued that the coach perceived that they were required to interact socially with other contextual stakeholders such as technical staff to maintain their status of power. This is in accordance with Giddens (1984) conceptualization of power that showed the subservient parties had the ability to change the balance of power relationships through social interactions. This was further validated by Purdy et al. (2008) when the athletes showed resistance in addition to compliance and co-operation to a coach in turmoil (Locke, 1985).

The concept of the power dynamic struggles between asymmetrical relationships is well documented and as a result of hierarchical relationships (Cushion et al., 2003; Jones et al., 2009). However, it was suggested that a strong relationship identified through the 3+1C's model (Jowett, 2007) could negate the conflict that has often been associated with this type of dyad which would result in the coach often looking to teach and guide the protégé (Jowett et al., 2012a). McCalla and Fitzpatrick (2016) argued that although micro-politics are prevalent within high performance teams, when a synergy exists between the value of each contributing facet, and the experts of each field work within their remit, the potential of the staff can contribute to harmonious working environments. However, if the boundaries become blurred, then anxiety and confusion could develop (Frost et al., 2005).

Wright et al. (2013) examined 48 completed questionnaires from performance analysts and found that 89.4% of participants stated that the relationship between the coach and analyst was "Very Important." They discovered that analysts were consulted to varying degrees within professional football but very rarely led feedback sessions. They summarized that this was due to a number of factors including coaches trust in the analyst, but suggested further investigation was required. They also spoke of the negotiations around the design of analytical processes and defining measures of successful performance. This collaborative workflow contradict the results of Bampouras et al. (2012). Whilst they acknowledged the relationship was instrumental for analytical system success, the perception was that the analyst was responsible for purely collecting the information as directed by the coach. This idea of an unbalanced power relationship has been further supported by Huggan et al. (2015) when an analyst considered the value of the role and their own self-esteem due to the dominance of the coach in the applied setting.

Sarmento et al. (2015) provided evidence of the numerous benefits and attributes that analysts brought to a technical team. However, of the six coaches interviewed, only one coach had access to a full-time analyst which suggests other coaches may have based this opinion on beliefs or past experiences, rather than current circumstance. Huggan et al. (2015) had first hand narrative evidence from a Performance Analyst which reported the participant placed an emphasis on creating strong working relationships with cooperative and supportive colleagues. Manzanares et al. (2014) concluded that bridging the gap between the scientific analysis and the practical coaching process would be mutually beneficial and would only serve to enhance the development of athletes performance. The authors acknowledged the workload and resources required by the analysts within elite sport that was required to support the needs of the coach to make reliable technical and tactical appraisals of performance. Fernandez-Echeverria et al. (2017) have criticized the lack of studies which consider how the analyst is utilized by coaches within the coaching process. These suggestions have been highlighted in football, particularly as the role of a dedicated performance analyst is now a necessity in the current staffing structure (Reeves and Roberts, 2013).

As performance analysts have become more integral to the coaching and feedback process, Hughes (2004) indicated that analysis has interjected into the coach–athlete relationship. They found that the addition of another stakeholder in the process (gathering and analyzing data) allowed greater information share which is instrumental in developing teams. For this to be a successful working relationship, mutual trust and respect must be observed for all parties (Francis and Jones, 2014).

The research outlined above has provided evidence that the quality of the relationships coaches have with their athletes, and their ability to maintain them at a good level, has a correlation with the success that the athletes are able to attain. This coupled with the literature that identifies the performance analyst to be a key component in the coaching process justifies the need to examine the relationship of the coach and the performance analyst to investigate if maintenance strategies are transferable across to this dyad. There is limited research into the relationships between coaches and members of their sports science support staff, so this paper will aim to fill a gap within the literature that can further enhance the coaching process and expand the knowledge base within performance analysis and coaching. The aim of the study is to investigate the relationship between the coach and performance analyst within professional football. Specifically, the research is looking to confirm behaviors that relate to maintenance strategies within this dyad.

Aim 1. Investigate the main components of maintaining the coach–analyst relationship.

Aim 2. Determine if the conceptualized coach–athlete COMPASS model is adaptable to the coach–analyst relationship.

Aim 3. Understand any other pertinent trends which arise from the data.

MATERIALS AND METHODS

Participants

Expert purposive sampling was employed to enlist six current first team performance analysts working full time in professional football clubs in England. By stipulating first team analysts, the researcher was able to gain understanding from participants with significant experiences which hoped to enrich the data provided thorough insight into coach analyst relationships at the highest levels of professional sport (Simonton, 1999; Jowett and Cockerill, 2003). They were also required to have maintained a current or past coach analyst relationship for a minimum of 6 months (Jowett et al., 2012a,b; Jowett and Carpenter, 2015). The selected contributors were recruited personally due to pre-existing relationships with the researcher who had a previous career within the industry. Participants received an information pack which clarified the aims of the study, included an information sheet about the underlying 3+1C's model and an informed consent sheet.

The six participants ranged in age from 25 to 37 years with a mean age of 30.3 years (±4.88 years) and had an average of 8.16 years (±3.2 years) experience working as a performance analyst within professional football. Five out of the six interviewees had worked for four professional teams and the sixth had worked for two teams during their nine years' experience. The participants current coach analyst relationships ranged between 3 and 24 months (mean = 10.3 ± 7.5 months). The shortest dyadic working relationship encountered during the analyst's careers was acknowledged as 21 days by A3 who was also involved in the longest continuous relationship (5 years). The average for the shortest relationship was 84 days (±46 days) and 30 months (±17.69) for the longest relationship.

Procedures

Ethical approval was granted by the University of Worcester's ethics and research governance committee to undertake this study. Written and voluntary informed consent was obtained from all participants within the study. The interview questions were validated through a pilot interview with an experienced performance analyst (greater than 10 years' experience) to assist in identifying any epistemological concerns (Kim, 2010). This initial authentication process resulted in the addition of one question to the schedule to improve the balance of the questions being asked.

The interviews were conducted via telephone (O'Donoghue, 2010, p. 39; Jowett et al., 2012a). This style of data collection negated any restrictions on participation based on the analyst location and has been validated as useful for shorter, focused interviews with busy people (Miller, 1995). The duration of the interviews lasted between 21 min, 14 s and 50 min, 25 s. Semi structured, open ended questions were used with prompts where required based on the conceptualized COMPASS model, the validation of the categories via the CARM-Q framework (Rhind and Jowett, 2010, 2012) and the 3+1C's framework (Jowett, 2007). The interview was split into three parts; an introductory section to build rapport with the interviewees and collect demographic information (Kvale and Brinkmann, 2009, pp. 123–125). Secondly, the main section of the interview asked four questions pertaining to the analyst's perceptions and experiences of relationship maintenance strategies (**Supplementary Data Sheet 1**). Finally, the participants were offered an opportunity to provide any further information they deemed pertinent to the investigation.

An independent coder who had experience of both the applied Performance Analyst role (3 years) and theoretical Academic role (2 years) was employed to assess the raw data units obtained from interview one to ensure the results were not biased via the researcher's knowledge or experiences (Woods and Thatcher, 2009; Jones et al., 2014). Fifty-seven deductive data units and forty inductive data units were investigated and categorized by the coder which resulted the re-categorization of two units.

Owing to the researchers 10 years' experience of working within professional football, knowledge of all participants annulled the need to spend time *in situ* building rapport with the analysts. This closeness and prior knowledge of the industry could have led to personal bias, so the researcher practiced bracketing of their opinion through the pilot study and continued this during the main study (Tufford and Newman, 2010). Transcripts of all interviews were sent to the respective interviewee to confirm the accuracy of their account. All participants had their data anonymized whereby each interviewee was referred to as A1–A6 and where names were referred to, pseudonyms were used where required to hide the true identity of those involved.

Data Analysis

Content analysis was used to systematically discover themes within the data (Weber, 1990, p. 41). After reviewing the interview transcriptions, a deductive content analysis identified themes and sub themes based upon previous research (Rhind and Jowett, 2010, 2012). An inductive approach was also used to identify themes previously not recorded (Rubin and Rubin, 1995; Elo and Kyngäs, 2008). 215 meaningful units were found in the deductive analysis and 142 units were created through the inductive analysis. All units were highlighted and catergorised accordingly.

RESULTS AND DISCUSSION

"COMPASS Model" in the Coach–Analyst Relationship

The coded results showed (**Table 1**) that raw data units were divulged for all seven themes within the amended "COMPASS Model" (Rhind and Jowett, 2010, 2012). All six analysts provided insights regarding six of the seven themes yielding varying levels of raw data units ranging between 6 and 18.1% of the total raw units. In percentage contribution order, the results were; Support (18.1%), Preventative Strategies (16.3%), Motivation and Social Networks (14.5%), Conflict Management (11.2%), and Assurance (6%). of the total raw data, Openness provided statements by five out of six participants although it had the highest total number of raw data units of any of the themes commanding 19.5% of the total number of units.

Conflict Management

Conflict management was responsible for the reactive elements of maintaining relationships. This is in contrast to Rhind and Jowett (2010) as the pro-active statements were later considered to be their own category (Rhind and Jowett, 2012). It correlated the findings of the subcategory "Consequences of Unmet Expectations" with nine observations (4.2%). These ranged from not allowing conflict to affect the relationship by A1 who stated:

> "*if I overstepped the mark, he would either let it go, or he would pull you up on it but it wouldn't ever be a negative thing*"

Through to severe consequences that ended the association for A3:

> "*When you stop being part of a group, or the group I suppose, then I found myself out the door with my p45 so you know, there's cause and effect*"

Five of the six interviewees reported attempts to diffuse conflicts once they had arisen to enable the relationship to be maintained. These predominately focused around confronting the issue:

> "*if you do have an issue, that it's not just kind of brushed under the carpet, it's raised in the right way, communicated in the right way and its dealt with at the appropriate time*" (A6: 8 of 15 data units in this sub category)

Or trying to provide solutions with various statements beginning in this manner:

> "*Now I tried to resolve this...*" (A3)

> "*I think there was smaller things in place where I'd try and get round it...*" (A2)

> "*I ended up realising that all I had to do...*" (A5)

The attempts to resolve the situations through co-operative acts was in correlation with the findings of Rhind and Jowett (2010). This was also confirmed by Jowett (2003) who found that if either member of the dyad was unwilling to try and understand the source of the conflict, then the relationship could not be restored to its previously successful state. This studies results suggest the analysts were able to engage in these conversations although the threat of being dismissed due to conflict was still evident from two analysts.

Openness

Openness contained two of the three sub categories that were also reported by Rhind and Jowett (2010). Other awareness (understanding how the coach is feeling) was not conveyed although 42 units highlighting both non-sport communication (8.8%) and talk about anything (10.7%) themes were present. The two main subcategories to emerge from non-sport communicating were honesty and trust which centered around discussion of topics that were still work related (Rhind and Jowett, 2010). Examples were provided by A4, A5, and A6 respectively:

> "*have that honesty and openness between the both of you to try and improve what you're doing*"

> "*But in terms of having conversations that I know, they wouldn't want to leave them four walls, you've obviously been in plenty of them, and I guess that's a good sign, that you're trusted and accepted*"

> "*I think the key things trust between the two, the coach and the analyst. So, they've got to be able to have two way trust in each other so the coach can trust that the analyst is giving them good information and the analyst trusts that the coach is going to use it and use it the correct way*"

For the analyst, the thought of being trusted and respected was paramount in maintaining open relationships with the coach. This perception of closeness (Jowett and Meek, 2000) was imperative for the analyst to feel they were deemed competent by the coach (Jowett and Cockerill, 2003) and has been shown to differentiate between harmonious and non-harmonious relationships (Canary and Stafford, 1994; Francis and Jones, 2014). These findings built upon Wright et al.'s (2013) call for more research into the trust between the coach and analyst.

TABLE 1 | Summary of the results from the COMPASS Model.

	Frequencies				Frequencies				Frequencies		
Compass model	***n***	**%**	**Analysts**	**Higher order**	***n***	**%**	**Analysts**	**Lower order**	***n***	**%**	**Analysts**
Conflict management	24	11.2	6/6	Reactive	24	11.2	6/6	Consequences of unmet expectations	9	4.2	4/6
								Diffusion of conflict	15	7.0	5/6
Openness	42	19.5	5/6	Non-sport communication	19	8.8	5/6	Honesty	14	6.5	5/6
								Trust	5	2.3	3/6
				Talk about anything	23	10.7	5/6	Approachability	13	6.0	3/6
								Providing your opinion	10	4.7	5/6
Motivation	31	14.4	6/6	Effort	7	3.3	3/6	Commitment to the coach	6	2.8	3/6
								Positivity	1	0.5	1/6
				Fun	4	1.9	2/6	Humor	4	1.9	2/6
				Motivate the other	9	4.2	5/6	Togetherness	6	2.8	3/6
								Multidisciplinary team togetherness	3	1.4	2/6
				Show ability	11	5.1	4/6	Hard work	11	5.1	4/6
Preventative strategies	35	16.3	6/6	Avoiding conflict	14	6.5	6/6	Awareness of coach expectations	5	2.3	3/6
								Submissive avoidance	9	4.2	4/6
				Relationship continuity	8	3.7	5/6	Establishing early understanding	4	1.9	4/6
								Judging dyadic preferences	4	1.9	3/6
				Respecting boundaries	13	6.0	4/6	Respecting others	11	5.1	4/6
								Solution based opinion	2	0.9	1/6
Assurance	13	6.0	6/6	Constructive feedback	1	0.5	1/6	Advice	1	0.5	1/1
				Sport communication	12	5.6	6/6	Relationship building phase	4	1.9	3/6
								Providing analytical expertise	8	3.7	5/6
Support	39	18.1	6/6	Person support	10	4.7	3/6	Mutual respect	4	1.9	2/6
								Unconditional support	6	2.8	2/6
				Sport support	29	13.5	6/6	Communication	5	2.3	4/6
								Understanding coach requirements	24	11.2	5/6
Social networks	31	14.4	6/6	Socialization	4	1.9	1/6	Maintaining previous relationships	4	1.9	1/6
				Shared network	27	12.6	6/6	Casual interactions	10	4.7	5/6
								Obligatory socialization	7	3.3	3/6
								Socialization through sport	10	4.7	4/6
Total	215	100.0		Total	215	100.0		Total	215	100.0	

The present results may have been found due to the length of the dyadic relationships which were not reported within the Wright study.

"Approachability" and "Providing Your Opinion" materialized within the "Talk About Anything" sub category although the overriding premise still surrounded work-based conversations. A6 talked extensively (6 of 13 units) about approachability and examples included:

> "*if you've got a good relationship with someone, regardless of if you agree with them. I mean, it can go both ways. You can get on with someone personally but not agree with them professionally, or the other way around, but as long as you've got at least one of those relationships, you can be, you can have that conversation*"

> "*it's important you get to know the coach as well as you can on an individual work level and how they like information*"

This correlated with the results from Rhind and Jowett (2010) and was further underpinned by the "Openness" facet of Stafford and Canary's (1991) work.

Motivation

Unlike the findings of Rhind and Jowett (2010), Motivation was not the most frequently discussed form of relationship maintenance, although it was mentioned by 100% of participants. It provided 14.4% of the total units and was catergorised into effort, fun, motivate the other and show ability in line with previous literature (Rhind and Jowett, 2010). Effort suggested a commitment to the coach and was highlighted by the following quotes:

> "*So results affect you more and you're more willing to go the extra mile. For example, we lost a game earlier in the season and I was up until... I stayed up until. I think it was like 5 o clock in the morning after that night game, changing this match report because I was motivated to help and make things better.*"

> "*I think sometimes the best relationships, you probably are willing to do the extra that you might not if you didn't have that relationship with the coach*"

Motivate the other resulted in quotes that alluded to togetherness of the multidisciplinary team as well as the specific dyad in question. A2 and A4 spoke enthusiastically about this subject:

> "*He knows it's not just always all about him. And that there's he has a team of staff and he wants to keep them happy, he wants you to want to work for him*"

> "*empowered straight away if someone is going to be willing to listen to your opinions based on your analysis that you've done. Umm, so yeah, very empowered, very valued from that interaction*"

The following quotes regarding the requirement of the analyst to work hard in order to show ability was mirrored by 4 out of the 6 analysts interviewed.

> "*if you keep performing as they asked or above, then they get more faith in you, they'll give you more respect, more pressure, and then you'll build a better relationship*"

> "*standards remain really high, so the quality of the work you're producing is still of the standard that's required that I think that helps maintain that relationship along the way*"

Akin to the findings of Huggan et al. (2015), the analyst's willingness to provide extra effort based upon the perceived strength of the relationship was also demonstrated. Their findings also allied to the suggestions that portraying motivation also created more supportive colleagues, leading to stronger relationships (Huggan et al., 2015).

Preventative Strategies

This dimension was considered important by all participants and provided 16.3% of the total raw units. The sub categories were made up of "Avoiding Conflict," "Respecting Boundaries" (respecting others role and responsibility within the team) and "Relationship Continuity" (through establishing early understanding and judging dyadic preferences. The relative contribution to these results suggest that the requirement to be separate from Conflict Management was justified (Rhind and Jowett, 2012).

By establishing early understanding of the coaches' methods, it was perceived that the analyst could adapt their work to suit the preferences of the manager. A4 summarized this by stating:

> "*Is to very quickly understand what they require and kind of, shape your work to that because if you don't, I think that's when you start to encounter problems*"

3 of 6 interviewees built upon this, suggesting that by having the ability to judge the preferences and character of the coach, they could then ensure the relationship strength was maintained. A3 stressed this by saying:

> "*I think you have to get a read on people and rather than chase people round stadiums and pitches with a laptop you need to know when to, when to speak, when you're allowed to speak, and when to say nothing*"

The concept of respecting boundaries continued the closely associated themes with 5.1% of the data units acknowledging that:

> "*Really clear guidelines and like, a real good understanding of what was required from both sides*" (A4)

was key to the success of the relationship. By establishing rules, not only did the relationship reduce the possible conflict scenarios, but also allows for greater motivation from both parties (Jowett and Carpenter, 2015).

Avoiding conflict was subdivided into two themes. "Awareness of Coach Expectations" and "Submissive Avoidance" both showed aspects of the micro-politics associated within this type of dyadic relationship. A2 talked about coach expectations of the analyst:

> "*I think delivering, delivering results so like, getting stuff ready or like hitting deadlines etc. – if the coach or manager has asked you for something for a certain time, ya know, have you delivered on time. If you're failing to deliver then they'll stop asking you for things, that relationships gunna break down*"

And A3 spoke around submissive avoidance in order to maintain parity within the relationship:

> "*So they say, we might do a meeting, and then you know that they won't, but you have do it anyway, just in case you do have to do it*"

These outcomes add to the current literature surrounding the requirement for the performance analyst to be subordinate to the coach in order for relationships to be maintained (Bampouras et al., 2012; Huggan et al., 2015).

Assurance

Assurance was an adaptation from the original COMPASS Model (Rhind and Jowett, 2010) after it replaced "Advice" but it was responsible for the lowest collection of data units, registering just 6% of the total findings. It was however, supported by all participants of the study and primarily revolved around sport communication (12 of 13 total units). Similarly to Preventative Strategies, an emphasis was placed upon the building phase of the relationships to cement the status of the relationship, but data units suggested that they would provide assurances of how they could impact on the success of the athletes rather than being submissive. A6 and A1 supposed:

> "*I think probably try and at the very start, in terms of getting an understanding of what they want, and try just to say look this is, this is how I think this could be better*"

> "*once that relationship starts building up they will start asking you more and more questions regarding more tactical side of things. So once I had built that relationship up, they were asking me, and I felt open enough to suggest ideas of how meetings could be led and how we can engage players more and how we can get players to get more out of the meetings*"

It was suggested that providing analytical expertise would have a positive effect on the relationship with the coach. A3 and A4 recalled:

> "*And he'll walk in the next day and you have the successful and unsuccessful crosses broken down and you'll say, ya know, just based on what you said to the other coaches, here's some bits and pieces and he might show that back to the lads*"

> "*quite a lot of our discussion around the pre match was normally verbal, rather than documents if you like so, we would sit an brief the manager on kinda, how we were going to play or how the opposition play*"

There was consensus with previous findings that show how the analyst's skill-set and alternative viewpoint allowed for greater opportunities for athletes to improve (Hughes, 2004; Francis and Jones, 2014; Huggan et al., 2015).

Support

Three of the analysts referenced the personal support that they felt was important within the coach–athlete dyad. A4 provided 3 of the 4 units for this subcategory and suggested:

> "*I think respect, kind of a mutual respect between the two is very important*"

This was contradicted, primary by A1 and A2 who believed they were required to give their unconditional support to the coach, as in A2's words:

> "*the gaffer is the one at the top, with the decision making. He's got the final say on everything, but he's got to have his own staff, and he's got to have staff that want to work for him*"

This challenges the findings of Jowett and Cockerill (2003), who perceived that interpersonal relationships were ineffective if the coaches support and knowledge were deemed inadequate by the athlete.

Sport Support was supported with 29 data units (13.5% of the total recorded) from 6 out of 6 analysts'. The majority (24) of these focused around understanding the coaches' requirements. A3 suggested that part of the responsibility lay with the analyst when they said:

> "*you should almost be able to anticipate what the coach wants*"

Whereas A6 had experienced coaches that prescribed the support they required explicitly.

> "*I've worked with coaches that, they know exactly what they want, and they don't really want to deviate from that so it's a case of this is what you're going to do, this is how you're going to do it, that's it!*"

These conflicting viewpoints of the participant have been shown to be important for maintaining relationships as the coach and analyst may need to show leading roles in addition to support roles in certain circumstances throughout the lifespan of the relationship (Jowett et al., 2012a; Yang and Jowett, 2013).

Social Networks

Socialization (the social interaction which only included the two members of the dyad) was only alluded to by A1. The 4 (1.9%) examples they provided related to maintaining previous relationships with coaches they are not currently working with:

> "*13 of my 14 managers I get on with, still got my back, pick up the phone to them now and speak to them now*"

> "*But in a positive way, I've been asked to work for previous managers on a few occasions and I've had to decline. But I think that shows they value me, and my honesty and my relationship with them*"

This was in stark distinction to previous research which found that 21 of 25 data units were focused upon socializing solely with the coach (Rhind and Jowett, 2010). The participants were mainly sub elite and individual sport focused so may not have been involved within such large sporting environments that employed numerous technical and coaching staff. By showing that maintaining relationship with coaches they were not currently working with professionally, the analyst was able to provide future opportunities for employment within a dyad they perceived as strong and could therefore lead to greater job satisfaction and motivation (Butterworth and Turner, 2014; Huggan et al., 2015).

The remaining units (27–12.6%) were focused around shared networks and were cited by all six analysts. This sub category was further divided into three themes of "Casual

Interactions" (non-sport or work-related activities), "Obligatory Socialization" (situations where attendance was mandatory such as end of season awards, or team meals during away travel) and "Socialization Through Sport" (both within work and outside work). A4 defined their interactions with the coach as compulsory:

"*There was always a work kind of emphasis on those kind of... You know, if it was a meal or a get together, it was always kind of work related*"

This was in stark contrast to 5 of 6 analysts, including A2, who provided positive examples of casual interactions with the coach:

"*it just gives you that sort of extra, you get to know more about the person, it's not just always a working relationship. You get to learn a bit more outside which then helps your working relationship*"

Socialization through sport, especially within the confines of the working environment was discussed optimistically on 10 occasions by 4 of the analysts. A6 talked about head tennis matches with staff:

"*the court opens up and it's a good interaction for staff from different departments, not just coach and analyst but it gets you the opportunity to kind of have a bit of, a bit of fun, a bit of a laughter, a bit of joking around, a bit of competition and you kind of see how the coach reacts in different ways*"

This correlates with findings that social interaction could have positive correlations on the dyad in addition to wider relationships (Jowett and Chaundy, 2004; Rhind and Jowett, 2010). Huggan et al. (2015) also concluded that the social interactions created greater co-operation within the coach–analyst relationship.

Power Relationships in the Coach–Analyst Relationship

The inductive content analysis provided 142 raw data units related to power relationships and micro-politics (**Table 2**). Whilst there was data units that aligned to previous research (French and Raven, 1959), especially coercive power:

"the managers great but ya know, he still the manager and he's still the one that's gunna sack ya at the end of the day" (A3)

"the managers more inclined to get rid of you because you don't have a connection and relationship with him" (A1)

And legitimate power:

"whatever he says in fine. Don't feel as if you can say, ya know, why don't we try this instead? I listen to whatever he says, and whether I like it not, you go away and do it which I guess is the point of the manager, but at the same time, my expertise is in analysis. That's where my expertise lies and I might know more than them, I might know better way to do things but I don't feel as though I can bring that up because I don't feel as though they're going to want to hear it or they'll shoot me down" (A2)

"I said about just listening and producing exactly what they want rather than what you want to do" (A1)

TABLE 2 | Summary of results of Power Relationships in the Coach–Analyst Relationship.

Theme	Hierarchical	Task focused	Social	Total
Authority	**37**	**53**	**5**	**95**
%	26.1	37.3	3.5	66.9
No of analysts	5/6	6/6	4/6	6/6
Equality	**11**	**19**	**17**	**47**
%	7.7	13.4	12.0	33.1
No of analysts	5/6	6/6	4/6	6/6
Total	**48**	**72**	**22**	**142**
%	33.8	50.7	15.5	
No of analysts	6/6	6/6	5/6	

It was felt the data suggested a very specific type of relationships that was governed by three main higher order themes. These original themes were identified as Hierarchical (thoughts and feelings, non-specific), Task Focused (work related tasks and activities) and Social (non-work related). 66.9% of the points allied to an authoritarian approach whereby the coach was controlling of the relationship. All six analysts provided responses which represented both an authoritarian (Coach dictates) and an equal (where responsibility or behaviors are on a matched level). This was in connection with prior empirical evidence around compliance and co-orientation (Locke, 1985; Purdy et al., 2008).

Hierarchical Theme

The following two quotes denoted how the behavior of analyst was dictated by the coach:

"*Be respectful, that's difficult sometimes when you're feeling down and your struggling for motivation. At the end of the day, he's the manager of the football club. Whether he deserves respect or not, you have to give it him because that the nature of the industry we're in*" (A1)

"*I think a lot of the time, the coach analyst relationship, if one of you is wrong, the analyst has to take it and go ok, well I guess I'm wrong*" (A5)

This form of compliance was responsible for 26.1% of the inductive results and was in-keeping with the findings of Cushion and Jones (2006) and Purdy and Jones (2011). The analysts perceived themselves to be in a similar predicament to the athletes, in that any rebellion against the coaches, may jeopardize their future career within elite sport. In contradiction to these findings, a desire for a more equal relationship was alluded to by just 7.7% of the units suggesting that the coach does command power over the analysts within the workplace.

Task Focused Theme

The greatest number of comments were recorded in the Task Focused Authority group and offered 37.3% of the total units analyzed. Comments were recorded from all 6 analyst's and suggested that most work processes and analysis that was undertaken was controlled by the coach. A2 summarized this section by stating:

"*I listen to whatever he says, and whether I like it not, you go away and do it which I guess is the point of the manager, but at the same time, my expertise is in analysis. That's where my expertise lies and I might know more than them, I might know better way to do things but I don't feel as though I can bring that up because I don't feel as though they're going to want to hear it or they'll shoot me down*"

Although sometimes begrudgingly, the analysts showed that they entered into a consented coach dominated scenario which led to a legitimate power relationship (Cushion and Jones, 2006). This category helps to unearth some of the intricacies' of how the analyst is deployed by coaches within professional football which was considered to be previously sparse (Fernandez-Echeverria et al., 2017).

In repost, A4 provided examples of equality with one particular coach which was perceived by visiting coaches as usual. They suggested that under this coach:

"*it would be very much open and for example, developing a game plan for the weekend. He might say, Oh, I want to play this formation, I would say well, if we play that formation, this might, these are the problems we might encounter. You know, have you thought about doing this?*"

Giddens (1984) argued that within any structure, the persons within must sanction power being exerted over them for that power to be successful. Therefore, if both parties have an alternative mindset, this may lead to a different relationship that deserves further scrutiny.

Social Theme

The social theme was the only category which provided greater responses surrounding equality (12%) than authoritative behaviors (3.5%). Just five comments were recorded, which centered around financial authority and humor. A5 said:

"*have a good sense of humor between you, you're more than happy to take the stick, more than you're probably giving it, I think it's quite important*"

Purdy et al. (2008) found that the use of humor and banter between coaches and athletes was often used to instill a belief of influence over the other. They also found that in accordance with Giddens (1984), social interactions were used to change the balance of power and this was validated by the current study with comments being expressed to support this argument:

"*they're great exercise because the manager stops being the manager and becomes the person that you're sat in the pub with*" (A3).

CONCLUSION

This study outlines that the COMPASS Model, developed through research into the coach–athlete relationship, is transferable across dyads within sport with only minor alterations based upon the roles and responsibilities of analysts. The strategies suggested for maintaining the relationship are centered around the analyst understanding the requirements of the coach to support their needs. By employing a hard working ethos, underpinned by honesty and being approachable, the analysts perceive that the relationship can be productive. The results also highlight the need to employ strategies to prevent conflict occurring as it can lead to the breakdown of relationships if not dealt with swiftly and utilizing the aforementioned behaviors. The respondents also found that socialization through sport and casual interactions was a positive contributor of healthy relationships as it balances the *status quo* of the relationship. This was highlighted by an inductive analysis has also that showcased the existence of authoritative coach behavior's that, whilst not always appreciated by the analyst, often serve to provide the rules that govern relationships.

The results offer aspiring performance analysts insight into the working relationships within first team elite football environments. This is often perceived as an inaccessible environment due to the secretive nature of professional football and as such, it offers relatively unreported insight. This provides clarity for behaviors which may shape the success and ability of analysts to maintain close working relationships that have been shown to correlate to increased technical and tactical insights for opportunities to improve performance outputs. This paper also provides coaches with knowledge of the perceptions of the performance analyst within this working relationship and how their actions may have a positive or negative effect on the analysts view of the dyad. This may enable coaches to consider their behavior to maintain or enhance their relationships with the analyst and other sport science support staff.

Although the underlying research that developed the COMPASS Model acknowledged the transferability of the conceptualization, only interviewing one half of the investigated dyad may have had an impact on the generalizability of the results. Future studies should look to interview both the coach and analyst to better understand the perspectives and meta perspectives of both persons as the coach would likely have a different portrayal of events. Whilst the use of telephone interviews was justified due to geographical locations of the participants, the inability to view the non-verbal cues of the analyst's may have caused the researcher to impact upon the flow of conversation.

As this study has investigated a previously unreported area, it should serve as a basis for future research and not be considered conclusive on the subject. Further studies may wish to consider if similar results are found in academy football relationships or across different sports. The identification of power within the relationship may serve as a foundation for future exploration of this phenomena within other relationships within coaches and technical staff within elite sport so that we may provide academia with insight from the applied world.

DATA AVAILABILITY

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the University of Worcester with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the University of Worcester.

AUTHOR CONTRIBUTIONS

MB organized the data collection and analysis, and provided the draft one. GJ read and edited necessary revisions to the manuscript. Both the authors contributed to the conception and design of the work, and confirmed the version was ready for submission.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02064/full#supplementary-material

REFERENCES

Adie, J. W., and Jowett, S. (2010). Meta-perceptions of the coach-athlete relationship, achievement goals, and intrinsic motivation among sport participants. *J. Appl. Soc. Psychol.* 40, 2750–2773. doi: 10.1111/j.1559-1816.2010.00679.x

Bampouras, T. M., Cronin, C., and Miller, P. K. (2012). Performance analytic processes in elite sport practice: an exploratory investigation of the perspectives of a sport scientist, coach and athlete. *Int. J. Perf. Anal. Sport* 12, 468–483. doi: 10.1080/24748668.2012.11868611

Butterworth, A. D., and Turner, D. J. (2014). Becoming a performance analyst: autoethnographic reflections on agency, and facilitated transformational growth. *Reflect. Pract.* 15, 552–562. doi: 10.1080/14623943.2014.900014

Canary, D. J., and Stafford, L. (1994). *Maintaining Relationships Through Strategic and Routine Interaction. in Communication and Relational Maintenance*. San Diego, CA: Academic Press.

Carson, P., Carson, K., and Roe, W. (1993). Social power bases: a meta-analytic examination of interrelationships and outcomes. *J. Appl. Soc. Psychol.* 23, 1150–1169. doi: 10.1111/j.1559-1816.1993.tb01026.x

Côté, J., Salmela, J. H., Baria, A., and Russell, S. J. (1993). Organizing and interpreting unstructured qualitative data. *Sport Psychol.* 7, 127–137. doi: 10.1123/tsp.7.2.127

Clement, D., and Arvinen-Barrow, M. (2013). "Sport medicine team influences in psychological rehabilitation: A multidisciplinary approach," in *The Psychology of Sport Injury and Rehabilitation*, eds M. Arvinen-Barrow and N. Walker (New York, NY: Routledge/Taylor and Francis Group), 156–170.

Cushion, C., and Jones, R. L. (2006). Power, discourse, and symbolic violence in professional youth soccer: the case of albion football club. *Sociol. Sport J.* 23, 142–161. doi: 10.1123/ssj.23.2.142

Cushion, C. J., Armour, K. M., Jones, R. L., Cushion, C. J., Armour, K. M., Coach, R. L. J., et al. (2003). Coach education and continuing professional development: experience and learning to coach. *Quest* 55, 215–230. doi: 10.1080/00336297.2003.10491800

Dindia, K., and Canary, D. J. (1993). Definitions and theoretical perspectives on maintaining relationships. *J. Soc. Pers. Relatsh.* 10, 163–173. doi: 10.1177/026540759301000201

Elo, S., and Kyngäs, H. (2008). The qualitative content analysis process. *J. Adv. Nurs.* 62, 107–115. doi: 10.1111/j.1365-2648.2007.04569.x

Fernandez-Echeverria, C., Mesquita, I., González-Silva, J., Claver, F., and Perla Moreno, M. (2017). Match analysis within the coaching process: a critical tool to improve coach efficacy. *Int. J. Perf. Anal. Sport* 17, 149–163. doi: 10.1080/24748668.2017.1304073

Francis, J., and Jones, G. (2014). Elite rugby union players perceptions of performance analysis. *Int. J. Perf. Anal. Sport* 14, 188–207. doi: 10.1080/24748668.2014.11868714

French, J., and Raven, B. (1959). "The bases of social power," in *Studies in Social Power*, ed. D. Cartwright (Ann Arbor, MI: Institute for Social Research), 150–167.

Frost, N., Robinson, M., and Anning, A. (2005). Social workers in multidisciplinary teams: issues and dilemmas for professional practice. *Child Fam. Soc. Work* 10, 187–196. doi: 10.1111/j.1365-2206.2005.00370.x

Giddens, A. (1984). *The Constitution of Society: Outline of the Theory of Structuration*. Berkeley, CA: University of California Press.

Groom, R., Cushion, C., and Nelson, L. (2012). Analysing coach-athlete 'talk in interaction' within the delivery of video-based performance feedback in elite youth soccer. *Q. Res. Sport Exerc. Health* 4, 439–458. doi: 10.1080/2159676X.2012.693525

Gustafsson, H., Holmberg, H. C., and Hassmen, P. (2008). An elite endurance athleteŠs recovery from underperformance aided by a multidisciplinary sport science support team. *Eur. J. Sport Sci.* 8, 267–276. doi: 10.1080/17461390802195652

Huggan, R., Nelson, L., and Potrac, P. (2015). Developing micropolitical literacy in professional soccer: a performance analyst's tale. *Q. Res. Sport Exerc. Health* 7, 504–520. doi: 10.1080/2159676X.2014.949832

Hughes, M. (2004). Performance analysis – a 2004 perspective. *Int. J. Perf. Anal. Sport* 4, 103–109. doi: 10.1080/24748668.2004.11868296

Johns, D. P., and Johns, J. S. (2000). Surveillance, subjectivism and technologies of power: an analysis of the discursive practice of high-performance sport. *Int. Rev. Sociol. Sport* 35, 219–234. doi: 10.1177/101269000035002006

Jones, G. W., Høigaard, R., and Peters, D. M. (2014). Just going through the motions: a qualitative exploration of athlete perceptions of social loafing in training and competition contexts — implications for team sport coaches. *Int. J. Sports Sci. Coach.* 9, 1067–1082. doi: 10.1260/1747-9541.9.5.1067

Jones, R. (2006). *Dilemmas, Maintaining "Face," and Paranoia An Average Coaching Life*. Thousand Oaks, CA: Sage.

Jones, R. L., Harris, R., and Miles, A. (2009). Mentoring in sports coaching: a review of the literature. *Phys. Educ. Sport Pedagogy* 14, 267–284. doi: 10.1080/17408980801976569

Jowett, S. (2003). When the honeymoon is over. a case study of a coach-athlete dyad in crisis. *Sport Psychol.* 17, 444–460. doi: 10.1123/tsp.17.4.444

Jowett, S. (2007). "Interdependence analysis and the 3+1Cs in the coach-athlete relationship," in *Social Psychology in Sport*, eds S. Jowette, and D. Lavallee (Champaign, IL: Human Kinetics).

Jowett, S. (2009). Factor structure and criterion-related validity of the metaperspective version of the coach-athlete relationship questionnaire (CART-Q). *Group Dyn.* 13, 163–177. doi: 10.1037/a0014998

Jowett, S., and Carpenter, P. (2015). The concept of rules in the coach-athlete relationship. *Sports Coach. Rev.* 4, 1–23. doi: 10.1080/21640629.2015.1106145

Jowett, S., and Chaundy, V. (2004). An investigation into the impact of coach leadership and coach-athlete relationship on group cohesion. *Group Dyn.* 8, 302–311. doi: 10.1037/1089-2699.8.4.302

Jowett, S., and Clark-Carter, D. (2006). Perceptions of empathic accuracy and assumed similarity in the coach-athlete relationship. *Br. J. Soc. Psychol.* 45, 617–637. doi: 10.1348/014466605X58609

Jowett, S., and Cockerill, I. M. (2003). Olympic medallists' perspective of the althlete-coach relationship. *Psychol. Sport Exerc.* 4, 313–331. doi: 10.1016/S1469-0292(02)00011-0

Jowett, S., Kanakoglou, K., and Passmore, J. (2012a). The application of the 3+1Cs relationship model in executive coaching. *Consul. Psychol. J.* 64, 183–197. doi: 10.1037/a0030316

Jowett, S., Yang, X., and Lorimer, R. (2012b). The role of personality, empathy, and satisfaction with instruction within the context of the coach-athlete relationship. *Int. J. Coach. Sci.* 6, 3–20.

Jowett, S., and Meek, J. (2000). The coach-athlete relationship in married couples. *Sport Psychol.* 14, 157–175. doi: 10.1123/tsp.14.2.157

Jowett, S., and Ntoumanis, N. (2004). The coach–athlete relationship questionnaire (CART-Q): development and initial validation. *Scand. J. Med. Sci. Sports* 14, 245–257. doi: 10.1111/j.1600-0838.2003.00338.x

Kim, Y. (2010). The pilot study in qualitative inquiry. *Q. Soc. Work* 10, 190–206. doi: 10.1177/1473325010362001

Kvale, S., and Brinkmann, S. (2009). *InterViews: Learning the Craft of Qualitative Research Interviewing*. Thousand Oaks, CA: Sage.

Lafrenière, M.-A. K., Jowett, S., Vallerand, R. J., Donahue, E. G., and Lorimer, R. (2008). Passion in sport: on the quality of the coach–athlete relationship. *J. Sport Exerc. Psychol.* 30, 541–560. doi: 10.1123/jsep.30.5.541

Locke, L. (1985). "Research and the improvement of teaching: the professor as the problem," in *Myths, models and methods in sport pedagogy*, eds M. Barrette, G. Feingold, R. Rees, and R. Pieron (Champaign, IL: Human Kinetics), 1–26.

Manzanares, P., Palao, J., and Ortega, E. (2014). The coach's perception of the performance of game actions in training sessions. a case study in volleyball. *Int. J. Perf. Anal. Sport* 14, 894–906. doi: 10.1080/24748668.2014.11868766

McCalla, T., and Fitzpatrick, S. (2016). Integrating sport psychology within a high-performance team: potential stak. *J. Sport Psychol. Act.* 7, 33–42. doi: 10.1080/21520704.2015.1123208

McKenna, J., and Mutrie, N. (2003). Emphasizing quality in qualitative papers. *J. Sports Sci.* 21, 955–958. doi: 10.1080/02640410310001641359

Miller, C. (1995). In-depth interviewing by telephone: some practical considerations. *Eval. Res. Educ.* 9, 29–38. doi: 10.1080/09500799509533370

O'Donoghue, P. (2010). *Research Methods for Sports Performance Analysis*. Abingdon: Routledge.

Olympiou, A., Jowett, S., and Duda, J. L. (2008). The psychological interface between the coach-created motivational climate and the coach-athlete relationship in team sports. *Sport Psychol.* 22, 423–438. doi: 10.1123/tsp.22.4.423

Patchen, M. (1974). The locus and basis of influence on organizational decisions. *Organ. Behav. Hum. Perf.* 11, 195–221. doi: 10.1016/0030-5073(74)90014-2

Patton, M. Q. (2002). *Qualitative Research & Evaluation Methods*. Thousand Oaks, CA: Sage.

Poczwardowski, A., Barott, J. E., and Henschen, K. P. (2002). The athlete and coach: their relationship and its meaning. results of an interpretive study. *Int. J. Sport Psychol.* 33, 116–140.

Purdy, L., Potrac, P., and Jones, R. (2008). Power, consent and resistance: an autoethnography of competitive rowing. *Sport Educ. Soc.* 13, 319–336. doi: 10.1080/13573320802200693

Purdy, L. G., and Jones, R. L. (2011). Choppy waters: elite rowers' perceptions of coaching. *Soc. Sport J.* 28, 329–346. doi: 10.1123/ssj.28.3.329

Raven, B. (1965). "Social influence and power," in *Current Studies in Social Psychology*, eds I. Steiner, and M. Fishbein (New York, NY: Holt McDougal), 371–382.

Raven, B. (1992). A power/interaction model of interpersonal influence: french and raven thirty years later. *J. Soc. Behav. Pers.* 7, 217–244.

Raven, B. (1999). Kurt Lewin address: influence, power, religion, and the mechanisms of social control. *J. Soc. Issues* 55, 161–186. doi: 10.1111/0022-4537.00111

Reeves, M. J., and Roberts, S. J. (2013). Perceptions of performance analysis in elite youth football. *Int. J. Perf. Anal. Sport* 13, 200–211. doi: 10.1080/24748668.2013.11868642

Reid, C., Stewart, E., and Thorne, G. (2004). Multidisciplinary sport science teams in elite sport: Comprehensive servicing or conflict and confusion? *Sport Psychol.* 18, 204–217. doi: 10.1123/tsp.18.2.204

Rhind, D. J. A., and Jowett, S. (2010). Relationship maintenance strategies in the coach-athlete relationship: the development of the COMPASS model. *J. Appl. Sport Psychol.* 22, 106–121. doi: 10.1080/10413200903474472

Rhind, D. J. A., and Jowett, S. (2012). Development of the coach-athlete relationship maintenance questionnaire (CARM-Q). *Int. J. Sports Sci. Coach.* 7, 121–137. doi: 10.1260/1747-9541.7.1.121

Rubin, H. J., and Rubin, I. (1995). *Qualitative Interviewing: the Art of Hearing Data*. Thousand Oaks, CA: SAGE Publications.

Rylander, P. (2016). Coaches' bases of power and coaching effectiveness in team sports. *Int Sports Coach. J.* 3, 128–144. doi: 10.1123/iscj.2015-0046

Sarmento, H., Bradley, P., and Travassos, B. (2015). The transition from match analysis to intervention: optimising the coaching process in elite futsal. *Int. J. Perf. Anal. Sport* 15, 471–488. doi: 10.1080/24748668.2015.11868807

Simonton, D. K. (1999). Significant samples: the psychological study of eminent individuals. *Psychol. Methods* 4, 425–451. doi: 10.1037/1082-989X.4.4.425

Stafford, L., and Canary, D. J. (1991). Maintenance strategies and romantic relationship type, gender and relational characteristics. *J. Soc. Pers. Relatsh.* 8, 217–242. doi: 10.1177/0265407591082004

Stafford, L., Dainton, M., and Haas, S. (2000). Measuring routine and strategic relational maintenance: scale revision, sex versus gender roles, and the prediction of relational characteristics. *Commun. Monogr.* 67, 306–323. doi: 10.1080/03637750009376512

Sweet, L. (2002). Telephone interviewing: is it compatible with interpretive phenomenological research? *Contemp. Nur.* 12, 58–63. doi: 10.5172/conu.12.1.58

Tufford, L., and Newman, P. (2010). Bracketing in qualitative research. *Q. Soc. Work* 11, 80–96. doi: 10.1177/1473325010368316

Wagstaff, C. R. D., Gilmore, S., and Thelwell, R. C. (2015). Sport medicine and sport science practitioners' experiences of organizational change. *Scand. J. Med. Sci. Sports* 25, 685–698. doi: 10.1111/sms.12340

Weber, R. (1990). *Basic Content Analysis*, 2nd Edn. Thousand Oaks, CA: Sage.

Woods, B., and Thatcher, J. (2009). A qualitative exploration of substitutes' experiences in soccer. *Sport Psychol.* 23, 451–469. doi: 10.1123/tsp.23.4.451

Wright, C., Atkins, S., Jones, B., and Todd, J. (2013). The role of performance analysts within the coaching process: performance analysts survey "the role of performance analysts in elite football club settings.". *Int. J. Perf. Anal. Sport* 13, 240–261. doi: 10.1080/24748668.2013.11868645

Wright, C., Carling, C., Lawlor, C., and Collins, D. (2016). Elite football player engagement with performance analysis. *Int. J. Perf. Anal. Sport* 16, 1007–1032. doi: 10.1080/24748668.2016.11868945

Yang, S. X., and Jowett, S. (2013). Conceptual and measurement issues of the complementarity dimension of the coach-athlete relationship across cultures. *Psychol. Sport Exerc.* 14, 830–841. doi: 10.1016/j.psychsport.2013.06.003

Yukl, G. (2006). *Leadership in Organizations*, 6th Edn. Upper Saddle River, NJ: Pearson Education.

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Exploiting Bi-Directional Self-Organizing Tendencies in Team Sports: The Role of the Game Model and Tactical Principles of Play

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Research has revealed how inherent self-organizing tendencies in athletes and sports teams can be exploited to facilitate emergence of dynamical patterns in synergy formation in sports teams. Here, we discuss how game models, and associated tactical principles of play, may be implemented to constrain co-existing *global-to-local* and *local-to-global* self-organization tendencies in team sports players during training and performance. Understanding how to harness the continuous interplay between these co-existing, bi-directional, and coordination tendencies is key to shaping system behaviors in sports training. Training programs are traditionally dominated by designs, which shape the self-organizing tendencies of players and teams at a *global-to-local* scale by coaches imposing a tactical/strategical plan with associated tactical principles of play. Nevertheless, recent research suggests that performers also need to be provided with opportunities to explore self-organizing tendencies that emerge at the *local-to-global* scale in training. This directional tendency in synergy formation can be facilitated by players being given opportunities to actively explore different adaptive and innovative performance solutions, coherent with principles of play circumscribed in an overarching game model. Developing methods (coaching sessions rooted on principles of dynamical systems theory that foment the development of such local-to-global relations) to exploit the continuous interplay between these co-existing tendencies within sports teams may promote more effective and efficient athlete skill training programs, in addition to enhancing performance.

Keywords: self-organization tendencies, bi-directional dynamical processes, game model, tactical principles of play, synergy formation, team sports

INTRODUCTION

In past decades, there has been a concerted attempt to conceptualize sports teams as complex adaptive systems (CAS) (Davids et al., 2005; Araújo and Davids, 2016). Such systems display similar tendencies (e.g., self-organization under constraints, pattern forming dynamics, synergy formation, emergent behaviors, and sensitive dependence on initial conditions) like those observed in other collective systems in nature (e.g., ant colonies, schools of fish, flocks of birds, and human communities) (Duarte et al., 2012; Riley et al., 2012). In such systems, emergent behaviors and self-organization under constraints appear to be instrumental in explaining how collective-system behaviors emerge. For example, in team sports, synergetic relations arise from the continuous individual component interactions (i.e., between players) (Vilar et al., 2012).

On the one hand, system order emerges from the self-organizing interactions of individual components without ordering from an external agent (i.e., an executive, coach or commander) (Halley and Winkler, 2008). On the other hand, emergence typically depicts a (global) system property (e.g., tactical patterns of behaviors in a sports team) that is not reducible to properties of individual system components (e.g., local interactions of individual players), from which it arises (Halley and Winkler, 2008). Both levels of interaction are intrinsically connected, giving rise to systems displaying both local-to-global and global-to-local self-organization tendencies (Riley et al., 2012). Local-to-global self-organizing processes imply that rich patterns of behavior observed in a complex adaptive system is constrained by local interactions generated through cooperative or interactive behaviors among system components (e.g., fish in a school, a murmuration of flocking birds or team players in sport) (Riley et al., 2011). Conversely, global-to-local self-organizing processes imply that global system behaviors govern or constrain local interactions of individual system components in a top-down fashion, exhibiting circular causality (Kelso, 1995; Araújo and Davids, 2016). Such circular causality processes evidenced in both global-to-local and local-to-global self-organizing processes signify, for example, that players may interact locally with their nearest teammates (e.g., retrieving the ball from the pressure zone after recovering it) to produce more complex set of behaviors. Such set or behaviors are expressed at higher levels, with players behaving as a collective social unit (e.g., increases in team width and length through increases of players' interpersonal distance values after recovering the ball). After the attainment of considerable levels of team width and length, there are some players that may need to cover crucial regions of the field in case of a momentarily ball-possession lose.

Essentially, circular causality (also known as non-linear causality) can be differentiated from linear causality due to the causal relationships established between the whole system and its constituents. While models involving linear causality follow a single, linear direction (event A causes an effect in B, while B has no demonstrable effect on A), non-linear causality depicts a circular causation between the whole system and its parts, involving global and local (bi-directional) self-organizing tendencies. Thus, linear causality in systems is characterized by processes of unidirectional flow of causation between both micro and macro levels, where higher levels (global system dynamics) are the unique result of the interactions between the constituent parts of the system (Raia, 2008). However, in non-linear systems with circular causality (e.g., sports teams), there is potential for a bi-directional flow to causation. This property of CAS reflects the constant interplay between both global-to-local and local-to-global dynamics in shaping system behaviors. For example, the article by Duarte et al. (2012) enlighted how interactions among grouping individuals (i.e., the players) scale to global collective system behaviors. These investigators proposed that teams can be viewed as functional integrated superorganisms, despite also revealing functional specialization, i.e., interindividual variation derived from genetic heritage, previous experiences, etc. Teams conceptualized as superorganisms reveal highly coordinated patterns in which the actions of individual players constrain and are constrained by the actions of neighboring players (teammates and/or opponents) toward the mutually exclusive goals of the collective. Importantly, research has provided substantial evidence that locally created information (e.g., approaching velocities of teammates and opponents, interpersonal distances) allows players to co-regulate actions with others (teammates and/or opponents) and the environment. Such process allows players to self-organize behaviors into newly formed structures, expressed at a global scale. These insights have some important implications when extrapolated to sports performance contexts. They signify, for instance, that individual players in sports teams co-adapt their actions to form specific intended collective structures (a systematic whole such as a tactical pattern of play). These system patterns emerge from players' local interactions (local-to-global effects) under the dynamic constraints of competitive performance environments (Passos et al., 2013). In turn, collective organizational structures can shape the dynamical, interpersonal interactions of individual players competing and cooperating with each other in a top-down process (global-to-local effects). Such processes demonstrate the deeply entwined interconnections of bottom-up (local-to-global) and top-down (global-to-local) processes in the continuous (re)organization of CAS.

Here, we outline an argument that traditional coaching methods may be failing to exploit the bi-directional influence of dynamics in sports teams as CAS by over-valuing the influence of *global-to-local* tendencies in formation of synergetic relations between players in training (Araújo and Davids, 2009). A major example of overarching task constraints that strongly influence the global-to-local self-organizing tendencies of players and teams during competitive team sports performance is the game model. This is the overarching, planned, tactical/strategical approach adopted, and tactical principles of play, conceived by coaches to enhance player functionality in specific sub-phases of play (Garganta, 1997; Guilherme, 2004). There is clear relevance of a game model and tactical principles of play in shaping individual and collective self-organizing behaviors of players and teams. However, there has been little effort directed to understanding how *local-to-global* tendencies for self-organization can be harnessed in producing adaptive teams, which can rapidly and effectively adjust and diversify tactical patterns of behavior as competitive performance conditions change (please see Passos et al., 2013). Successful team sports performance requires a complex and intertwined relationship between co-existing global-to-local and local-to-global self-organizing tendencies in optimizing team functionality. The bi-directional tendency of synergy formation between team sports athletes is a performance aspect that has been completely disregarded by the sports sciences community.

This void in the literature may be due to a lack of understanding of how a game model and tactical principles of play may impact as potent constraints in shaping self-organization tendencies within sports teams. Therefore, this paper aims to clarify how a game model, and associated tactical principles of play, could constrain both global-to-local and local-to-global self-organization tendencies within sports teams. Furthermore, we discuss how coaches could contribute to enhancing the impact of both self-organizing tendencies in the design of training programs to enhance synergy formation between cooperating teammates.

DEFINING A GAME MODEL AND TACTICAL PRINCIPLES OF PLAY

Previous literature (e.g., Bompa, 1994; Castelo, 1994; Guilherme, 2004) has emphasized that a game model provides a framework to map a set of characteristics to bound the implementation of defensive/offensive principles or systems of play in team sport athletes (including player roles and tactical system during play). Essentially, a game model encompasses tactical patterns of play, considered of fundamental importance for system (team) organization and functioning. A tactical principle of play encompasses a set of basic game rules (previously defined by the team coaches) that constrain the actions of the players and the teams toward intended performance outcomes for specific sub-phases of play (Garganta, 1997). Such sub-phases of play can be divided into the attacking phase (i.e., when team A is in possession of the ball – offensive organization) and the defending phase (when team B does not have the ball – defensive organization). Moreover, when team A loses ball possession (attack–defense transition or defensive transition), they try incessantly to recover it again, while team B gains ball possession (defense–attack transition or attacking transition) and seek to create goal-scoring opportunities.

Additionally, these principles articulate among themselves and represent a basic "level of process goal setting" that shapes the cooperative interactions and behaviors of players, individually and collectively, helping them to seek tactical solutions for contingencies emerging during competition (Garganta and Pinto, 1994; Garganta, 1997). Importantly, the game model itself appears to emerge not from a top-down process, but rather through a bottom-up process, since it is dependent on several interacting constraints such as the coaches' ideas, capacities of the available players, the "form of life" of the club (Rothwell et al., 2018), the coaching and sport science support staff, and the financial constraints of the available budget.

On the other hand, the term "tactic" has its origins in the middle of the 17th century and was originally used in military activities. According to Gelfand and Tsetlin (1962), tactics can be understood as the skill of employing available means to accomplish an end. Traditionally, this concept has long been utilized by team sports coaches to refer to specific patterns of play used during competition to achieve a specific objective (e.g., overcome opposition defensive organization, avoid defeat, achieve a specific outcome like negate opposition strength in attack or exploit a weakness). On the other hand, team strategy is related to specific tactics and can be viewed as a more general, long-term, and overarching concept highlighting how teams exploit the use of their resources (defensive strategy or attacking strategy) (Garganta, 1997; Davids et al., 2005). Strategies can be based, for example, on detailed gathering and sharing of knowledge about different patterns of play (e.g., exploring the opponent weaknesses when defending). Hence, tactics is expressed through a set of observable behaviors or tactical patterns of play aimed to achieve a specific end, which in turn are constrained by a defined strategy. A key distinction here is that tactical patterns of play can sometimes emerge from local to global interactions as adaptive performance behaviors can alter quickly as opponent adapt their formations or tactics (information required for teams' organization and functioning is constantly changing) (Duarte et al., 2012; Passos et al., 2013; Silva et al., 2013). In contrast, strategies constitute more long-term processes that involved experimentation, implementation, and formulation, which are constrained by global-to-local interactions (Silva et al., 2013). Here, we contend that tactics and strategy work jointly as a means to an end. Both comprehend intertwined concepts such as experimentation, implementation, and formulation for enhancing team performance. For instance, if a given principle advocated by a team coach is to progress with the ball upfield through both left- and right-hand sides of the opposing team, the players need to tactically adopt certain behaviors that favor team objectives in order to attract the opponents toward the midfield regions in order to create available space to be explored.

Principles of play articulate with and influence a team's game model as evidenced at different levels of team organization (macro/global to micro/local, and vice versa) (Garganta, 1997; Guilherme, 2004). This relationship shapes how performance strategies can be elaborated and implemented in competition. Such a body of knowledge can be used for developing specialized player development programs, as well as for the establishment of theoretical and practical frameworks for periodizing team training and performance in different sub-phases of play (Seifert et al., 2018). Through careful manipulation of constraints, coaches can help team players to perceive shared affordances that support desired team behaviors (in collective principles of play) through practice. Such affordances are available and attainable only by groups of individuals during specialized cooperative actions, presenting possibilities for group actions and do not exist outside this cooperative dynamic environment. This is particularly important because the perception of an individual affordance by an individual player, cooperating with others in a group, is dependent on the perception of *affordances of* and *for* others and of his/her own affordances by others (Silva et al., 2013).

For example, in football, a midfielder with the ball perceives an opportunity to make a long pass to a winger, who initiates a penetrating run behind the defensive line, through anticipating this affordance for his/her teammate. A third player, the striker, can also time a run into the penalty box to receive an anticipated cross from the winger, because he also perceived the affordances for the two teammates, while, at the same time, providing them with another affordance – receiving a cross to score. This collective movement pattern may, therefore, constitute how a principle of play, penetration, is sustained by the coordination of individual affordances that are shared locally to form a collective affordance for an attacking sub-system of players.

EXPLOITING GLOBAL-TO-LOCAL AND LOCAL-TO-GLOBAL SELF-ORGANIZING TENDENCIES IN SPORTS TEAMS

Essentially, global-to-local and local-to-global tendencies provide two main mechanisms through which self-organization gives rise to the emergence of a specific identity (Vernon et al., 2015), expressed by synergetic team behavioral patterns during performance.

The inter-level causality evidenced by both directional processes, in team sports, may function as a heterarchy rather than a hierarchy, meaning that there is not a dominant relation of the whole relative to the parts in the system self-organizing tendencies. Imagine a situation in which a team sport coach (e.g., basketball, handball, volleyball, football, etc.) defines a specific tactical principle for implementation in a particular sub-phase of play. Even though this principle acts at a global-to-local scale to constrain the individual dynamics of players at a local-to-global scale, players will always have the ability to use their unique resources (physical, perceptual–cognitive skills, etc.) to continuously reshape the proposed principle through development of local-to-global self-organizing tendencies. Hence, there is a reciprocal (but not symmetrical) interaction between both levels of self-organizing tendencies.

Thus, it is important to note that inter-level causal relations flow in both directions (global-to-local and local-to-global) continuously and mutually influencing each other. In team sports, a game model and tactical principles of play may be influential at a global-to-local scale, thus shaping the local interactions of players, which function at a local-to-global scale. For instance, in football (soccer), a coach may have defined as a tactical principle of play for the attacking sub-phase, to circulate the ball through the right- and left-hand sides of the opposing defense, aiming to cross the ball toward a targeted player. This principle (acting at a global-to-local scale) can influence the local-to-global self-organizing tendencies of players by leading them to attract the opponents toward the center of the pitch in order to create and explore possible empty spaces left in both right- and left-hand sides of the opposing team. Successful sports teams can harness these co-existing tendencies to enhance team synergy formation and performance, without solely relying on a game model framework imposed by a coach.

Global-to-local effects do not take the same form as local-to-global influences. The former typically entail modifications in order parameters (variables that capture a system's global state emerging from the interaction of its components) (Kelso, 1995, 2012). In contrast, local-to-global tendencies are captured in changes in interacting dynamical variables (e.g., circumstantial numerical relations, acting upon passing opportunities, and co-positioning of players), which constrain how players coordinate and regulate actions, supporting effective communications with other teammates (Araújo and Davids, 2016). Coaches typically tend to exert influence at the global-to-local scale, by managing a strategy, suggesting certain tactical behaviors, and designing selected practice tasks (in a top-down process). These externally imposed influences can provide an overarching constraint, operating at a slower timescale on players' perceptions, decisions, and actions as they seek to achieve specific performance outcomes. Importantly, the design of practice tasks is conditioned by specificities of the game model conceptualized by a coach, particularly with respect to strategical principles of play, which, altogether, interact globally-to-locally, to constrain individual and collective performance. Alternatively, team players' continuous local interactions function at the local-to-global scale (changing at a faster timescale than the global-to-local scale) and can support the emergence of specific tactical patterns of behavior (in a bottom-up process) in resolving a performance issue during play (e.g., rapid re-organization to prevent an underload in one part of the playing area).

This type of self-organizing tendency is paramount in athlete development programs since local-to-global interactions are instrumental in developing the co-adaptive processes (see Passos et al., 2016) needed in team games players. Indeed, they are the basis of co-adaptation between players because the constraints acting on the spontaneous self-organizing tendencies are wide-ranging (Passos et al., 2016). Thus, they should be the dominant self-organizing tendencies that athletes should be exposed to at all stages of their careers, especially at younger ages (Passos et al., 2016). Indeed, the promotion of such tendencies during practice and competition is fundamental for developing "intelligent performers in sport," capable of solving emerging performance and tactical (organizational) problems from experience. The development of learners in sport as "intelligent performers" and active decision makers has become a central aim in Physical Education curriculum documents worldwide. Across the world, recent government publications, national standards, professional bodies, and curriculum documents have recognized the role of thinking skills in physical education. In the United Kingdom, the National Curriculum Physical Education (NCPE), the NASPE (National Association for Sport and Physical Education) in the United States, and the Queensland Physical Education Senior Syllabus (Queensland Studies Authority, 2004) incorporate outcomes in all three of the major domains of learning: psychomotor, cognitive, and affective in their definition of a physically educated person (see Metzler, 2005; Byra, 2006; National Association for Sport and Physical Education USA, 2009; Queensland Studies Authority, 2010; Department for Education, 2013; Australian Curriculum, Assessment and Reporting Authority, 2015; Moy et al., 2019).

For example, the Queensland Studies Authority (2010, p. 3) states that "Intelligent performance is characterized by high levels of cognitive functioning, using both rational and creative thought. Students are decision makers engaged in the active construction of meaning through processing information related to their personal experience and to the study of physical activity."

In sport, environmental, individual and task constraints can alter every time an action is performed, and an "intelligent performer" is viewed as a skilled, adaptive individual who can achieve task goals or individualized functional performance solutions in different ways (Davids et al., 2006; Araújo and Davids, 2011). Adaptive skilled behavior, rather than being imposed by a pre-existing plan, model, or structure, emerges from this confluence of constraints as athletes seek individualized solutions to a specific performance problem through active exploration of a learning environment. Continuous interactions with performance contexts in practice enable learners to seek and perceive information to regulate actions, enhancing their knowledge and understanding of a competitive environment. This process will be most effective if coaches develop flexible and adaptable performers (they can rapidly alter and/or adapt their behaviors to changing performance constraints) who can perceive information on opposition tactical patterns and respond quickly and effectively during play.

MALLEABILITY OF THE GAME MODEL AND TACTICAL PRINCIPLES OF PLAY FOR DEVELOPING EFFECTIVE SELF-ORGANIZING TENDENCIES IN TEAM SPORTS

A challenging task for many coaches in team sports is to provide suitable learning environments for developing adaptive, "intelligent performers." Intelligent performers in sport have cognitions, perceptions, and actions deeply intertwined in all phases of play (Davids et al., 2015). They know how to use information to regulate their actions and are autonomous problem solvers, without constantly resorting to a coach for performance solutions (Davids et al., 2015). A fundamental misconception regarding the role of a game model and tactical principles of play is to consider them as being achieved by *pre-planned* and *pre-established* actions or mechanized movements that players should faithfully rehearse during practice (e.g., in shadow play during training when a team perform patterns of play without opponents present). Such misconceptions may negatively influence the frameworks for athlete development programs for development of expertise and performance.

Thus, it is important to emphasize that the principles of play underlying a game model stipulated with a coach for each sub-phase of play should not be rigid and inflexible (Garganta, 1997; Guilherme, 2004). Rather, they must be flexible and open to the shared affordances players utilize from it (in terms of possibilities for action) and how athletes can be prepared to exploit affordances by enhancing their action readiness [see Frijda (1986, 2007) for detailed descriptions on this concept]. During practice, coaches should allow players to freely explore a wide variety of performance solutions when guided by a particular principle of play (Guilherme, 2004). This approach to practice would facilitate co-adaptation of players using local information sources (e.g., teammate and opponent displacements, or co-positioning in a playing area relative to a scoring target or area markings) (Passos et al., 2016). This practice approach would enable athletes to explore principles of play through exploiting shared affordances and synergies formed through local-to-global self-organizing tendencies (Davids et al., 2015; Silva et al., 2013, 2016). Indeed, previous research (e.g., Araújo et al., 2004; Silva et al., 2013; Davids et al., 2015) have stressed the importance of athletes to perceive affordances by learning to detect relevant information sources that support successful task performance. Moreover, experiencing a vast amount of tactical solutions for achieving a specific principle of play will lead to adaptive movement variability, which is key for developing expert performers (Davids et al., 2015).

It is important to ensure that athletes cannot only co-adapt to one major constraint in synergy formation: harnessing global-to-local self-organizing tendencies (i.e., the coach staff imposing and implementing a tactical plan). Rather, athletes need to be facilitated in exploiting available local-to-global synergy forming tendencies by co-adapting to a variety of interacting personal, task and environmental constraints during performance and practice. They can achieve these adaptive skills by exploring a range of performance solutions coherent with principles of play (see **Figure 1**).

A key take-home message of this article is that for a given principle of play, there exists a multitude of performance solutions or coordination patterns (synergies) attainable by performers. Edelman and Gally (2001) identified "degeneracy" as an inherent property of CAS signifying "the ability of elements that are structurally different to perform the same function or yield the same output" (p. 13, see also Seifert et al., 2016). This conceptualization provides a theoretical foundation to propose why performers in sport should be encouraged to explore solutions for achieving task goals aligned with principles of play in team sports. When framed as a methodological approach for sport practice, it supports athletes in combining their unique resources (e.g., physical, technical, tactical, perceptual skills and awareness, psychological attributes, and emotional control) to seek and explore tactical behaviors through team synergy formation.

A TACTICAL LANDSCAPE FOR DEVELOPING TACTICAL PRINCIPLES OF PLAY CIRCUMSCRIBED IN A GAME MODEL

A fundamental question that can emerge from this opinion piece is: how can coaches develop through training both individual and collective behaviors of athletes in sports teams, in adhering to specific principles of play in different performance sub-phases?

Here, it is worth alluding to the dynamical notion of an ontogenetic landscape (Thelen and Smith, 1994) to refer to the related concept of a "tactical landscape" in sport performance settings. Using the landscape metaphor, an attractor is a stable state toward which a dynamical system (such as a sports team or an individual athlete) tends to evolve (e.g., a specific collective form of organization attained in an offensive sub-phase of play) (McGarry et al., 2002; Davids et al., 2005; Boeing, 2016). Through excellent coaching, team players may be attracted

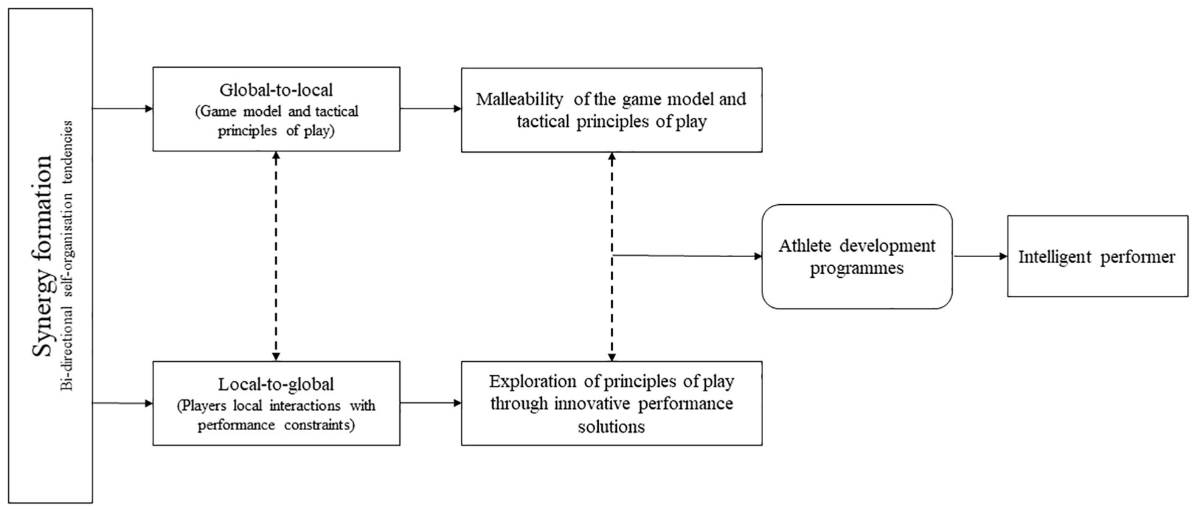

FIGURE 1 | Developing synergy formation processes through exploitation of self-organization tendencies in a global-to-local and local-to-global direction.

toward preferred, stable states of collective organization out of many possible states (e.g., those that support team functions with principles of play).

The continuous exposition of players to instabilities associated with *phase transitions* (transitions between states of system organization, for example, in team sports, between offensive and defensive patterns) furnishes a rich landscape of tendencies in system organization for performers to exploit (Williams et al., 1999; Araújo et al., 2004; Davids et al., 2005). Cultivating a landscape of synergetic possibilities can be achieved by providing integrated fields of affordances (opportunities or invitations for action) in practice contexts [most effectively through small-sided and conditioned games (SSCG)], through which skillful goal-directed behaviors of (intelligent) team sports performers may emerge (Rietveld and Kiverstein, 2014; Araújo and Davids, 2016). This learning process can be guided by manipulating key constraints that act upon each individual, and the team, collectively (Silva, 2014). Therefore, specific key constraints like issues related with strategy and coaching (e.g., tactical principles of play) may influence the creation of functional and goal-directed synergies (entirely novel perception-action relations) among players, during competitive and learning performance environments (Araújo et al., 2014; Silva et al., 2014). By manipulating specific key task constraints during SSCGs, coaches may provide important information sources or shared affordances that enable the creation of a specific communication system, allowing self-organization to be enhanced (Silva et al., 2013). During competitive performance, team players couple to form an interpersonal synergy based on perception–action systems in a social context, underpinned by the collective perception of shared affordances (Silva et al., 2013; Araújo et al., 2014, 2015).

A "landscape of affordances" is replete with possibilities for action available in a specific performance context, related to the whole spectrum of abilities available in socio-cultural context of a sport (Bruineberg and Rietveld, 2014; Rietveld and Kiverstein, 2014). Coaches can design specific invitations for action for performers in their training sessions through manipulation of ecological constraints of practice environments. In SSCGs, local-to-global synergy formation can be enhanced between players by using constraints such as manipulating numerical relations between players, varying playing area dimensions, and scoring targets. Through use of augmented informational constraints, such as verbal instructions and feedback, coaches and teachers can stimulate specific collective patterns of behavior prescribed in principles of play related to a particular game model. In this respect, a game model founded on principles of play facilitates the utilization of specific affordances or invitations for action in performers. Such affordances (Gibson, 1966, 1979) can be perceived during important sub-phases of play and can solicit or invite specific actions or collective behaviors (Withagen et al., 2012), enabling performers to achieve intended team performance goals (e.g., exploiting open space behind or in front of an opposing defensive line or preventing scoring opportunities for opponents in a playing area by deliberately aggregating players centrally to restrict space) during competitive performance. Here, the perception of shared affordances (Silva et al., 2013) guides the formation of synergetic networks for achieving specific team goals (Araújo and Davids, 2016; Ribeiro et al., 2017).

Utilization of shared affordances is thus paramount for harnessing each player's capacities, individually, and collectively in the team, in co-adapting to task and environmental constraints during practice and competition. Coaches should seek to promote and develop effective self-organizing tendencies at a local-to-global scale. Viewed this way, co-adaptation comprises a process that enhances, through implementing specific training methodologies, the relationship of players and teams with a competitive performance environment in specific directions. Co-adaptive moves in training enhances the fitness of individual athletes and teams in a performance environment

(Silva et al., 2016), coherent with the accomplishment of intended principles of play within a game model. In this sense, the term "fitness" does not refer to conditioning but to the capacities of performers to functionally adapt to the continuous dynamical constraints of the performance task and environment in achieving performance goals.

CONCLUSION AND PRACTICAL APPLICATIONS

We outlined that viewing athletes and sports teams as complex adaptive system entails understanding the process of synergy formation between system components during performance and practice. This process is continually shaped by exploiting inherent self-organizing tendencies in a global-to-local or local-to-global direction. Traditionally, imposition of a game model to harness tactical principles of play, by a coach, exploits global-to-local synergy formation as a major constraint on team sports performance. We highlighted the importance of coaches promoting and managing global-to-local self-organizing tendencies in teams in a flexible and adaptable manner. This approach to sport pedagogy would help develop effective local-to-global self-organizing tendencies between players, facilitating exploration of adaptive and innovative (intelligent) performance solutions coherent with the proposed principles of play circumscribed in an overarching game model. This is extremely important because for a given principle of play (e.g., exploring both right- and left-hand sides of the opposition structure to cross the ball into the penalty box), there is a multitude of possible tactical solutions [e.g., attracting the left/right defender out of his position to create available space through an individual movement (1 vs. 1), or by simply creating numerical overload (e.g., 2 vs. 1)] to be done.

Understanding the interplay between these tendencies in inherent self-organizing processes may help establish more effective athlete development programs, as well as enhancing team training and performance. Such an approach may be key in achieving the aim of developing the "intelligent performer" in sport, here defined as an athlete capable of adapting to changing performance constraints rapidly and effectively. More research is needed to theoretically and empirically scrutinize the inter-level causality evidenced by existing global-to-local and local-to-global self-organizing tendencies that shape synergy formation in team sports performance.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript/supplementary files.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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REFERENCES

Araújo, D., and Davids, K. (2009). Ecological approaches to cognition and action in sport and exercise: ask not only what you do, but where you do it. *Int. J. Sport Psychol.* 40, 5–37.

Araújo, D., and Davids, K. (2011). What exactly is acquired during skill acquisition? *J. Conscious. Stud.* 18, 7–23.

Araújo, D., and Davids, K. (2016). Team synergies in sport: theory and measures. *Front. Psychol* 7:1449. doi: 10.3389/fpsyg.2016.01449

Araújo, D., Davids, K., Bennett, S., Button, C., and Chapman, G. (2004). "Emergence of sport skills under constraints," in *Skill Acquisition in Sport: Research, Theory and Practice*, eds M. Williams, and N. Hodges, (London: Routledge), 409–433.

Araújo, D., Silva, P., and Davids, K. (2015). "Capturing group tactical behaviors in expert team players," in *Routledge Handbook of Sport Exercise*, eds J. Baker, and D. Farrow, (London: Routledge), 209–220.

Araújo, D., Silva, P., and Ramos, J. P. (2014). Affordance-based decisions guide team synergies during match performance. *Res. Phys. Educ. Sport Health* 3, 19–26.

Australian Curriculum, Assessment and Reporting Authority (2015). *National report on schooling in Australia*. Sydney, NSW: Australian Curriculum, Assessment and Reporting Authority.

Boeing, G. (2016). Visual analysis of nonlinear dynamical systems: chaos, fractals, self-similarity and the limits of prediction. *Systems* 4, 37–54.

Bompa, T. (1994). *Periodization: Theory and Methodology of Training*. Leeds: Human Kinetics.

Bruineberg, J., and Rietveld, E. (2014). Self-organization, free energy minimization, and optimal grip on a field of affordances. *Front. Hum. Neurosci.* 8:599. doi: 10.3389/fnhum.2014.00599

Byra, M. (2006). "Teaching styles and inclusive pedagogies," in *The Handbook of Physical Education*, eds D. Kirk, D. MacDonald, and M. O'Sullivan (London: Sage Publications), 449–466. doi: 10.4135/9781848608009.n25

Castelo, J. (1994). *Futebol—Modelo Técnico–Táctico do Jogo*. Lisboa: Edições Autor.

Davids, K., Araújo, D., Seifert, L., and Orth, D. (2015). "Expert performance in sport: an ecological dynamics perspective," in *Routledge International Handbook. Routledge Handbook of Sport Expertise*, eds J. Baker, and D. Farrow, (New York, NY: Routledge), 130–144.

Davids, K., Araújo, D., and Shuttleworth, R. (2005). "Applications of dynamical systems theory to football," in *Science and Football V*, eds T. Reilly, J. Cabri, and D. Araújo, (London: Routledge), 547–560.

Davids, K., Bennett, S., and Newell, K. (2006). *Movement System Variability*. Dublin: Dublin University Press Series.

Department for Education (2013). *National Curriculum in England: Physical Education Programmes of Study*. London: Department for Education.

Duarte, R., Araújo, D., Correia, V., and Davids, K. (2012). Sports teams as superorganisms: implications of sociobiological models of behaviour for research and practice in team sports performance analysis. *Sports Med.* 42, 633–642. doi: 10.2165/11632450-000000000-00000

Edelman, G. M., and Gally, J. A. (2001). Degeneracy and complexity in biological systems. *Proc. Natl. Acad. Sci. U.S.A.* 98, 13763–13768. doi: 10.1073/pnas.231499798

Frijda, N. (1986). *The Emotions*. Cambridge: Cambridge University Press.

Frijda, N. (2007). *The Laws of Emotion*. Mahwah, NJ: Erlbaum.

Garganta, J. (1997). *Modelação tática do jogo de futebol. Estudo da organização da fase ofensiva em equipas de alto rendimento*. doctoral dissertation, Faculdade de Ciências do Desporto e Educação Física, Porto.

Garganta, J., and Pinto, J. (1994). "O ensino do Futebol," in *O Ensino dos jogos Desportivos Coletivos*, eds A. Graça, and J. Oliveira, (Porto: Universidade do Porto), 95–135.

Gelfand, I. M., and Tsetlin, M. L. (1962). Some methods of control for complex systems. *Russ. Math. Surv*. 17, 95–116.

Gibson, J. (1966). *The Senses Considered as Perceptual Systems*. Boston, MA: Houghton Mifflin.

Gibson, J. (1979). *The Ecological Approach to Visual Perception*. Hillsdale, MI: Lawrence Erlbaum Associates.

Guilherme, J. (2004). *Conhecimento específico em futebol. Contributos para a definição de uma matriz dinâmica do processo de ensino-aprendizagem/treino do jogo*. master's thesis, Faculdade de Ciências do Desporto e Educação Física da Universidade do Porto, Porto.

Halley, J. D., and Winkler, D. A. (2008). Classification of emergence and its relation to self-organization. *Complexity* 13, 10–15. doi: 10.1002/cplx.20216

Kelso, J. A. S. (1995). *Dynamic Patterns: The self-Organization of Brain and Behavior*. Cambridge, MA: The MIT Press.

Kelso, S. (2012). Multistability and metastability: understanding dynamic coordination in the brain. *Philos. Trans. R. Soc. B.* 367, 906–918. doi: 10.1098/rstb.2011.0351

McGarry, T., Anderson, D., Wallace, S., Hughes, M., and Franks, I. (2002). Sport competition as a dynamical self-organizing system. *J. Sports Sci.* 20, 771–781. doi: 10.1080/026404102320675620

Metzler, M. (2005). *Instructional Models for Physical Education*, 2nd Edn. Arizona: Holcomb Hathaway.

Moy, B., Renshaw, I., Davids, K., and Brymer, E. (2019). Preservice teachers implementing a nonlinear physical education pedagogy. *Phys. Educ. Sport Peda.* 24, 1–17. doi: 10.1080/17408989.2019.1628934

National Association for Sport and Physical Education USA (2009). *Opportunity to Learn: Guidelines for High School Physical Education*, 3rd Edn. Reston, VA: NASPE.

Passos, P., Araújo, D., and Davids, K. (2013). Self-organization processes in field-invasion sports: implications for leadership. *Sports Med.* 43, 1–7. doi: 10.1007/s40279-012-0001-1

Passos, P., Araújo, D., and Davids, K. (2016). Competitiveness and the process of co-adaptation in team sport performance. *Front. Psychol.* 7:1562. doi: 10.3389/fpsyg.2016.01562

Queensland Studies Authority (2010). *Physical Education Senior Syllabus*. Brisbane, QLD: QSA.

Raia, F. (2008). Causality in complex dynamic systems: a challenge in earth systems science education. *J. Geosci. Educ.* 56, 81–94. doi: 10.5408/1089-9995-56.1.81

Ribeiro, J., Silva, P., Duarte, R., Davids, K., and Garganta, J. (2017). Team sports performance analysed through the lens of social network theory: implications for research and practice. *Sports Med.* 9, 1689–1696. doi: 10.1007/s40279-017-0695-1

Rietveld, E., and Kiverstein, J. (2014). A rich landscape of affordances. *Ecol. Psychol.* 26, 325–352. doi: 10.1080/10407413.2014.958035

Riley, M., Richardson, M., Shockley, K., and Ramenzoni, V. (2011). Interpersonal synergies. *Front. Psychol.* 2:38. doi: 10.3389/fpsyg.2011.00038

Riley, M., Shockley, K., and Van Orden, G. (2012). Learning from the body about the mind. *Top. Cogn. Sci.* 4, 21–34. doi: 10.1111/j.1756-8765.2011.01163.x

Rothwell, M., Davids, K., and Stone, J. (2018). Harnessing socio-cultural constraints on athlete development to create a form of life. *J. Expert.* 1, 94–102.

Seifert, L., Komar, J., Araújo, D., and Davids, K. (2016). Neurobiological degeneracy: a key property for functional adaptations of perception and action to constraints. *Neurosci. Biobehav. Rev.* 69, 159–165. doi: 10.1016/j.neubiorev.2016.08.006

Seifert, L., Papet, V., Strafford, B. W., Coughlan, E. K., and Davids, K. (2018). Skill transfer, expertise and talent development: an ecological dynamics perspective. *Mov. Sport Sci.* 102, 39–49. doi: 10.1051/sm/2019010

Silva, P. (2014). *Shaping Tactical Behaviours in Football: An Ecological Dynamics Approach*. Porto: Faculdade de Desporto da Universidade do Porto. Published doctoral dissertation.

Silva, P., Chung, D., Carvalho, T., Cardoso, T., Keith Davids, K., Araújo, D., et al. (2016). Practice effects on intra-team synergies in football teams. *Hum. Mov. Sci.* 46, 39–51. doi: 10.1016/j.humov.2015.11.017

Silva, P., Garganta, J., Araújo, D., Davids, K., and Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports. Med.* 43, 765–772. doi: 10.1007/s40279-013-0070-9

Silva, P., Travassos, B., Vilar, L., Aguiar, P., Davids, K., Araújo, D., et al. (2014). Numerical relations and skill level constrain co-adaptive behaviours of agents in sports teams. *PLoS One* 9:e107112. doi: 10.1371/journal.pone.0107112

Thelen, E., and Smith, L. (1994). *A Dynamic Systems Approach to the Development of Cognition and Action*. Cambridge, MA: MIT Press.

Vernon, D., Lowe, R., Thill, S., and Ziemke, T. (2015). Embodied cognition and circular causality: on the role of constitutive autonomy in the reciprocal coupling of perception and action. *Front. Psychol.* 6:1660. doi: 10.3389/fpsyg.2015.01660

Vilar, L., Araújo, D., Davids, K., and Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Med.* 42, 1–10. doi: 10.2165/11596520-000000000-00000

Williams, A. M., Davids, K., and Williams, J. G. (1999). *Visual Perception and Action in Sport*. London: E & FN Spon.

Withagen, R., de Poel, H. J., Araújo, D., and Pepping, G. (2012). Affordances can invite behavior: reconsidering the relationship between affordances and agency. *New Ideas Psychol.* 30, 250–258. doi: 10.1016/j.newideapsych.2011.12.003

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The Attacking Process in Football: A Taxonomy for Classifying How Teams Create Goal Scoring Opportunities Using a Case Study of Crystal Palace FC

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Purpose: Whilst some studies have comprehensively described the different features associated with the attacking process in football they have not produced a methodology of practical use for performance enhancement. This study presents a framework of comprehensive and meaningful metrics to objectively describe the attacking process so that useful performance profiles can be produced.

Methods: The attacking process was categorized into three independent situations, no advantage (stable), advantage, and unstable (potential goal scoring opportunity) situations. Operational definitions for each situation enhanced their reliability and validity. English Premier League football matches (n = 38) played by Crystal Palace Football Club in the 2017/2018 season were analyzed as an exemplar.

Results: Crystal Palace FC created a median of 53.5 advantage situations (IQR = 16.8) and 23 unstable situations (IQR = 8.8) per match. They frequently utilized wide areas (Median = 21.5, IQR = 9.8) to progress, but only 26.6% resulted in unstable situations (Median = 6.0, IQR = 3.8), the lowest rate compared to the other advantage situations.

Conclusion: This classification framework, when used with contextual factors in a multi-factorial manner, including individual player contributions, will provide practically useful information for applied practice. This approach will help close the so called theory-practice gap and enable academic rigor to inform practical problems.

Keywords: attacking process, playing patterns, unstable situations, football, taxonomy

INTRODUCTION

Football is an invasion sport with the main aim of breaking through an opponent's defense to score a goal. Since goal scoring is the key to being a successful football team (Wright et al., 2011), many previous notational analysis studies have concentrated on the measurement of scoring related indicators (Hughes and Bartlett, 2002). For example, Reep and Benjamin (1968) identified that 10 shots were needed for one goal and 80% of goals scored from less than 3 passes. Future goal scoring studies considered the impact of: the number of passes in a possession (Hughes and Franks, 2005), pitch area where goals were scored from Yiannakos and Armatas (2006), body part used (Muhamad et al., 2013), set-piece or open play (Muhamad et al., 2013), action prior to a goal (Michailidis et al., 2013) and time period (Armatas et al., 2009) on the number of goals scored. These studies measured the who, when and where goals were scored but neglecting, to some extent, the how but entirely the why.

Match analysis, from a coach's perspective in the applied world, will invariably focus on the why and how events occurred (Lames and McGarry, 2007) rather than the simple statistics prevalent in the research literature, the so called theory-practice gap (Mackenzie and Cushion, 2013). Mackenzie and Cushion (2013) critically reviewed performance analysis in football over five decades and suggested that a focus on key performance indicators was prevalent, based on availability rather than for developing a deeper understanding of performance. James (2009) also made the point that unless the processes undertaken to achieve outcomes are investigated then meaningful performance improvement information cannot be achieved. This academic perspective is quite different from the approach taken by coaches who plan training sessions following a comprehensive analysis of factors such as the opposition's strengths and weaknesses and attacking/defending playing patterns (Borrie et al., 2002), referred to as tactical analysis (Garganta, 2009). This process typically involves both the team being coached, and the forthcoming opponents, as it is the interaction between the two teams that coaches try to manipulate. From the theoretical perspective, Hewitt et al. (2016) suggested that identifying playing patterns (referred to as playing style), using more detailed analyses than evident in the literature, would impact training practices, and enable coaches and sport scientists to have a clearer understanding of what teams need to do in order to win. This view strongly advocates the analysis of the "developmental processes" involved prior to a team having goal scoring opportunities. This approach, therefore, requires a systematic breakdown of how teams develop ball possessions into goal scoring opportunities and goals, with the added benefit that this methodology would also enable recurrent patterns to be discerned, allowing the possibility of developing individual team profiles under different playing conditions.

Researchers have suggested that understanding playing patterns could help the development of tactical strategies to improve a team's performance (James et al., 2002; Tenga et al., 2015). Playing patterns have usually been divided into "possession play" or "direct play" through measuring the number of passes prior to goal (Reep and Benjamin, 1968; Bate, 1988; Hughes and Franks, 2005; Redwood-Brown, 2008) or duration of team possessions (James et al., 2002; Jones et al., 2004; Bloomfield et al., 2005; Lago and Martìn, 2007; Lago, 2009; Lago-Peñas and Dellal, 2010). These studies suggested that playing patterns could be discriminated through a simple data selection process (Fernandez-Navarro et al., 2016) e.g., possession play determined for longer possession durations or number of passes. However, this approach does not allow for possessions which contain elements of different playing patterns. For example, a possession involving multiple passes between defenders in their defensive third of the pitch (generally regarded as possession play) followed by a long pass to an attacker in the attacking third (direct play) would simply be classified as possession play. Thus, this methodology has the potential for failing to classify possession types fully (if multiple possession types were nor classified) or correctly (if one possession type was deemed to supersede another).

Other studies measured multidimensional qualitative variables e.g., direction, type and distance of passes, location where possession started, speed of attack etc., to discriminate playing patterns (Sarmento et al., 2010; Tenga et al., 2010; Tenga and Sigmundstad, 2011; Lago-Ballesteros et al., 2012; Sarmento et al., 2014). Kempe et al. (2014) calculated an index of offensive behaviors (positive values indicated possession play, negative values direct) to characterize playing patterns which included 11 parameters related to passing, direction, speed, accuracy, distance and player involvement. Recently, factor analysis was used to classify team playing style by grouping performance variables perceived to be relevant measures. For example, Fernandez-Navarro et al. (2016) clustered four possession features (direct/possession, cross/no cross, wide/narrow and fast/slow progression) that identified 8 different attacking patterns of play i.e., features that were not mutually exclusive but could present the propensity to utilize a particular attacking pattern. Similarly, Lago-Peñas et al. (2017) measured 20 variables to elicit 5 factors (possession, counter attack, set-piece, regaining ball and losing ball) where values for each factor discriminated how much each team utilized each specific playing pattern. Gomez et al. (2018) extracted 8 factors (ball possession, ending actions, individual challenges, counter attack, set-piece, transitional play, fouling actions and free-kick) and identified changes of team style according to the situational variables match location and team quality.

Although previous papers identified different team playing styles, based on overall match statistics, the authors have typically not distinguished the "how" different attacking procedures evolved e.g., how teams initiate or develop build-up play, progress attacks, create goal scoring opportunities. Some papers have tried to analyze the process of creating goal scoring opportunities by measuring pertinent performance variables such as possession start zone, penultimate action and finishing action (Gonzalez-Rodenas et al., 2019; Mitrotasios et al., 2019). However, these studies simply determined which areas or actions were most prevalent in goal scoring possessions. Kim et al. (2019) suggested that different quality English Premier League (EPL) teams created unstable situations (defined as potential goal scoring opportunities) in different ways. Five specific potential goal scoring situations were identified according to pitch location, game situation or specific action using coach and analyst validated definitions. However, "how" these specific moments in the game arose remains unanswered.

Therefore, the aims of this paper were, (1) to establish a taxonomy of the different ways in which potential goal scoring opportunities (unstable situations) arise and (2) to provide a framework for identifying team profiles for attacking patterns of play. This will provide a rigorous methodology for players and coaches to collect information pertinent to identifying an opponent's attacking patterns. Additional information regarding individual player names (not used in this methodology) would thus generate the type of information appropriate to plan training sessions and game plans for upcoming matches.

MATERIALS AND METHODS

Sample

All the league matches (n = 38) played by Crystal Palace Football Club in the EPL in the 2017/2018 season were selected. All data, including video footage of the all matches, was officially provided by the football club. Ethical approval for the study was provided by the sports science sub-committee of Middlesex University's ethics committee in accordance with the 1964 Helsinki declaration.

Creating a Taxonomy for the Process of Creating Unstable Situations

This study describes the attacking process by differentiating stable, advantage and unstable situations (**Figure 1**). Each team possession could start by regaining the ball from the opponent, in any of these three situations or with a new possession i.e., a set piece (lines in **Figure 1** indicate the start and progression of possessions).

Operational definitions were devised for each situation to enhance their reliability and validity. A stable situation was defined as a situation in which neither team had a clear advantage. This occurred when a team had possession of the ball in their middle or defensive third of the pitch and the opponents were in their normal positions with their midfield and defenders goal side of the ball.

The advantage situation was deemed to occur when the game state changed to one where the possibility of an unstable situation arising became clear. These situations arose when (1) a team in possession broke the opposition team's midfield line i.e., had possession between their midfield and defensive lines; (2) a team had possession in zone 14 (**Figure 2**); (3) a team had possession in a wide area of the final third of the pitch with the opportunity to pass, cross or dribble into the penalty box or shoot directly at the goal; (4) a team regained the ball and had the opportunity to counter attack; (5) free kick in position where a shot or cross was possible; (6) corner kick.

Unstable situations were previously defined by Kim et al. (2019), who validated the five specific situations used here (**Figure 1**). Penalty kicks were excluded from both papers because penalties are the consequence of an attack and the kick deemed a new possession.

Procedure

All matches were viewed and coded in SportsCode Elite v10.3.36, to enable time stamps for each advantage state and when unstable situations arose (see also Kim et al., 2019). Apple

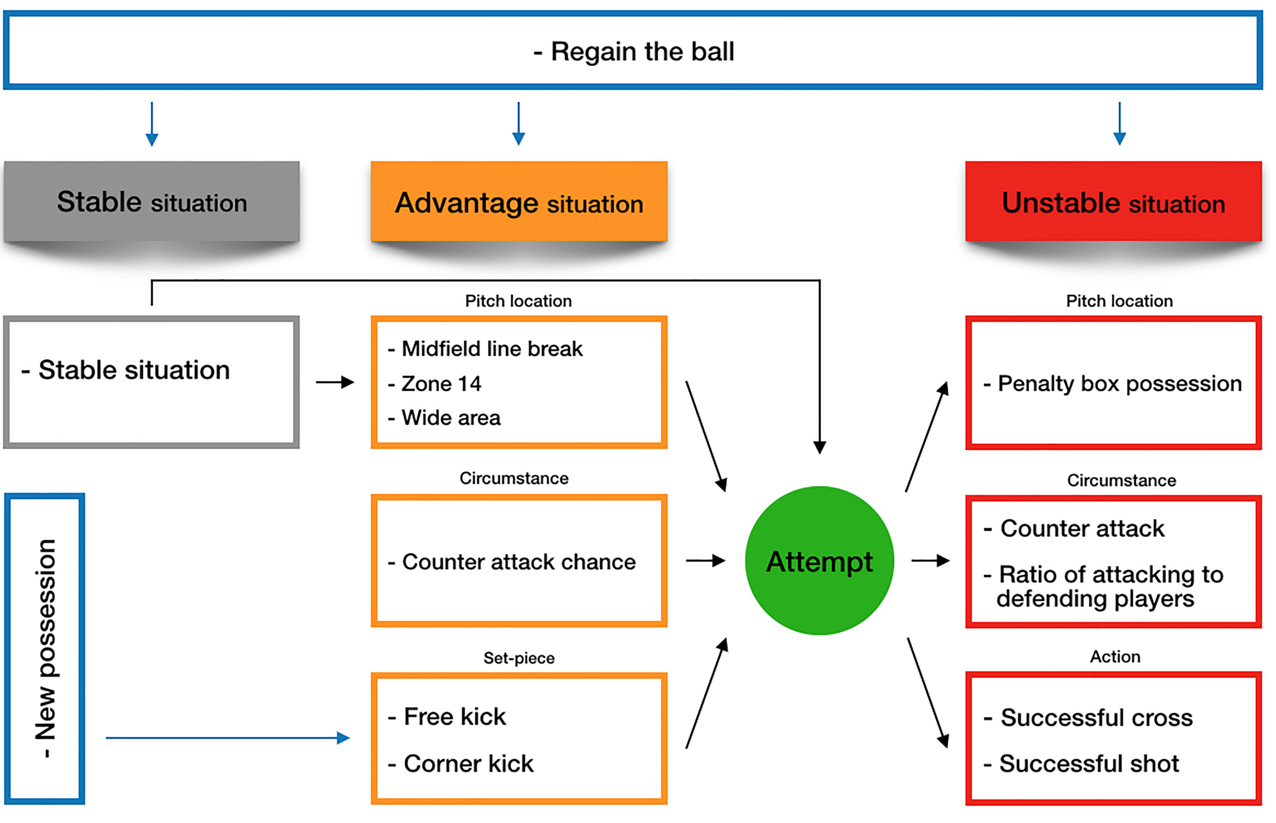

FIGURE 1 | A framework for categorising the attacking process in football.

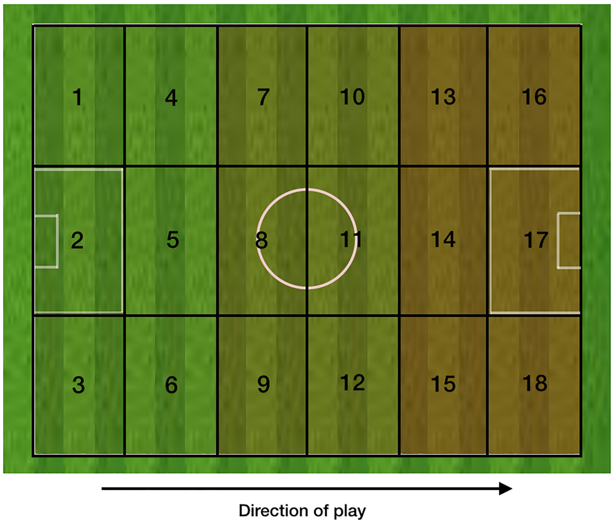

FIGURE 2 | The pitch of play divided into 18 zones.

Movist v1.3.6 was also used to facilitate coding due to ease of video manipulation.

On some occasions, a team in possession of the ball could be described in more than one category of advantage situation during a single possession. For example, if a team in possession in zone 14 switched the ball into a wide area, the two advantage situations were coded separately so that each specific situation was recorded. Similarly, different unstable situations could occur during a single possession. In this scenario, only the first unstable situation was coded because the aim of the study was to identify the moment the game state changed (stable to unstable) e.g., a counter attack could result in a penalty box possession situation but the latter was deemed irrelevant as there was no game state change between the counter attack and the penalty box possession. This could, however, be on interest to future analyses.

Reliability

Intra- and inter-observer tests were performed to determine whether the advantage situations (n = 6), unstable situations (n = 5) and outcomes (n = 3) were reliably categorized (James et al., 2007). The researcher (intra-, over four weeks after the first coding to nullify memory effects) and an independent experimenter (inter-, who was trained for each operational definition) re-coded three randomly selected matches using the same post-event coding procedure as outlined above. Advantage situations had high Kappa values for intra- (0.97, n = 362 comparisons) and inter- experimenter (0.86, n = 372). Discrepancies tended to arise when an experimenter missed an event especially wide area chances (intra = 2 and inter = 12). Also, Unstable situations had high Kappa values for intra- (0.94, n = 138) and inter- (0.87, n = 146). Discrepancies tended to arise when an experimenter failed to distinguish counter attacks (intra = 3 and inter = 8). Outcome had the same high Kappa value for both inter- and intra- (0.96, n = 76).

Statistical Analysis

All data were analyzed in IBM SPSS 25.0. Descriptive statistics were performed to provide median and interquartile range values for advantage, unstable situations and outcomes as variables were skewed. A Kruskal–Wallis H test was used to determine statistical differences for each situation and Mann–Whitney U test used to compare playing at home and away. The level of significance set at $p < 0.05$.

RESULTS

Crystal Palace football club created a median of 53.5 advantage situations (IQR = 16.8), 40 attempts (IQR = 11.3), 23 unstable situations (IQR = 8.8), 12 shots (IQR = 6.8) and 1 goal (IQR = 2) per match (**Figure 3**). Most unstable situations developed from advantage situations (Median = 20.5, IQR = 7.8) with a few from possession regains in unstable situations (Median = 2.5, IQR = 2.8) and from stable situations which did not involve an intermediary advantage situation (Median = 1, IQR = 1.8) i.e., a long ball.

Crystal Palace created 21.5 wide area chances (IQR = 9.8) per match, 41.4% of all advantage situations, which was significantly higher (χ^2 = 88.63, $p < 0.05$) than the other five advantage situations (midfield line break- Median = 5.5, IQR = 5.0, zone 14- Median = 10.0, IQR = 5.0, counter attack chance- Median = 7.0, IQR = 5.0, free kick- Median = 3.0, IQR = 2.0, corner kick- Median = 5.0, IQR = 4.0). However, only 26.6% of wide area chances resulted in unstable situations, the lowest rate (χ^2 = 190.0, $p < 0.05$) compared to the others (**Figure 4**).

A total of 79.9% unstable situations occurred from open play (Median = 18.5, IQR = 7.8) and 20.1% from set piece (Median = 4.0, IQR = 3.0). Unstable situations were most likely to be penalty box possessions (Median = 8.0, IQR = 5.0) or successful crosses (Median = 7.0, IQR = 4.5), accounting for 63.5% of all unstable situations (χ^2 = 54.0, $p < 0.05$, **Figure 3**). Penalty box possessions occurred from midfield line break chances (Median = 1.0, IQR = 2.0), zone 14 chances (Median = 1.0, IQR = 1.0), wide area chances (Median = 2.5, IQR = 2.0) and regaining the ball directly in an unstable situation (Median = 1.0, IQR = 2.0).

Shots were most likely to occur from successful crosses (Median = 3.0, IQR = 2.5) and successful shot (Median = 3.0, IQR = 3.0) situations (χ^2 = 56.71, $p < 0.05$) compared to the other unstable situations whilst shots on target occurred most frequently from successful crosses (Median = 1.0, IQR = 1.0) and penalty box possessions (Median = 1.0, IQR = 2.0) (χ^2 = 16.78, $p < 0.05$). However, in terms of the rate of creating shots, the ratio of attacking to defending players was the most likely situation to result in a shot (48.8%, χ^2 = 57, $p < 0.05$), a shot on target (22.1%, χ^2 = 16.78, $p < 0.05$) and a goal (5.8%, χ^2 = 15.8, $p < 0.05$).

There were no significant differences for total advantage situations, unstable situations and shots (all $p > 0.05$, **Table 1**) between playing at home and away. In detail, however, they created more penalty box possession unstable situations ($p < 0.05$) when playing at home (Median = 10.0, IQR = 5.5) than away (Median = 7.0, IQR = 4.0).

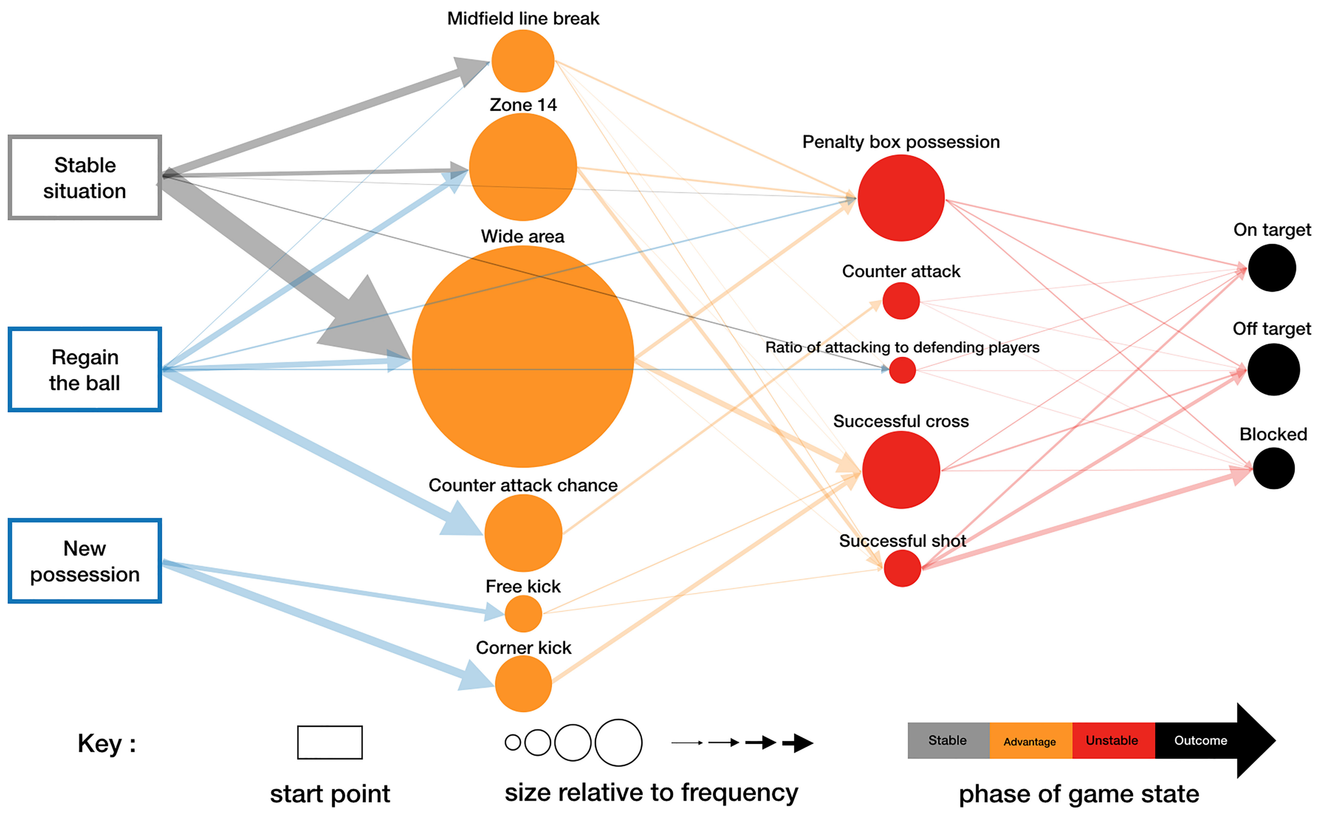

FIGURE 3 | The attacking process network of Crystal Palace Football Club in the 2017/2018 season.

DISCUSSION

The identification of a team's playing pattern is highly likely to be beneficial to coaches and sport scientists as this would impact training methodologies as a consequence of having a clear understanding of what teams need to do in order to win (Hewitt et al., 2016). The academic literature, however, has often considered playing pattern as simply "direct play" or "possession play," determined by simplistic measures such as the number of passes (e.g., Reep and Benjamin, 1968; Bate, 1988) or duration of team possessions (e.g., Jones et al., 2004; Hughes and Franks, 2005). This classification has clear face validity, given that the terms are ubiquitous in the football media, but offer little insight to applied practice whose goal is performance improvement. This limitation has prompted more recent research to consider multidimensional qualitative variables (e.g., offensive behaviors, Kempe et al., 2014; and factor analysis, Fernandez-Navarro et al., 2016; Lago-Peñas et al., 2017; Gomez et al., 2018). Gonzalez-Rodenas et al. (2019) presented specific actions e.g., penultimate or finishing action and subspaces i.e., areas of the pitch involved in the play, prior to goals being scored. However, no information was provided regarding how teams developed their attacks e.g., midfield line breaks or counter attacks. Similarly, Mitrotasios et al. (2019) presented attacking categories i.e., counter, combinative, fast and direct attacks, but did not consider any further details such as pitch locations, players involved etc. These studies comprehensively described the different features associated with the attacking process but failed to produce a methodology of practical use for performance enhancement. It was this limitation that prompted this study i.e., the development of a classification framework of the attacking process in football, with the aim of providing a suitable methodology for applied practice.

Kim et al. (2019) presented five specific situations that were described as unstable situations, more importantly defined as potential goal scoring opportunities. Of interest here was "how" one team achieved these in different situations. An analysis of all 38 matches in the 2017/2018 EPL suggested that the attacking process can be encapsulated by three different game situations, stable, advantage and unstable. These situations did not occur for every possession and the transition between situations was not uniform. Indeed, possession could originate in any of the situations with the way a team plays (playing pattern) likely to determine the frequency of each situation. For example, a team that employs the high press frequently is likely to win possession in an unstable situation more often than a team that does not.

In this study, 79.9% of unstable situations occurred in open play situations, which was similar to the occurrence of penultimate actions leading to goals during open play (75.9%; Gonzalez-Rodenas et al., 2019). Crystal Palace were shown to frequently utilize the wide areas to progress their attacks which resulted in their goal scoring opportunities as a consequence

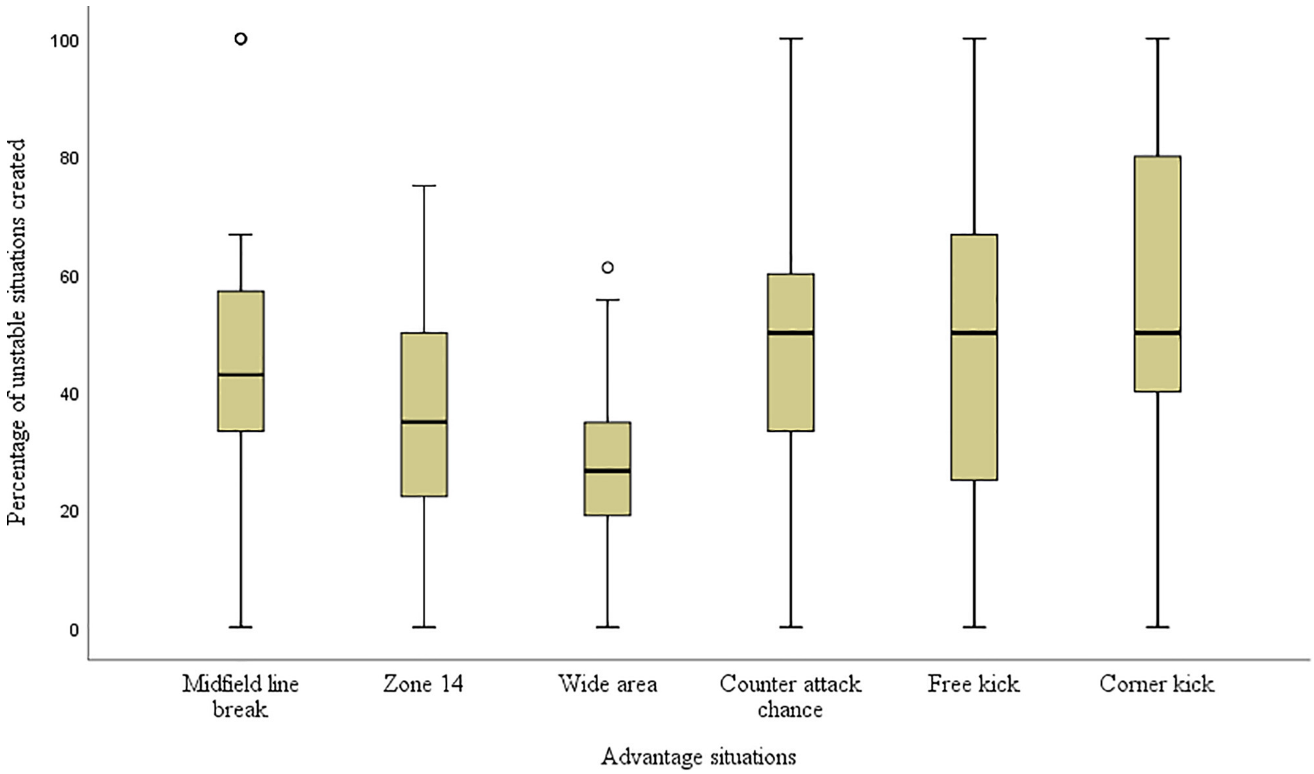

FIGURE 4 | Percentage of unstable situations created from advantage situations.

TABLE 1 | Frequency of specific advantage and unstable situations by match location.

	Advantage situation					Unstable situation					
	Home		Away		p		Home		Away		p
	Median	IQR	Median	IQR			Median	IQR	Median	IQR	
MLB	5.0	4.0	6.0	5.5	0.67	PBP	10.0	5.5	7.0	4.0	0.02
Z14	12.0	6.0	9.0	4.0	0.05	CA	3.0	4.0	3.0	2.5	0.98
WA	26.0	10.5	20.0	6.0	0.75	RAD	2.0	6.0	2.0	1.5	0.64
CAC	7.0	6.0	7.0	4.0	0.15	SC	7.0	4.0	6.0	4.0	0.42
FK	3.0	3.0	3.0	1.5	0.18	SS	3.0	1.5	3.0	2.5	0.77
CK	5.0	2.5	5.0	4.0	0.95						
Total	59.0	14.0	51.0	12.5	0.10	Total	25.0	7.0	22.0	7.0	0.10

MLB = midfield line break, Z14 = zone 14, WA = wide area, CAC = counter attack chance, FK = free kick, CK = corner kick, PBP = penalty box possession, CA = counter attack, RAD = ratio of attacking to defending players, SC = successful cross, SS = successful shot.

of penalty box possessions and successful crosses. The corner kick was shown to be their most effective method of creating an unstable situation. It is widely perceived that Crystal Palace's best players operate in the attacking wide areas i.e., wingers, Wilfred Zaha and Andros Townsend. It was thus not surprising that these analyses showed the prevalence of attacks from wide areas. Similarly, fullbacks Wan-Bissaka and Patrick van Aanholt are recognized as the players who make passes to the wingers and support their play in the wide area. This paper did not include player names as the purpose was to generate a rigorous methodology rather than a specific analysis of a team. However, names of players would be utilized by teams adopting this approach given their requirement of producing a tactical game plan to defeat a future opponent. The emphasis of Crystal Palace's attacking play using the wide areas supports the notion that they do not have players like to hold onto the ball in midfield areas and build up play using good passes, hence low midfield line breaks and low zone 14 possessions.

Since this research developed a previous study by Kim et al. (2019) no record was made of unstable situations that occurred subsequent to an initial one occurring during a single team possession. This meant that an accurate portrayal of all unstable situations was not possible. However, this extra information relates to how unstable situations sometimes develop and may provide additional information of value in the future. Similarly, the time during which events took place was not recorded. Temporal information may elucidate specific patterns e.g., Manchester City are well known for slow build up play i.e., the average time of their possessions in stable situations would be very different to a team like Leicester City who tend to focus on quick counter attacks. Time has also been shown to be useful in t-pattern analysis (Borrie et al., 2002) and would be a useful tool for further exploring this type of data. Other factors such as the number of passes, forward passes etc. were also omitted from this study, some of which have been used to discriminate playing patterns e.g., distance of passes (Tenga et al., 2010). Long passes are generally associated with direct play where defenders or midfielders pass to forward near the opponent's defensive line. In this study these passes were classified as either counter attacks (regain the ball in advantage situation) or when situations changed from stable to unstable but bypassed the advantage situation. Hence, the playing patterns generally referred to as "possession" would typically involve transition from stable to midfield line breaks/zone 14/wide area to penalty box possessions. In contrast direct play would miss out some of these situations either by involving no stable situation or missing out the advantage situation.

This study analyzed all matches from a season without considering well-known factors likely to influence performance. For example, match status, whether a team is winning, drawing or losing at the time and opponent quality have all been shown to influence performance. A simple analysis of the effect of match venue showed that Crystal Palace produced slightly more penalty box possession at home compared to away but this did not consider the other factors of importance. In future studies, these factors need to be investigated in a multi-factorial manner e.g., how does a team play when losing against a top rated opponent playing away. This classification framework also needs to be expanded to include individual player contributions if practically useful information is to be gained. Whilst academic literature tends to gravitate toward large data sets and statistical significance the usefulness of such an approach has been questioned for practically useful insights (Mackenzie and Cushion, 2013).

CONCLUSION

A novel methodology for classifying the attacking process in football has been presented with a view to providing a scientifically valid approach for use in the applied world. However, for this framework to be of practical benefit, future analyses need to consider contextual information in a multi-factorial manner. In this way teams can analyze their future opponents to determine how they create goal scoring opportunities during different scenarios, such as when their main striker is not playing.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript/supplementary files.

AUTHOR CONTRIBUTIONS

NP and BA assisted in reliability testing, data collection, and error checking. JK, NJ, and GV designed the study, conducted the analysis, interpreted the data, and wrote the manuscript. All authors read and approved the final manuscript.

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REFERENCES

Armatas, V., Yiannakos, A., Papadopoilou, S., and Skoufas, D. (2009). Evaluation of goals socred in top ranking soccer matches: greek "superleague" 2006-2007. *Serbian J. Sports Sci.* 3, 39–43.

Bate, R. (1988). "Football chance: tactics and strategy," in *Science and Football*, eds T. Reilly, A. Lees, K. Davids, and W. J. Murphy (London: E and FN Spon), 293–301.

Bloomfield, J. R., Polman, R. C. J., and O'Donoghue, P. G. (2005). Effects of score-line on team strategies in the FA premier league soccer. *J. Sports Sci.* 23, 192–193.

Borrie, A., Jonsson, G. K., and Magnusson, M. S. (2002). Temporal pattern analysis and its applicability in sport: an explanation and exemplar data. *J. Sports Sci.* 20, 845–852. doi: 10.1080/026404102320675675

Fernandez-Navarro, J., Fradua, L., Zubillaga, A., Ford, P. R., and McRobert, A. P. (2016). Attacking and defensive styles of play in soccer analysis of spanish and english elite teams. *J. Sports Sci.* 34, 2195–2204. doi: 10.1080/02640414.2016.1169309

Garganta, J. (2009). Trends of tactical performance analysis in team sports: bridging the gap between research training and competition. *Revista Portuguesa De Ciencias Do Desporto* 9, 81–89. doi: 10.5628/rpcd.09.01.81

Gomez, M., Mitrotasios, M., Armatas, V., and Lago-Penas, C. (2018). Analysis of playing styles according to team quality and match location in greek professional soccer. *Int. J. Perform. Anal. Sport* 18, 986–997. doi: 10.1080/24748668.2018.1539382

Gonzalez-Rodenas, J., Lopez-Bondia, I., Aranda-Malaves, R., Desantes, A. T., Sanz-Ramirez, E., and Malaves, R. A. (2019). Technical, tactical and spatial indicators related to goal scoring in European elite soccer. *J. Hum. Sport Exerc.* (in press).

Hewitt, A., Greenham, G., and Norton, K. (2016). Game style in soccer: what is it and can we quantify it? *Int. J. Perform. Anal. Sport* 16, 355–372. doi: 10.1080/24748668.2016.11868892

Hughes, M., and Franks, I. M. (2005). Analysis of passing sequences, shots and goals in soccer. *J. Sports Sci.* 23, 509–514. doi: 10.1080/02640410410001716779

Hughes, M. D., and Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *J. Sports Sci.* 20, 739–754.

James, N. (2009). Performance analysis of golf: reflections on the past and a vision of the future. *Int. J. Perform. Anal. Sport* 9, 188–209. doi: 10.1080/24748668.2009.11868476

James, N., Mellalieu, S. D., and Hollely, C. (2002). Analysis of strategies in soccer as a function of European and domestic competition. *Int. J. Perform. Anal. Sport* 2, 85–103. doi: 10.1080/24748668.2002.11868263

James, N., Taylor, J. B., and Stanley, S. (2007). Reliability procedures for categorical data in performance analysis. *Int. J. Perform. Anal. Sport* 7, 1–11. doi: 10.1080/24748668.2007.11868382

Jones, P., James, N., and Mellalieu, S. (2004). Possession as a performance indicator in soccer. *Int. J. Perform. Anal. Sport* 4, 98–102. doi: 10.1080/24748668.2004.11868295

Kempe, M., Vogelbein, M., Memmert, D., and Nopp, S. (2014). Possession vs. direct play: evaluating tactical behaviour in elite soccer. *Int. J. Sports Sci.* 4, 35–41.

Kim, J., James, N., Parmar, N., Ali, B., and Vučković, G. (2019). Determining unstable game states to aid the identification of perturbations in football. *Int. J. Perform. Anal. Sport* 19, 302–312. doi: 10.1080/24748668.2019.1602439

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *J. Sports Sci.* 27, 1463–1469. doi: 10.1080/02640410903131681

Lago, C., and Martìn, R. (2007). Determinants of possession of the ball in soccer. *J. Sports Sci.* 25, 969–974. doi: 10.1080/02640410600944626

Lago-Ballesteros, J., Lago-Peñas, C., and Rey, E. (2012). The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. *J. Sports Sci.* 30, 1455–1461. doi: 10.1080/02640414.2012.712715

Lago-Peñas, C., and Dellal, A. (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. *J. Hum. Kinet.* 25, 93–100. doi: 10.2478/v10078-010-0036-z

Lago-Peñas, C., Gomez-Ruano, M., and Yang, G. (2017). styles of play in professional soccer an approach of the chinese soccer super league. *Int. J Perform. Anal. Sport* 17, 1073–1084. doi: 10.1080/24748668.2018.1431857

Lames, M., and McGarry, T. (2007). On the search for reliable performance indicators in game sports. *Int. J. Perform. Anal. Sport* 7, 62–79. doi: 10.1080/24748668.2007.11868388

Mackenzie, R., and Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *J. Sport Sci.* 31, 639–676. doi: 10.1080/02640414.2012.746720

Michailidis, Y., Michailidis, C., and Primpa, E. (2013). Analysis of goals scored in European championship 2012. *J. Hum. Sport Exerc.* 8, 367–375. doi: 10.4100/jhse.2012.82.05

Mitrotasios, M., Gonzalez-Rodenas, J., Armatas, V., and Aranda, R. (2019). The creation of goal scoring opportunities in professional soccer. tactical differences between spanish la liga, english premier league, german bundesliga and Italan seria a. *Int. J. Perform. Anal. Sport* 19, 452–465. doi: 10.1089/big.2018.0067

Muhamad, S., Norasrudin, S., and Rahmat, A. (2013). Differences in goal scoring and passing sequences between winning and losing team in UEFA EURO championship 2012. *World Acad. Sci. Eng. Technol.* 7, 332–337.

Redwood-Brown, A. (2008). Passing patterns before and after goal scoring in FA premier league soccer. *Int. J. Perform. Anal. Sport* 8, 172–182. doi: 10.1080/24748668.2008.11868458

Reep, C., and Benjamin, B. (1968). Skill and chance in association football. *J. R. Stat. Soc. Ser. A* 131, 581–585.

Sarmento, H., Anguera, M. T., Pereira, A., Marques, A., Campanico, J., and Leitao, J. (2014). Patterns of play in the counterattack of elite football teams- a mixed method approach. *Int. J. Perform. Anal. Sport* 14, 411–427. doi: 10.1080/24748668.2014.11868731

Sarmento, H., Anguera, T., Campanico, J., and Leitao, J. (2010). Development and validation of a notational system to study the offensive process in football. *Medicina* 46, 401–407.

Tenga, A., Holme, I., Ronglan, L. T., and Bahr, R. (2010). Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. *J. Sports Sci.* 28, 245–255. doi: 10.1080/02640410903502766

Tenga, A., and Sigmundstad, E. (2011). Characteristics of goal-scoring possessions in open play comparing the top, in-between and bottom teams from professional soccer league. *Int. J. Perform. Anal. Sport* 11, 545–552. doi: 10.1080/24748668.2011.11868572

Tenga, A., Zubillaga, A., Caro, O., and Fradua, L. (2015). Explorative study on patterns of game structure in male and female matches from elite spanish soccer. *Int. J. Perform. Anal. Sport* 15, 411–423. doi: 10.1080/24748668.2015.11868802

Wright, C., Atkins, S., Polman, R., Jones, B., and Sargeson, L. (2011). Factors associated with goals and goal scoring opportunities in professional soccer. *Int. J. Perform. Anal. Sport* 11, 438–449. doi: 10.1080/24748668.2011.11868563

Yiannakos, A., and Armatas, V. (2006). Evaluation of the goal scoring patterns in European championship in Portugal 2004. *Int. J. Perform. Anal. Sport* 6, 178–188. doi: 10.1080/24748668.2006.11868366

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Analysis of Cricket Ball Type and Innings on State Level Cricket Batter's Performance

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Background: The aim of this investigation was to compare the type of cricket balls utilized and innings on cricket batting performance in the First-Class Australian competition.

Methods: Batting performance measures of 43 state level cricket batters were collected from two seasons of the Sheffield shield tournament (N = 60 games) that incorporated both Kookaburra™ (n = 30 games) and Duke™ (n = 30 games) cricket balls.

Results: First-innings batting performances were significantly greater for the average number of runs scored (37.5 ± 13.4 vs. 31.2 ± 11.3), balls faced (60.7 ± 26.2 vs. 49.9 ± 23.6), boundary 4s (3.8 ± 1.9 vs. 2.9 ± 1.4), and boundary 6s (0.2 ± 0.3 vs. 0.1 ± 0.3) scored per game ($p < 0.05$), as well as centuries scored (5.74 ± 8.56 vs. 1.49 ± 5.14%) compared to second innings performances ($p < 0.05$). There were no differences for any batting performance measures as a result of ball type ($p > 0.05$). However, significantly more wickets were taken by pace bowlers during Duke™ ball games (85.0 ± 12.8 vs. 76.4 ± 13.9%), while relatively more wickets were taken by spin bowlers during Kookaburra™ ball games (14.2 ± 12.5 vs. 22.0 ± 14.1%; $p < 0.05$).

Conclusions: Cricket batting performance was comparable in games involving the Kookaburra™ or Duke™ ball. However, pace bowlers were more successful transferring their skill to the Duke™ ball, while spin bowlers were more successful with the KB™ ball. Subsequently, batters may be able to effectively adapt their movement technique, and transfer their skill to the Duke™ ball conditions. Future research is suggested to examine the influence of the cricket playing surface's deterioration on cricket batter's interceptive performance.

Keywords: cricket batting, performance analysis, constraints, ecological dynamics, coaching

INTRODUCTION

Cricket batting is a complex perceptual-motor skill that also involves overcoming capricious task demands and permutable constraints. One major task constraint thought to impact on batting performance is the physical properties of the ball (Mehta et al., 1983; Weissensteiner et al., 2011). The majority of cricket played internationally use different types of cricket balls depending on the home country. For example, the Australian cricket competition uses a Kookaburra™ (KB™) ball that has a reported wider and flatter seam compared with an English Duke™ ball, which is slightly smaller and has a more pronounced seam (Rundell, 2009). Anecdotally, the Duke™

ball has also been stated to retain its smooth polished surface (referred to as ball shine) better after repeated contacts with the ground and bat. Studies have indicated that seam prominence and ball shine are pertinent factors that can alter the aerodynamics of a ball such that it follows a curvilinear flight path (i.e., swing bowling) (Mehta, 1985; Alam et al., 2007). These physical properties have been shown to contribute to larger ball swing (i.e., curvilinear movement through the air), albeit judicious use of the ball seam position by fast bowlers (Mehta, 2005) and ideal ball properties are also necessary ingredients (Barton, 1982). While ball trajectory (i.e., linear versus curvilinear) has been reported to alter cricket batter's gaze behavior (Sarpeshkar et al., 2017a) and kinematics (Sarpeshkar et al., 2017b), it is yet to be substantiated whether different ball types demonstrate different ball-flight characteristics, bowler performance and subsequent batting performance. This would seem particularly important, as the Australian domestic competition has introduced a Duke™ ball during the latter half of their First-Class competition, in an effort to help batters adapt to the ball used in English conditions. Evaluating the impact of ball type on batting performance would have a substantial impact on the acute and chronic preparation of skilled cricket batters.

Another unique factor thought to impact upon batting performance is the order of innings, or more specifically, game time. Batters must contend with the deterioration of the playing pitch surface, which occurs across multiple innings (Carré and Haake, 2000; James et al., 2005). Interestingly, the influence of a changing pitch surface on cricket batting movements and behavior has been scarcely investigated. In other interactive sports such as tennis, studies have reported that various ground conditions (i.e., clay vs. grass surfaces) can change tactical strategies (O'Donoghue and Ingram, 2001; O'Donoghue and Liddle, 2002), physiological demands (Pereira et al., 2016), and performance outcomes (Gillet et al., 2009; Reid et al., 2013). However, there has been limited to no empirical examination in relation to the various cricket specific skills. Cricket batting is particularly unique in that, as pitch surfaces change their physical properties due to repeated forceful contact of the ball and players running on the pitch, so can the ball trajectory spontaneously change when contacting uneven areas of the pitch (James et al., 2005). These changes in ball trajectory and bounce height may create opportunities for certain cricket shots to emerge, while the opportunity to play other shots declines (Chow et al., 2005; Pinder et al., 2012). Expert cricket coaches have stated that cricket batters needed to be constantly attuned (e.g., perceive and use key sources of information) (Davids et al., 2012) to the slow but continuous state of change in pitch conditions, in order to score runs and minimize the chance of being dismissed (Connor, 2018). Therefore, the integrity of the pitch as game time progresses is thought to be a potentially important factor influencing cricket batting performance.

The majority of cricket batting research to date has explored skill level differences in batting technique (Stuelcken et al., 2005; Portus and Farrow, 2011; Penn and Spratford, 2012), visual anticipatory information (Renshaw and Fairweather, 2000; Müller and Abernethy, 2006), physiological demands (Scanlan et al., 2016), and the role of the individual and environment in shaping emergent behaviors (Renshaw, 2010; Connor et al., 2018). However, there has been far less analysis of performance *in situ*. Greater understanding of this area would allow for the identification of specific constraints that influence performance, and subsequently, allow practitioners and coaches to produce representative practice environments. Newell (1986) described the individual (e.g., cognitions, physical characteristics), task (e.g., equipment or implements, rules, and goals of the task) and environment (e.g., physical and socio-cultural factors) as being three critical constraints which shape emergent behavior (Higgins, 1977; Renshaw et al., 2010). For example, constraints in the form of individual cognitions play an integral role in coordinative behavior. Sarpeshkar et al. (2017b) investigated the influence of ball-swing on cricket batting performance and reported that the presence of ball swing alone resulted in altering batter's movement timings. That is, external factors within the environment, such as ball-swing, impact a batter's coordinative actions. Understanding what constraints impact on player's decision-making behavior and performance is critical to creating practice environments that represent the demands of the game (Pinder et al., 2011; Barris et al., 2013).

Cricket is a unique sport in that international level teams travel and play opposition teams all around the world where different types of cricket balls and pitch or surface conditions are used depending on the home team. While there is evidence that home teams have a performance advantage because of their familiarity with these constraints (Morley and Thomas, 2005), the impact of ball type or first or second innings (an indirect marker of pitch surface deterioration) on cricket batting performance during actual game-play has yet to be examined. Therefore, the aim of this study was to investigate whether cricket batting performance is altered by the type of cricket ball used during games, and across different innings, in sub-elite, Australian cricket competition. It was hypothesized that cricket batting performance measures such as runs scored, balls faced, boundaries scored and score categories would be adversely affected during games where the Duke™ cricket ball was utilized. Further, batting performance was worse during the second innings of games, likely due to deterioration in pitch conditions. A secondary aim was to examine whether changes in ball type also impacted the mode of batter's dismissal. Pace bowlers were hypothesized to take more wickets with the Duke™ ball compared to the Kookaburra™ based upon reported properties of the Duke™ ball.

MATERIALS AND METHODS

Game performance indicators from a total of 60 games during the 2016/17 and 2017/18 Australian Sheffield shield seasons were extracted from a commercially accessible source (http://www.espncricinfo.com; accessed from February 22nd, 2018). The analysis included 43 cricket players classified as specialist batters (i.e., listed within the first seven positions on the team list; inclusive of players, who also specialized in other roles such as wicketkeeper and all-rounders) and who played a minimum of three innings across all four experimental conditions (first innings, second innings, KB™ and Duke™ balls). The average number of games played by each batter analyzed was 15.4 ± 4.2 and were played across 15 venues around Australia. The KB™ cricket ball type was used during the first half of each season, before being switched for Duke™ balls, which were used for the second half of both seasons. All research procedures were approved by the James Cook University Human Research Ethics Committee.

Data Analysis

Batting performance measures included average number of runs scored per inning (per dismissal), average number of balls faced, average number of boundary 4s and boundary 6s hit per game, and average strike rate (runs scored per ball and per game). Batting scores were also grouped into number of zero scores, scores of 10–24, 25–49, 50–99 and scores of 100 or more (i.e., centuries) as a percentage of the total innings included in the analyses. The relative number of wickets taken by three modes of dismissal (pace bowler, spin bowler, or run out) was also recorded as a percentage of total wickets per game.

Statistical Analysis

Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS, version 24, IBM, IL, USA). A two-way repeated (ball type × innings) measures analysis of variance (ANOVA) was conducted on all cricket batting performance measures including runs scored, number of balls faced, average number of boundary 4 and 6s per game, and average strike rate. Finally, a three-way repeated measures ANOVA (wickets by bowler × ball type × innings) was used to compare the total relative number of wickets taken by pace bowlers, spin bowlers, or run outs when the KB™ and Duke™ cricket ball was utilized (expressed as a percentage of total games played) across both innings. For *post hoc* analyses, pairwise comparisons with Bonferroni correction were used for any significant main effects. Cohen's D effect sizes (ES) were also computed to determine the magnitude of differences for performance measures between experimental conditions (i.e., ball type, innings). For ES calculations, 0.2 was considered as a small difference, 0.5 as a moderate difference and ≥ 0.8 as a large difference (Cohen, 1992). Statistical significance for all analyses was set at 0.05.

RESULTS

Batting Performance

No significant interactions were found between innings and ball type for average runs scored [$F(1, 42) = 0.02$, $p = 0.90$], average balls faced [$F(1, 42) = 0.26$, $p = 0.61$], boundary 4s [$F(1, 42) = 0.08$, $p = 0.78$], boundary 6s [$F(1, 42) = 0.002$, $p = 0.96$], and strike rate [$F(1, 42) = 0.25$, $p = 0.62$; **Table 1**]. Main effects of innings demonstrated that the first innings had greater average runs scored [$F(1, 42) = 5.13$, $p < 0.05$; 37.5 ± 13.4 vs. 31.2 ± 11.3; ES = 0.45] average balls faced [$F(1, 42) = 8.00$, $p < 0.05$; 60.7 ± 26.2 vs. 49.9 ± 23.6; ES = 0.43], boundary 4s [$F(1, 42) = 13.23$, $p < 0.01$; 3.8 ± 1.9 vs. 2.9 ± 1.4; ES = 0.52], and boundary 6s [$F(1, 42) = 10.28$, $p < 0.05$; 0.2 ± 0.3 vs. 0.1 ± 0.3; ES = 0.33] compared to the second innings. No difference of innings were found for strike rate [$F(1, 42) = 0.03$, $p = 0.86$; 45.9 ± 15.9 vs. 46.3 ± 17.8; ES = 0.02].

Finally, no main effect of ball type between KB™ and Duke™ was found for any variable, including average runs scored [$F(1, 42) = 0.17$, $p = 0.70$; 34.1 ± 13.5 vs. 35.3 ± 13.0; ES = 0.09], average balls faced [$F(1, 42) = 0.02$, $p = 0.88$; 55.6 ± 24.4 vs. 55.0 ± 26.6; ES = 0.02], boundary 4s [$F(1, 42) = 0.13$, $p = 0.73$; 3.3 ± 1.8 vs. 3.4 ± 1.7; ES = 0.04], boundary 6s [$F(1, 42) = 10.28$, $p < 0.05$; 0.2 ± 0.2 vs. 0.2 ± 0.3; ES = 0.07] or strike rate [$F(1, 42) = 2.32$, $p = 0.14$; 44.1 ± 12.1 vs. 48.0 ± 20.4; ES = 0.24].

Batting Scores

No significant interaction were found between innings and ball type for scores of zero [$F(1, 42) = 0.62$, $p = 0.44$], scores of 10–24 [$F(1, 42) = 0.58$, $p = 0.45$], scores of 25–49 [$F(1, 42) = 0.23$, $p = 0.64$], scores of 50–99 [$F(1, 42) = 0.7$, $p = 0.80$], or scores of 100 of more [$F(1, 42) = 0.47$, $p = 0.50$; **Table 2**]. The only main effect found for score type was innings, which showed that the first innings had greater average scores of 100 or more runs [$F(1, 42) = 15.45$, $p < 0.01$; 5.74 ± 8.56 vs. 1.49 ± 5.14%; ES = 0.62] than the second innings. No main effect of innings was found for scores of zero [$F(1, 42) = 0.43$, $p = 0.52$; 8.91 ± 12.67 vs. 10.45 ± 13.93%; ES = 0.12], scores of 10–24 [$F(1, 42) = 0.18$, $p = 0.67$; 50.03 ± 20.95 vs. 51.45 ± 23.84%; ES = 0.06], scores of 25–49 [$F(1, 42) = 1.70$, $p = 0.20$; 19.31 ± 15.09 vs. 22.77 ± 18.56%; ES = 0.21] and scores of 50–99 [$F(1, 42) = 0.89$, $p = 0.35$; 5.81 ± 23.54 vs. 13.88 ± 13.96%; ES = 0.43].

No main effect of ball type between KB™ and Duke™ ball was found for scores of zero [$F(1, 42) = 0.01$, $p = 0.93$; 9.60 ± 12.30 vs. 9.76 ± 14.30%; ES = 0.01], scores of 10–24 [$F(1, 42) = 0.15$, $p = 0.70$; 51.40 ± 22.15 vs. 50.09 ± 22.73%; ES = 0.06], scores of 25–49 [$F(1, 42) = 0.29$, $p = 0.59$; 20.45 ± 16.93 vs. 21.63 ± 17.07; ES = 0.07] scores of 50–99 [$F(1, 42) = 0.02$, $p = 0.88$; 9.34 ± 18.42 vs. 10.36 ± 21.03%; ES = 0.07], or scores of 100 or more [$F(1, 42) = 0.14$, $p = 0.71$; 3.83 ± 7.16 vs. 3.41 ± 7.58%; ES = 0.06].

Batting Dismissals

No interaction was reported between wicket taken by bowler, ball and innings [$F(2, 84) = 0.64$, $p = 0.53$]. Similarly, no interaction was found between wickets taken by bowler and innings (first innings vs. second innings: pace = 80.3 ± 11.1 vs. 82.1 ± 14.4, ES = 0.14; spin = 18.5 ± 10.6 vs. 16.7 ± 14.1, ES = 0.14; run outs = 1.2 ± 2.9 vs. 1.1 ± 3.6, ES = 0.02) [$F(2, 84) = 0.55$, $p = 0.58$]. An interaction was found between ball type and mode of dismissal [$F(2, 84) = 7.60$, $p < 0.01$]. *Post hoc* analysis revealed that a greater proportion of wickets were taken by pace bowlers with the Duke™ ball (ES = 0.72), and by spin bowlers with the KB™ ball (ES = 0.59) (**Figure 1**). No difference between ball types was found for run out (ES = 0.27).

TABLE 1 | Cricket batting performance measures during each innings and for each ball type (mean ± SD).

		Runs scored	Balls faced	Boundary 4s	Boundary 6s	Strike rate
Innings 1	KB™	38.7 ± 17.6	60.0 ± 23.6	3.8 ± 2.0	0.2 ± 0.3	44.5 ± 10.6
	Duke™	36.3 ± 20.2	61.3 ± 28.9	3.8 ± 1.9	0.2 ± 0.3	47.3 ± 19.9
Innings 2	KB™	31.9 ± 17.2	51.2 ± 24.7	2.8 ± 1.5	0.1 ± 0.2	43.7 ± 13.5
	Duke™	32.0 ± 19.1	48.7 ± 22.6	3.0 ± 1.4	0.1 ± 0.3	48.8 ± 21.2

TABLE 2 | Percentage of games where batters scored within a certain scoring category across innings and ball type (mean ± SD).

Scores		0	10–24	25–49	50–99	100+
First innings	KB™	8.0% ± 10.6	52.1% ± 23.0	18.0% ± 15.6	4.7% ± 21.3	6.4% ± 7.8
	Duke™	9.8% ± 14.5	48.0% ± 18.7	20.6% ± 14.6	7.0% ± 25.8	5.1% ± 9.3
Second innings	KB™	11.2% ± 13.7	50.7% ± 21.5	22.9% ± 18.0	14.0% ± 13.7	1.3% ± 5.5
	Duke™	9.7% ± 14.3	52.2% ± 26.2	22.7% ± 19.3	13.7% ± 14.4	1.7% ± 4.8

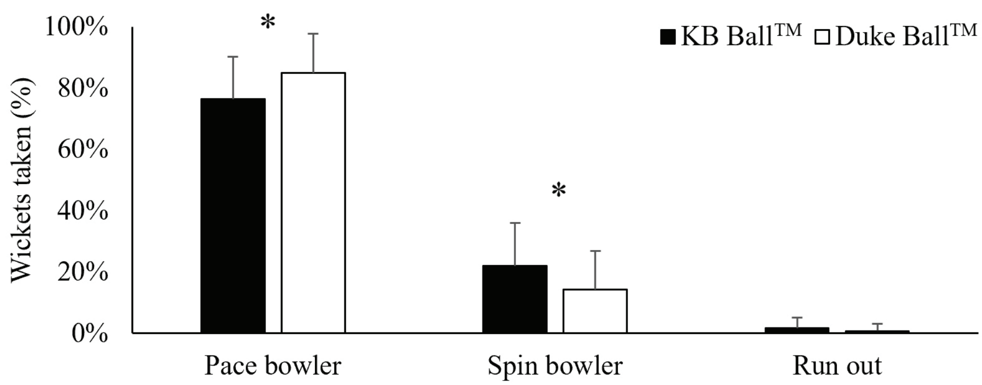

FIGURE 1 | Relative number of wickets taken by either an opposition pace bowler, spin bowler, or run out. *Significant difference between ball types ($p < 0.05$).

DISCUSSION

The aims of this study were to examine: (1) the impact of evolving constraints, specifically innings and ball type, on batting performance; and (2) whether batter's dismissal by pace or spin bowlers was affected by innings or ball type. Ball type had no impact upon batting performance, whereas greater batting performance was identified during the first innings compared to the second innings. Further, ball type influenced the relative number of wickets taken by bowlers with pace bowlers taking more wickets with the Duke™ ball while spin bowlers took more wickets with the KB™ ball. These findings suggest that state level cricket batters transferred batting performance from the KB™ ball to the Duke™ ball; however, did not transfer their skills as effectively to the changing constraints associated with second inning's performances. Given pace bowlers took a greater proportion of wickets with the Duke™ ball, differences between the two ball types may exist with future studies needed to confirm. These findings are important to coaches and players when preparing for an upcoming game, whereby the batter's preparation and subsequent game strategy should be individualized to the game constraints.

Interestingly, no differences were found in batting performance measures during games that used either the KB™ or Duke™ ball. The overall findings with respect to ball type were somewhat surprising given anecdotal reports of players, and previous empirical work, highlighting the increased challenge of batters in intercepting a swinging ball (Sarpeshkar and Mann, 2011; Sarpeshkar et al., 2017a,b). The properties of the Duke™ ball have been purported to induce greater swing and for a longer duration (Alam et al., 2007; Rundell, 2009), however this has not been established empirically in cricket. The current study identified that the relative scoring distribution during KB™ and Duke™ ball games were minor as evident by small ES, suggesting that any potential changes in the ball flight trajectory as a result of the Duke™ ball's innate properties did not impact upon batting performance measures. That is, batters successfully transferred their batting skill to the alternate ball conditions. Alternatively, batters' may not have needed to change behavior due to a lack of clear difference between the Duke™ and KB™ ball's ability to swing to a greater extent. Further empirical clarification is required in this area.

Regardless of the type of cricket ball used, the significant impact of innings on cricket batting performance measures was in line with previous findings (Borooah and Mangan, 2010). Specifically, Borooah and Mangan (2010) analyzed top performing cricket batters and reported that 80% of the top 50, highest batting average players scored more runs during the first innings than the second innings. In the current study, batting performance (i.e., runs scored, balls faced, boundaries 4s and 6s, and centuries scored) were all significantly lower during the second innings with a moderate effect size identified for boundary 4s. Previous research has shown that successful batting performance and run scoring is associated with greater quality of bat-ball contact (Connor et al., 2018). However, the majority of research to date on cricket batting has been conducted under controlled settings with limited discussion on the state of the playing surface. Cricket pitches often deform when repeatedly impacted by external factors (e.g., cricketer's running on the pitch, bowling deliveries, etc.), influencing the consistency of the ball trajectory (Carré et al., 1999; Carré and Haake, 2000) and can create greater spatio-temporal demands of batters trying to achieve bat-ball contact. Carré et al. (1999) reported changes in ball velocity and rebound angle (i.e., bounce) when comparing the pitch surface properties from day one to day four, a similar time period of sub-elite cricket games. Therefore, one possible explanation for the current results may be that batters achieved better bat-ball contact quality during the first innings, where the pitch surface had yet to deteriorate, which reduced the opportunities for the opposition bowler to bring about a dismissal. However, further work which includes mechanistic data (e.g., bat-ball contact quality, shot type, etc.) is required to support this explanation. Further research is also recommended to examine whether the speed/pace, bounce and/or consistency properties of the pitch influence cricket batting behavior or performance.

Another substantial difference between first and second innings is the overall situation of the game, and thus, the roles and responsibilities of the batter (Scarf et al., 2011). The second innings require batters to score a sufficient number of runs, such that the opposition cannot (1) score as many or (2) bat for a duration that takes the game to a draw if the team is unable to win. Akhtar and Scarf (2012) highlighted the complexity of second innings' performances, whereby a 10% increase in required runs beyond a critical point can result in a 20% reduction in win probability. Reductions in second inning's performance may result from an increase in perceptual and technical demands, thought to be associated with a deteriorating pitch surface and spontaneous changes in ball trajectory, as well as the greater cognitive demands from an evolving penultimate game situation leading to the final game outcome. It is important to note that within this study, there was no difference in strike rate (i.e., runs scored per hundred balls) identified between first and second innings' performances, suggesting that the game scenario demands did not differ enough to alter the speed in which runs needed to be scored between innings. It is recommended that coaches create practice environments that both mimic the playing surface that commonly occurs during second innings (e.g., 3- or 4-day old pitch surfaces) coupled with scenarios that batters are likely to experience during second inning's performances.

Finally, scores of ≥100 (5.74 vs. 1.49%, moderate ES) occurred significantly more during the first innings when compared with the second innings. Effect sizes for all other score comparisons (0, 1–24, 25–49, and 50–99) were small. It is suggested that the observed differences in average runs scored between innings occur in part due to the batter's inability to convert scores of 50–99 (5.81 ± 23.54 vs. 13.88 ± 13.96%) into 100 or more during the second innings. By this late stage of the game, both physical (Scanlan et al., 2016; Cooke et al., 2018) and mental (Veness et al., 2017) fatigue are likely to be contributing factors to performance. It has also been previously reported that batters experience heightened anxiety when achieving important milestones (e.g., scoring 100 or more runs) and during the initial period of batting (Slogrove et al., 2002).The aforementioned pitch deterioration is likely to be another significant factor on batting performance (Carré et al., 1999). Together, these greater individual and environmental demands upon the batter, occurring in the latter part of the second innings, may explain the decline in performance. To counteract these performance decrements, it is recommended that coaches and practitioners ensure players are exposed to conditions that they are likely to experience during a game, such as physical and mental fatigue, anxiety and pitch deterioration (e.g., uneven ball bounce and pace). Following a representative learning design approach would ensure players maintain both action fidelity and functionality during their training (Pinder et al., 2011).

Interestingly, despite no impact of ball type on batting performance, opposition pace bowlers took relatively more wickets with the Duke™ ball than during games involving the KB™ ball. The greater bowling success of pace bowlers with the Duke™ ball may be a result of the opposition team exploiting the propensity of Duke™ balls to swing more, and thus, predominantly utilize pace bowlers during the game rather than spinners. Additionally, fast bowler's may also adapt their bowling technique (e.g., keeping the seam more upright) to provide the greatest opportunity for the ball to swing. While a swinging ball perturbs batting technique and perceptual demands (Sarpeshkar and Mann, 2011; Sarpeshkar et al., 2017b), which can result in reduced proficiency of an interceptive task (Craig et al., 2006), the current study demonstrates that batting performance was not affected as a result of the type of cricket ball. While it is not known exactly how batters were able to effectively adapt to different ball types, one explanation may be the logistical ease in which coaches can incorporate different cricket balls into their practice environments. By doing so, players can calibrate their actions to any potential altered ball trajectory associated with various ball types. Future research should examine the duration of time required for batters to effectively transfer skills to various ball types used in cricket games, so as to provide evidence-based coaching recommendations for match preparation during the preseason.

A limitation inherent in this study was the order effect in which batters were exposed to different cricket ball conditions. Across both seasons, the first half of the season utilized the KB™ ball while the latter half utilized the Duke™. Ideally, comparing both ball conditions would be conducted with a randomized cross-over design to enable examination of the transfer of skills from the Duke™ to KB™ ball, and from the KB™ to the Duke™ ball. However, the real-world collection of data meant that this was not feasible. It is therefore unclear whether the preparation time between the first and second half of the season was a primary factor for batting performance being relatively unaffected by the use of a different cricket ball. It was also unclear as to whether different pitch surfaces deteriorated more quickly than others during games, which should be a factor considered in future research. Analytical approaches may have also impacted the current outcomes; although this was unlikely given that additional analyses on individual case data were conducted using linear mixed modeling, to consider the variance across individual performances, with similar outcomes produced. Cricket batting performance may also be best analyzed in conjunction with additional performance indicators and mechanistic measures of cricket batting (e.g., types and efficiency of shots executed). This is due to performance being dependent on a multitude of factors that exist within the use of different ball types or pitch surfaces. For example, a number of individual (e.g., emotions, motivations, intentions) and task constraints (e.g., situation of the game, field-settings) are influential factors that need to be considered and standardized to an extent between participants. While cricket batting performance measures are crucial to understanding the real-world effect, future research should investigate the impact of ball type, and the constraints associated with different innings, following a representative approach under controlled conditions.

CONCLUSIONS

The current study demonstrated that cricket batting performance was comparable in games involving the KB™ and a Duke™ ball, despite pace bowlers being more successful with a Duke™ ball and spin bowlers more successful with the KB™ ball. Therefore, state level cricket batters were able to transfer their batting performance from the KB™ ball to the Duke™ ball condition. Further, batters were not able to commensurately adapt to the constraints concomitant with second innings of the game, with batting performance significantly less during the second innings regardless of ball type. Deteriorating pitch surfaces and the mutable role of the batter during the second innings, which may result in a shift in intentions and batting technique, may partly explain the decline in performance. Future research could identify how batting technique and actions differ between innings and allow coaches to create practice environments that are representative of the demands of the game. The practical applications of this study can be used by coaches to incorporate second innings' conditions in their training practices, similar to the way different ball types are utilized during practice. Logistically, it may only be possible to implement this over a significant period of time during pre-season preparation. This learning design would provide batters with the opportunity to adapt their own individual game and movement-specific strategies in response to the real demands experienced during the second innings of cricket matches.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

All research procedures were approved by the James Cook University Ethics Committee. All data utilized in this study was accessed from an opensource website (www.espncricinfo.com) which displayed the game performance scores of each individual player. Therefore, consent of individual participants was not required.

AUTHOR CONTRIBUTIONS

All authors contributed ideas to the design of this study. JC performed the statistical analyses. JC developed the first paper draft, and all authors revised the manuscript for important intellectual content and approved the final version of the article.

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REFERENCES

Akhtar, S., and Scarf, P. (2012). Forecasting test cricket match outcomes in play. *Int. J. Forecast.* 28, 632–643. doi: 10.1016/j.ijforecast.2011.08.005

Alam, F., La Brooy, R., and Subic, S. (2007). "Aerodynamics of cricket ball-an understanding of swing" in *The impact of technology on sport II*. eds. F. K. Fuss, A. Subic, and S. Ujihashi (Florida, USA: Taylor & Francis Group), 311–316.

Barris, S., Davids, K., and Farrow, D. (2013). Representative learning design in springboard diving: is dry-land training representative of a pool dive? *Eur. J. Sport Sci.* 13, 638–645. doi: 10.1080/17461391.2013.770923

Barton, N. (1982). On the swing of a cricket ball in flight. *Proc. R. Soc. Lond. A* 379, 109–131. doi: 10.1098/rspa.1982.0008

Borooah, V. K., and Mangan, J. E. (2010). The "Bradman class": an exploration of some issues in the evaluation of batsmen for test matches, 1877-2006. *J. Quant. Anal. Sports* 6, 1–21. doi: 10.2202/1559-0410.1201

Carré, M., Baker, S., Newell, A., and Haake, S. (1999). The dynamic behaviour of cricket balls during impact and variations due to grass and soil type. *Sports Eng.* 3, 45–160. doi: 10.1046/j.1460-2687.1999.00029.x

Carré, M., and Haake, S. (2000). Predicting the dynamic behaviour of cricket balls after impact with a deformable pitch. Paper presented at the Proceedings of the 3rd International Conference on the Engineering of Sport.

Chow, J., Davids, K., Button, C., and Koh, M. (2005). Decaying and emerging task constraints in the acquisition of soccer kicking skills. Paper presented at the United Nations International Conference on Sport and Education. Bangkok, Thailand.

Cohen, J. (1992). A power primer. *Psychol. Bull.* 112, 155–159. doi: 10.1037/0033-2909.112.1.155

Connor, J. D. (2018). *Utilising representative learning design to underpin the measurement and development of cricket batting expertise*. Victoria University.

Connor, J. D., Farrow, D., and Renshaw, I. (2018). Emergence of skilled behaviours in professional, amateur and junior cricket batsmen during a representative training scenario. *Front. Psychol.* 9:2012. doi: 10.3389/fpsyg.2018.02012

Cooke, K., Outram, T., Brandon, R., Waldron, M., Vickery, W., Keenan, J., et al. (2018). The difference in neuromuscular fatigue and workload during competition and training in elite cricketers. *Int. J. Sports Physiol. Perform.* 14, 1–20. doi: 10.1123/ijspp.2018-0415

Craig, C. M., Berton, E., Rao, G., Fernandez, L., and Bootsma, R. J. (2006). Judging where a ball will go: the case of curved free kicks in football. *Naturwissenschaften* 93, 97–101. doi: 10.1007/s00114-005-0071-0

Davids, K., Araújo, D., Hristovski, R., Passos, P., and Chow, J. Y. (2012). "Ecological dynamics and motor learning design in sport" in *Skill Acquisition in Sport: Research, Theory and Practice*. eds. N. J. Hodges and A. M. Williams (New York, USA: Routledge), 112–130.

Gillet, E., Leroy, D., Thouvarecq, R., and Stein, J.-F. (2009). A notational analysis of elite tennis serve and serve-return strategies on slow surface. *J. Strength Cond. Res.* 23, 532–539. doi: 10.1519/JSC.0b013e31818efe29

Higgins, J. R. (1977). *Human movement: An integrated approach*. USA: Mosby.

James, D., Carre, M., and Haake, S. (2005). Predicting the playing character of cricket pitches. *Sports Eng.* 8, 193–207. doi: 10.1007/BF02844162

Mehta, R. D. (1985). Aerodynamics of sports balls. *Annu. Rev. Fluid Mech.* 17, 151–189.

Mehta, R. D. (2005). An overview of cricket ball swing. *Sports Eng.* 8, 181–192. doi: 10.1007/BF02844161

Mehta, R., Bentley, K., Proudlove, M., and Varty, P. (1983). Factors affecting cricket ball swing. *Nature* 303, 787–788. doi: 10.1038/303787a0

Morley, B., and Thomas, D. (2005). An investigation of home advantage and other factors affecting outcomes in English one-day cricket matches. *J. Sports Sci.* 23, 261–268. doi: 10.1080/02640410410001730133

Müller, S., and Abernethy, B. (2006). Batting with occluded vision: an *in situ* examination of the information pick-up and interceptive skills of high-and low-skilled cricket batsmen. *J. Sci. Med. Sport* 9, 446–458. doi: 10.1016/j.jsams.2006.03.029

Newell, K. (1986). "Constraints on the development of coordination" in *Motor development in children: Aspects of coordination and control*. eds. M. G. Wade and H. T. A. Whiting (Boston: Martinus Nijhoff), 341–360.

O'Donoghue, P., and Liddle, D. (2002). "A match analysis of elite tennis strategy for ladies' singles on clay and grass surfaces" in *Science and racket sports II*. eds. A. Lees, I. Maynard, M. Hughes, and T. Reilly (London: Routledge), 247.

O'Donoghue, P., and Ingram, B. (2001). A notational analysis of elite tennis strategy. *J. Sports Sci.* 19, 107–115. doi: 10.1080/026404101300036299

Penn, M. J., and Spratford, W. (2012). Are current coaching recommendations for cricket batting technique supported by biomechanical research? *Sports Biomech.* 11, 311–323. doi: 10.1080/14763141.2011.638387

Pereira, L. A., Freitas, V., Moura, F. A., Aoki, M. S., Loturco, I., and Nakamura, F. Y. (2016). The activity profile of young tennis athletes playing on clay and hard courts: preliminary data. *J. Hum. Kinet.* 50, 211–218. doi: 10.1515/hukin-2015-0158

Pinder, R. A., Davids, K., and Renshaw, I. (2012). Metastability and emergent performance of dynamic interceptive actions. *J. Sci. Med. Sport* 15, 437–443. doi: 10.1016/j.jsams.2012.01.002

Pinder, R. A., Davids, K., Renshaw, I., and Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *J. Sport Exerc. Psychol.* 33, 146–155. doi: 10.1123/jsep.33.1.146

Portus, M. R., and Farrow, D. (2011). Enhancing cricket batting skill: implications for biomechanics and skill acquisition research and practice. *Sports Biomech.* 10, 294–305. doi: 10.1080/14763141.2011.629674

Reid, M. M., Duffield, R., Minett, G. M., Sibte, N., Murphy, A. P., and Baker, J. (2013). Physiological, perceptual, and technical responses to on-court tennis training on hard and clay courts. *J. Strength Cond. Res.* 27, 1487–1495. doi: 10.1519/JSC.0b013e31826caedf

Renshaw, I. (2010). "A constraints-led approach to talent development in cricket" in *Athlete-centred coaching: Developing decision makers*. eds. L. Kidman and B. Lombardo (Christchurch, NZ: Innovative).

Renshaw, I., Chow, J. Y., Davids, K., and Hammond, J. (2010). A constraints-led perspective to understanding skill acquisition and game play: a basis for integration of motor learning theory and physical education praxis? *Phys. Educ. Sport Pedagog.* 15, 117–137. doi: 10.1080/17408980902791586

Renshaw, I., and Fairweather, M. M. (2000). Cricket bowling deliveries and the discrimination ability of professional and amateur batters. *J. Sports Sci.* 18, 951–957. doi: 10.1080/026404100446757

Rundell, M. (2009). *Wisden dictionary of cricket*. London: A&C Black.

Sarpeshkar, V., Abernethy, B., and Mann, D. L. (2017a). Visual strategies underpinning the development of visual–motor expertise when hitting a ball. *J. Exp. Psychol. Hum. Percept. Perform.* 43, 1744–1772. doi: 10.1037/xhp0000465

Sarpeshkar, V., and Mann, D. L. (2011). Biomechanics and visual-motor control: how it has, is, and will be used to reveal the secrets of hitting a cricket ball. *Sports Biomech.* 10, 306–323. doi: 10.1080/14763141.2011.629207

Sarpeshkar, V., Mann, D. L., Spratford, W., and Abernethy, B. (2017b). The influence of ball-swing on the timing and coordination of a natural interceptive task. *Hum. Mov. Sci.* 54, 82–100. doi: 10.1016/j.humov.2017.04.003

Scanlan, A. T., Berkelmans, D. M., Vickery, W. M., and Kean, C. O. (2016). A review of the internal and external physiological demands associated with batting in cricket. *Int. J. Sports Physiol. Perform.* 11, 987–997. doi: 10.1123/ijspp.2016-0169

Scarf, P., Shi, X., and Akhtar, S. (2011). On the distribution of runs scored and batting strategy in test cricket. *J. R. Stat. Soc. A. Stat. Soc.* 174, 471–497. doi: 10.1111/j.1467-985X.2010.00672.x

Slogrove, L., Potgieter, J. R., and Foxcroft, C. D. (2002). Batting related experiences of south African universities cricketers. *South Afr. J. Res. Sport Phys. Educ. Recreat.* 24, 101–112. doi: 10.4314/sajrs.v24i1.25853

Stuelcken, M., Portus, M., and Mason, B. (2005). Off-side front foot drives in men's high performance cricket. *Sports Biomech.* 4, 17–35. doi: 10.1080/14763140508522849

Veness, D., Patterson, S. D., Jeffries, O., and Waldron, M. (2017). The effects of mental fatigue on cricket-relevant performance among elite players. *J. Sports Sci.* 35, 2461–2467. doi: 10.1080/02640414.2016.1273540

Weissensteiner, J. R., Abernethy, B., and Farrow, D. (2011). Hitting a cricket ball: what components of the interceptive action are most linked to expertise? *Sports Biomech.* 10, 324–338. doi: 10.1080/14763141.2011.629303

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Spatiotemporal Comparisons Between Elite and High-Level 60 m Hurdlers

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Despite the existence of literature on the athletics hurdles event, no previous studies have examined the kinematic behavior of athletes during the race. The aims of the present research were (1) to compare the spatiotemporal parameters of elite and high-level hurdlers (men and women) in the approach run, hurdles-unit and run-in phases and (2) to relate these parameters to the 60 m end race results. Split times, step lengths, step widths, step times, contact times and flight times were calculated for the 60 m hurdlers ($n = 110$) who participated in the 44th Spanish Indoor Championship and in the 12th IAAF World Indoor Championship. Both men and women elite-level hurdlers obtained shorter split times than high-level hurdlers in the approach run (δ 0.14 ± 0.01 and 0.18 ± 0.02 s, respectively), the hurdles-unit (δ 0.11 ± 0.01 and 0.13 ± 0.01 s, respectively) and the run-in (δ 0.10 ± 0.01 and 0.20 ± 0.02 s, respectively) race phases. Elite-level men athletes also presented lower step lengths in the approach run phase (δ 0.01 ± 0.00 m), greater take-off distances (δ 0.10 ± 0.03 m) and shorter landing distances (δ 0.17 ± 0.05 m) than high-level athletes, although elite-level women hurdlers only showed longer landing step length (δ 0.07 ± 0.02 m) than high-level athletes. Finally, in the run-in phase, elite-level hurdlers had longer step lengths than high-level hurdlers (men: δ 0.09 ± 0.03 m; women: δ 0.11 ± 0.03 m). Step times, contact times and flight times were also different between both levels of performance in most of the race phases. Correlational analysis with the race result showed large ($r > 0.5$), very large ($r > 0.7$), or nearly perfect ($r > 0.9$) relationships for most of the mentioned kinematic parameters. These results indicate that elite-level athletes were faster than high-level in the three phases of the 60 m hurdles event, specifically in some new spatiotemporal parameters (e.g. step length in the run-in phase) as well as others already studied. Accordingly, coaches and athletes should implement their training programs to have an impact on these key variables.

Keywords: track and field, kinematics, performance analysis, competition, DLT algorithms

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INTRODUCTION

The International Association of Athletics Federations (IAAF) included the 60 m hurdles since the first World Indoor Championship (Indianapolis, USA) in 1987. The height and position of the hurdles from the starting line is the same in the 60 m as in the men 110 m and women 100 m hurdles events. The main difference between the events is the reduction of the number of hurdles from 10 to 5 from the 110–100 to the 60 m hurdles event. The positioning of the hurdles serves as a reference for the division of the event into the following phases (Brüggemann, 1990): approach run phase (from the starting line to the first hurdle), hurdle unit phase (race and clearance of the hurdles), and run-in phase (from the last hurdle to the finishing line). Additionally, the hurdle unit phase is subdivided into preparatory, hurdle, landing, and recovery steps (McDonald and Dapena, 1991).

The most common analysis of the hurdle's races has been carried out through an evaluation of the hurdle split times (from touchdown to touchdown behind the hurdle), using video recordings with a fixed or panned video-camera both in 110 and 100 m (Muller and Hommel, 1997; Graubner and Nixdorf, 2011; Tsiokanos et al., 2017; Pollitt et al., 2018a,b) as of 60 m hurdles (Walker et al., 2019a,b). López del Amo et al. (2018) found that the reaction time and the approach run time were predictors of race performance, however, Tsiokanos et al. (2017) did not observed a significant relationship between reaction time and the race performance. Similarly, Tsiokanos et al. (2017) determined that the correlation between the intermediate times and final performance was decisive from the fifth hurdle onwards in the 110 m hurdles event (r = 0.77 – 0.98). The temporal analysis in the hurdle event is usually completed with the hurdle flight times, although there is a lack of relationship between hurdle clearance times and race performance according to Tsiokanos et al. (2017). Also, Pollitt et al. (2018a,b) have studied the contact and flight times during the run-in phase in the 110 and 100 m hurdles event.

Technical information of the hurdle events has been completed with two- and three-dimensional kinematic analyses of a single hurdle, which is usually selected between the second and sixthhurdle (Mann and Herman, 1985; Rash et al., 1990; McDonald and Dapena, 1991; Coh and Dolenec, 1996; Salo et al., 1997; McDonald, 2002; Coh, 2003; Park et al., 2011; Ryu and Chang, 2011; Coh and Iskra, 2012; Pollitt et al., 2018a,b). There is only one precedent (Ho et al., 2020) who have analyzed all ten hurdles of a 110 m hurdle event, measuring take-off (2.04 ± 0.07 m) and landing (1.47 ± 0.03 m) distances. Findings from these kinematical analyses suggest that efficient hurdle clearance technique is associated to the take-off contact time, take-off to landing point ratio in relation to the hurdle and to the hurdle flight time. In addition to the hurdle unit phase, the approach run phase (Rash et al., 1990; López del Amo et al., 2018; Walker et al., 2019a,b) has been subjected to kinematic analysis. To our knowledge, the run-in phase has been excluded from all the investigations carried so far, except for the research carried out by Pollitt et al. (2018a,b). The fact that most studies have been carried out in training situations, including a low sample of non-elite athletes, makes it difficult to obtain benchmark values representative of elite-level practitioners of the hurdle event performance.

Therefore, the aims of the present research were: (1) to compare the distance and time variables of elite-level and high-level hurdlers (men and women) in the approach run phase, hurdles phase and run-in phase, and (2) to relate these variables to the end race results. Our hypothesis is that elite-level hurdlers would be faster than high-level athletes in the three race phases, with a different step length pattern in some steps of the race. Additionally, we hypothesize that these differences in the step patterns will have a relationship with the end race result.

METHODS

All the races were filmed during the 60 m hurdle event of the 44th Spanish Indoor Championship and 12th IAAF World Indoor Championship (2008). The best performance of each participant men (n = 59) and women athlete (n = 51) from the heats, semifinal and final rounds were included in the study (**Table 1**). These performances were further subdivided into two groups (elite-level and high-level), according to the median of their official times achieved during the competition. All experimental procedures were carried out in accordance with the Declaration of Helsinki and were approved by the Ethics Committee of the Technical University of Madrid.

The races were analyzed according to the following phases: approach run phase, hurdle unit phase, and run-in phase. For the split times, the approach run phase was calculated from the starting gun to the contact on the ground after the first hurdle, the hurdle unit phase was recorded as the mean of the times between each hurdle and the run-in phase included the time from the contact after the last hurdle to the final race time (Brüggemann, 1990). For the spatial analysis, the following model was used (McDonald and Dapena, 1991): (1) the approach run phase included the first eight steps before the first hurdle (the four men athletes who carried out seven steps in this phase were excluded from the analysis), (2) the hurdle unit phase (**Figure 1**) integrated the preparatory step, hurdle step (divided into take-off distance and landing distance), landing step and recovery step, and (3) the run-in phase which contained the steps between the last hurdle and the finish line.

Six fixed video cameras JVC GY-DV300 (Japan Victor Company, Japan) located at the main stands and operating at 50 Hz (shutter speed: 1/1,000) were used to filmed the races, similarly to that previously described in other studies (McDonald and Dapena, 1991; Coh and Dolenec, 1996; Salo et al., 1997; Coh, 2003; Graubner and Nixdorf, 2011; Coh and Iskra, 2012). Camera 1 recorded the first 13 m; camera 2 from 13 to 30 m; camera 3 from 30 to 47 m, and camera 4 the last 13 m (47–60 m) of the race. Complementarily, and in order to avoid athletes' visual occlusion, cameras 5 and 6 were located with a frontal view: camera 5 filming the first 30 m (including the referees' starting gun) and camera 6 the last 30 m (**Figure 2**).

TABLE 1 | Sample size (n), age, and end race result of the men and women athletes who participated in the 60 m hurdle races of the 44th Spanish Indoor and 12th IAAF World Indoor Championships.

Gender	Level	Age (years)	Race time (s)
Men (n = 59)	Elite-level (n = 30)	26.8 ± 3.6	7.71 ± 0.12 (7.46 – 7.93)
	High-level (n = 29)	22.6 ± 3.9	8.39 ± 0.28 (7.97 – 8.93)
Women (n = 51)	Elite-level (n = 27)	26.3 ± 3.3	8.14 ± 0.20 (7.80 – 8.46)
	High-level (n = 24)	22.9 ± 4.5	9.06 ± 0.32 (8.54 – 9.72)

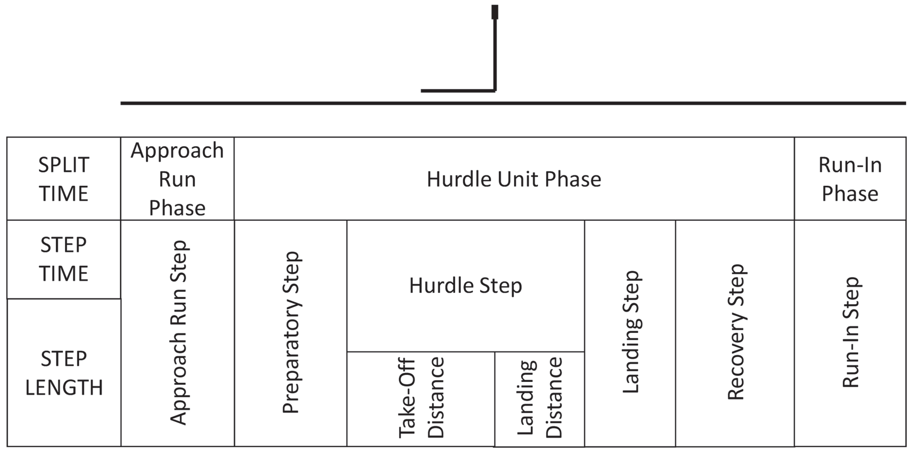

FIGURE 1 | Race phases and Hurdle Unit Phase model (based on McDonald and Dapena, 1991).

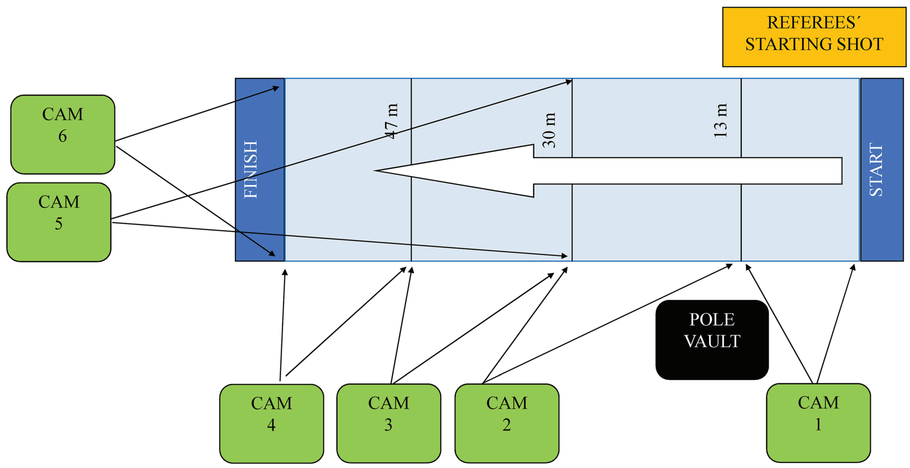

FIGURE 2 | Camera setup position.

The athletes' foot landing and take-off points were identified and manually digitized by an experimental observer from the race footage using Photo 23D software (Technical University of Madrid, Spain; Cala et al., 2009). Six control points, uniformly distributed in each camera view and represented by official line marks, were employed for calibration purposes and Direct Linear Transformation algorithms (Abdel-Aziz and Karara, 1971) were used to reconstruct the real coordinates (in meters) from the screen coordinates (in pixels). The measurements were validated and a Root Mean Square Error (Allard et al., 1995) lower than 0.04 m was determined for the step length and step width on the six cameras, in line with previous research on race analysis (Veiga et al., 2013). Intra-observer reliability by repeatedly digitizing (30 times) the same steps sequence in the eight competition lanes was 0.02 m in both axes.

Statistical analyses were performed using IBM SPSS statistics for Windows, version 22.0 (IBM Corp, Armonk, NY, United States). Split times, step lengths, step times, contact times, and flight times of the athletes were compared with a repeated measures analysis of variance according to the race phase (approach run phase, hurdle unit phase, preparatory step, hurdle step, take-off distance, landing distance, landing step, recovery step, and run-in phase), gender (men or women), and competitive level (elite-level or high-level). Planned repeated contrast tests between successive race phases were carried out. *Post hoc* tests were used to determine statistical effects ($p < 0.05$) between factors using Bonferroni corrections and were interpreted using effect sizes (partial η^2) with 0.01, 0.06, and 0.14 threshold values for small, medium, and large effects (Cohen, 1992). Pearson correlation coefficients were used to relate all the spatiotemporal race parameters to the end race results, being 0.1, 0.3, 0.5, 0.7, and 0.9, the threshold values that represented small, moderate, large, very large, and nearly perfect correlations (Hopkins et al., 2009).

RESULTS

Split times during the competitive 60 m hurdles races (**Table 2**) had inter-level differences in all race phases, both for men ($F_{1.42}$ = 6.30, p = 0.007, η^2 = 0.09) and women ($F_{1.60}$ = 9.98, p = 0.001, η^2 = 0.17) athletes.

Figure 3 shows mean steps lengths for men athletes, with elite-level participants achieving a shorter step length than high-level athletes (δ 0.01 ± 0.00 m; p = 0.03) in the approach run phase and a longer step length in the run-in phase (δ 0.09 ± 0.02; p = 0.004). In the case of women athletes (**Figure 3**), the elite-level group had a greater length in the landing step than the high-level participants (1.52 ± 0.02 m vs. 1.45 ± 0.02 m, p = 0.009, respectively) and in the run-in phase (1.95 ± 0.02 m vs. 1.84 ± 0.02 m, p = 0.001, respectively). Specifically, during the hurdle step elite-level men athletes presented a greater take-off distance (elite-level: 2.15 ± 0.02 m, high-level: 2.04 ± 0.02 m; p = 0.001, η^2 = 0.27) and a shorter landing distance (elite-level: 1.59 ± 0.03 m, high-level: 1.76 ± 0.03 m; p = 0.001, η^2 = 0.27), whereas no significant inter-level differences were observed for women athletes both in the take-off and landing distances.

Step times (**Figure 4A**) had meaningful differences according to the level of competition in all phases both in men ($F_{2.30}$ = 22.34, p = 0.001, η^2 = 0.30) and women ($F_{2.56}$ = 22.81, p = 0.001, η^2 = 0.32) athletes. Contact times of elite-level men and women athletes (**Figure 4B**) were shorter (p = 0.05–0.000) than for high-level participants in all the phases of the race, except for the approach run in the men category. Flight times of men athletes (**Figure 4C**) had significant inter-level differences (p = 0.023) in the approach run phase while, in the hurdle unit phase, the elite-level athletes obtained a shorter flight time in the hurdle (elite-level: 0.35 ± 0.01 s, high-level: 0.41 ± 0.01 s, p = 0.001) and recovery (elite-level: 0.12 ± 0.00 s, high-level: 0.13 ± 0.00 s, p = 0.001) steps. In the case of women athletes, inter-level flight time differences were observed in the approach run phase (elite-level: 0.10 ± 0.00 s, high-level: 0.11 ± 0.00 s, p = 0.001) and in the preparatory (elite-level: 0.10 ± 0.00 s, high-level: 0.10 ± 0.00 s, p = 0.012), hurdle (elite-level: 0.32 ± 0.01 s, high-level: 0.37 ± 0.01 s, p = 0.001) and recovery (elite-level: 0.13 ± 0.00 s, high-level: 0.15 ± 0.00 s, p = 0.001) steps.

The correlation analysis with the final time had nearly perfect relationships (r > 0.90, p = 0.001) with the split times (**Table 3**) in all the race phases in both men and women events. In addition, step times (**Table 4**) had large (r > 0.05, p = 0.001) or very large (r > 0.7, p = 0.001) correlations in all the race phases for both men and women athletes, specifically during the hurdle step (men: r = 0.869, p = 0.001; women: r = 0.881, p = 0.001). Contact times and flight times had moderate to very large correlations in some race phases for men athletes, and large to very large correlations for women athletes. In particular, the flight time during the hurdle step had high correlations for both men (r = 0.815, p = 0.001) and women (r = 0.822, p = 0.001) participants. Regarding the step length, a negative correlation was found in the run-in phase in men (r = −0.494, p = 0.001) and women (r = −0.555, p = 0.001) groups. Complementarily, a negative correlation was observed in the preparatory step (r = −0.294, p = 0.038) and in the landing step (r = −0.285, p = 0.042) for women hurdlers, whereas the final time in the race had a significant correlation with the final time in the take-off distance (r = −0.439, p = 0.001) and landing distances (r = 0.471, p = 0.001) in men hurdlers.

TABLE 2 | Split times (s) of elite-level and high-level (men and women) hurdlers on the approach run, hurdle unit and run-in race phases during the 60 m event of the 44th Spanish Indoor and 12th IAAF World Indoor Championships.

		Approach run phase	Hurdle unit phase	Run-in phase
Men	Elite-level	2.64 ± 0.01*	1.04 ± 0.01*	0.90 ± 0.01*
	High-level	2.77 ± 0.01	1.15 ± 0.01	1.00 ± 0.01
Women	Elite-level	2.68 ± 0.01*	1.03 ± 0.01*	1.36 ± 0.01*
	High-level	2.86 ± 0.01	1.16 ± 0.01	1.55 ± 0.01

**Inter-level statistical differences at a p level of 0.001.*

DISCUSSION

The present research aimed to compare the spatiotemporal parameters of elite and high-level 60 m hurdlers on the race

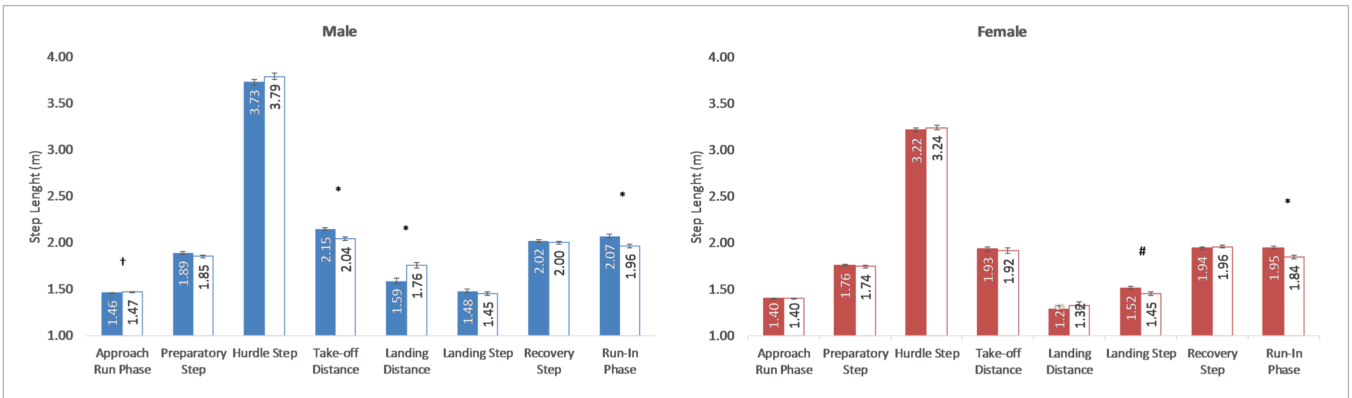

FIGURE 3 | Mean step length (m) in the race phases of the elite-level (colored) and high-level (white) men and women athletes participating in the 60 m hurdler race of the 44th Spanish Indoor and 12th IAAF World Indoor Championships. Statistical inter-level differences: †p < 0.05; #p < 0.01; *p < 0.001.

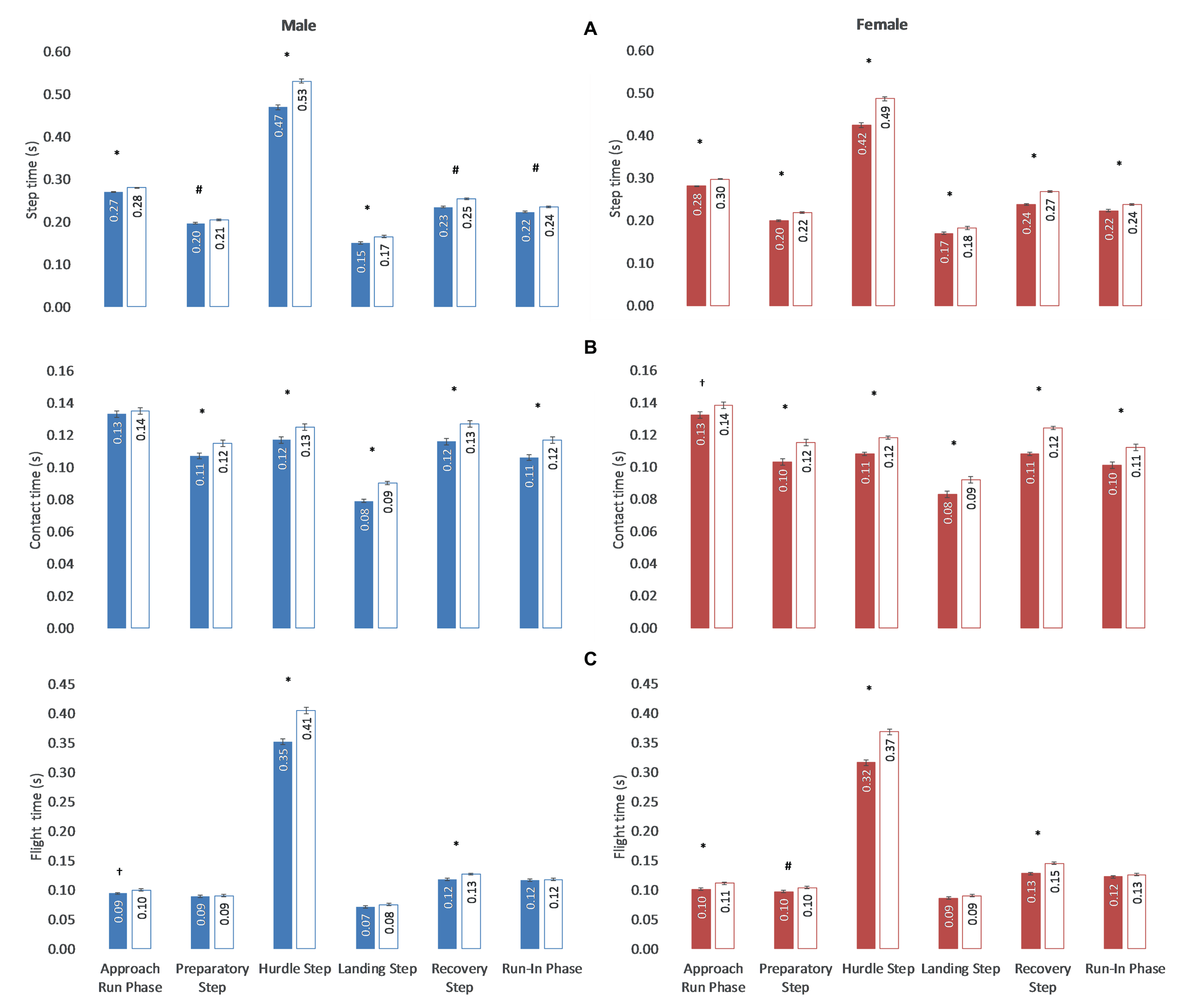

FIGURE 4 | Step **(A)**, contact **(B)** and flight **(C)** times (s) in the race phases of the elite-level (colored) and high-level (white) athletes (men and women) participating in the 44th Spanish Indoor and 12th IAAF World Indoor Championships. Statistical inter-level differences: $^{\dagger}p < 0.05$; $^{\#}p < 0.01$; $^{*}p < 0.001$.

TABLE 3 | Relationships (*r*) between split times and the 60 m hurdlers race results during the 44th Spanish Indoor and 12th IAAF World Indoor Championships.

	Approach run phase	Hurdle unit phase	Run-in phase
Men	0.91*	0.99*	0.94*
Women	0.92*	0.99*	0.97*

$^{*}p < 0.001$.

phases of the 44th Spanish Indoor and 12th IAAF World Indoor Championships. Results indicate that elite-level athletes were faster than high-level in the three phases of the 60 m hurdles event, specifically in some new spatiotemporal parameters (e.g. step length in the run-in phase) as well as others already studied. No previous studies had ever examined the spatiotemporal characteristics of competitive athletes on the race phases of the 60 m hurdlers event.

Split Times

Elite-level athletes had shorter split times in all race phases than high-level athletes (men: δ 5–11%; women: δ 7–14%). These results suggest that elite-level participants do not only perform a faster approach run (as also reported by López del Amo et al., 2018) and hurdle unit phases, but are significantly faster during the run-in phase.

The split times in the approach run phase of elite-level hurdlers (**Table 2**) were slightly greater than those reported in previous studies carried out with this standard of athletes (Muller and Hommel, 1997; Graubner and Nixdorf, 2011;

TABLE 4 | Relationships (*r*) between spatiotemporal parameters and the 60 m hurdlers race results during the 44th Spanish Indoor and 12th IAAF World Indoor Championships.

Variable	Approach run phase	Preparatory step	Hurdle step	Take-off distance	Landing distance	Landing step	Recovery step	Run-in phase
Men								
Step length	0.15	–0.13	0.21	–0.44*	0.47*	–0.18	–0.25	–0.49*
Step time	0.76*	0.56*	0.87*			0.52*	0.72*	0.53*
Contact time	0.24	0.40*	0.41*			0.55*	0.62*	0.62*
Flight time	0.26	0.16	0.82*			0.15	0.46*	–0.01
Women								
Step length	0.05	–0.29†	0.11	–0.20	0.21	–0.29†	0.09	–0.56*
Step time	0.85*	0.69*	0.88*			0.61*	0.87*	0.63*
Contact time	0.28†	0.59*	0.65*			0.61*	0.82*	0.57*
Flight time	0.51#	0.37#	0.82*			0.27	0.65*	0.26

†*p < 0.05;* #*p < 0.01;* **p < 0.001.*

Tsiokanos et al., 2017; López del Amo et al., 2018; Pollitt et al., 2018a,b; Walker et al., 2019a,b). These differences could be explained by the greater sample size employed in the present research (30 men and 27 women athletes) in comparison to the seven or eight finalists studied during the above-mentioned studies. In fact, the mean split times of the eight best hurdlers of the present research had similar values (2.59 s men and 2.63 s women) to those reported elsewhere. For the high-level hurdlers, split times in the approach run phase (2.77 s) were also faster than the times recorded by Ho et al. (2020) in an experimental set-up (2.86 s), which highlights the competitive level of the group of athletes examined in the current investigation.

For the hurdle unit phase, split times of elite-level hurdlers (**Table 2**) were also similar to those recorded for the first five hurdles by Muller and Hommel (1997), Graubner and Nixdorf (2011), Tsiokanos et al. (2017), Pollitt et al. (2018a,b) and Walker et al. (2019a,b). In addition, the average of the eight best hurdlers in the present research (1.02 s men and 0.99 women) equaled the best result mentioned. For the high-level male hurdlers, split times in the hurdle unit phase (**Table 2**) was greater than those registered by Ho et al. (2020) which contradicts what was found in the approach run phase. Probably, changing environment between competition and training situation could explain part of these differences.

For the run-in phase, split times of elite men hurdlers had similar values (δ 0.01 s) to those reported by Walker et al. (2019a) for the seven finalists. In case of women, elite hurdlers had greater split times (δ 0.06 s) to those registered by Walker et al. (2019b) for the eight finalists in the 2018 World Indoor Championship.

Step Length

Elite-level men hurdlers had smaller step length than high-level in the approach run phase (**Figure 3**), which allowed them to achieve greater take off distances in the first hurdle unit phase. These differences were not observed in the women races, probably due to differences in the hurdle height between men and women events (McDonald and Dapena, 1991; Salo et al., 1997). Indeed, there is a tendency in the last years between elite men hurdlers to perform seven steps in the approach run phase (probably to increase the take-off distance in the first hurdle), although this does not seem to be accompanied by faster times (Walker et al., 2019a,b).

In the hurdle step, step length values (**Figure 3**) Were in line to data from the last World Championships (Pollitt et al., 2018a,b), although greater than what has been reported for male athletes (Coh, 2003; López del Amo et al., 2018) The in-depth analysis of the hurdle step length indicated that elite-level men hurdlers obtained longer take-off (δ 0.10 m) and shorter landing (δ 0.16 m) distances than those athletes of lower level. This confirms the importance of the take-off and landing distances on performance (**Table 4**), as previously indicated by Coh and Iskra (2012). Values reported in the literature (McDonald and Dapena, 1991; Coh and Iskra, 2012; Pollitt et al., 2018a) showed similar take-off distances (from 2.04 to 2.31 m) but shorter landing distances (from 1.32 to 1.58 m). Unlike men, women races did not show inter-level differences either in the take-off or in the landing distances (**Figure 3**). This could indicate that the women 60 m hurdles event might have a lower technical component than men races due to the lower height of the hurdles (McDonald and Dapena, 1991; Salo et al., 1997). Men hurdlers should aim to maximize their take-off distance to have an impact on the trajectory of the CM above the hurdle and, therefore, to minimize the landing distance.

In the remaining steps of the hurdle unit phase, the step lengths for men (**Figure 3**) coincided with those provided by McDonald and Dapena (1991) and Coh (2003). In the case of women, the step lengths and the landing distance (**Figure 3**) were shorter than those reported by McDonald and Dapena (1991), Coh and Dolenec (1996), and Pollitt et al. (2018a,b), whereas the recovery step distance was longer. For the landing step length, there were inter-level differences in the women athletes (δ 0.07 m), and this parameter showed moderate correlation with the race results (**Table 4**). Therefore, in the case of women, this landing step could represent a key aspect of the hurdle unit phase where additional improvements could be obtained probably related to strength gains. Finally, in the run-in phase, both elite-level men and women athletes had a longer step length than high-level athletes (2.05 and 1.95 m, respectively), as previously reported in 100 m sprinters (δ 0.12 m; Ito et al., 2006). In addition, correlations between step length and the race result in men (r = −0.49; p = 0.001) and women (r = −0.56; p = 0.001; **Table 2**) suggest that the best hurdlers are also better sprinters, as a high correlation between step length and sprint running velocity has been previously reported for men and women athletes (men: r = 0.86; p < 0.01; women: r = 0.74; p < 0.01; Ito et al., 1998).

Step Time

Step times had differences in all race phases between the two levels of performance, both in men and women (**Figure 4**), with large and very large correlations with the race result. These data are in line with previous findings in women sprinters (r = 0.77; p < 0.01; Ito et al., 1998) and suggest the importance of the stride frequency on elite training programs. Indeed, a common practice between coaches (Iskra, 1995) is to train with reduced distances between hurdles (compared to official) to stress on step frequency. For the contact times, unlike men, elite-level women obtained shorter contact times in the approach run. However, in the rest of the race phases, elite-level athletes presented shorter contact times than those of high-level athletes, both men and women, indicating the importance of this parameter not only on the hurdle (Coh and Iskra, 2012) but also on the remaining race steps. The values for the hurdle-unit phase were similar than those presented by McDonald and Dapena (1991) during official competition, but shorter than those reported by Coh and Iskra (2012) during training situation. Because of this, coaches, in addition to developing short contacts (<0.13 s), should be careful when comparing training and competition values. Light times of elite-level athletes (men and women) in the approach run phase had small differences from those of high-level, being the greatest differences observed in the hurdle (δ 0.06 s men; δ 0.05 s women) and the recovery steps. Since it is customary for coaches to control the flight time at the hurdle step, it would be also recommended to register it also at the recovery step and the departure phase. In general, the registered values were similar to those observed in other championships (McDonald and Dapena, 1991; Muller and Hommel, 1997; Graubner and Nixdorf, 2011; Tsiokanos et al., 2017) or lower than those registered in by Rash et al. (1990), Salo et al. (1997), Coh (2003), and Ho et al. (2020). That is why the values in the present research (despite the low sampling rate of 50 Hz) seem to be representative of the competitive reality.

These results indicate that elite-level hurdlers achieved shorter step times differently in each race phase. In the approach run phase they obtained shorter flight times, whereas in the run-in phase they presented shorter contact times. Probably, high levels of inter-limb coordination (approach run phase) or reactive force (run-in phase) could be of a practical importance here. In the hurdle unit phase, on the other hand, a basic modification of the technical training between coaches, together with the inter hurdle distances, is to train with reduced height of hurdles (compared to official) to stress a shorter flight time over the hurdle and shorter contact times in the hurdle unit phase (Iskra, 1995).

Correlation Analysis

From a global point of view, the parameters that obtained a nearly perfect correlation with the 60 m hurdle race results were the split times for the hurdle unit phase, run-in phase and approach run phase (in this order), both for men and women athletes. Compared to the 110 and 100 m hurdle events (Tsiokanos et al., 2017), correlations of the approach run and run-in split times with final result were greater in the present study. Therefore, it seems important to work on the three race phases to be competitive internationally. The correlation of the mean split time in the hurdle unit phase (r = 0.99) were greater than those obtained for the individual split times between 6th (r = 0.84 – 0.82) and 10th (r = 0.97 – 0.98) hurdles by Muller and Hommel (1997) and Tsiokanos et al. (2017). This would indicate that the mean split time in the hurdle unit phase could be a good performance indicator parameter for athletes and coaches. Finally, in the hurdle unit phase, large correlations with final results were also observed for recovery step time, hurdle step time and hurdle flight time (men and women). This is in line with coaches usually employing hurdle exercises performed with trail leg or lead leg (Iskra, 1995).

Practical Application

Based on some of the spatiotemporal parameters presented in the present research, there are some performance indicators common to men and women: a greater step length in the run-in phase and a shorter step, contact and flight times in selected race phases. On the other hand, there are some specific variables important for each gender: a greater take-off distance (preceded by a shorter step length in the approach run phase) and a shorter landing distance in the case of men and a greater landing step and a shorter flight times at the preparatory step for women. Indeed, it could be stated that men seem to present a greater technical requirement on the hurdle unit phase, whereas women present inter-level differences before and after the hurdle phase. Also, from a global point of view, it seems necessary that hurdlers become also good sprinters and that they improve performance in all the race phases as, in the 60 m hurdle event (unlike the 110 or 100 m hurdle races), the three race phases performance is highly correlated to the final result.

CONCLUSION

Elite-level male hurdlers on 60 m events performed shorter step times, with shorter contact times and shorter step lengths on the approach to the first hurdle, which allowed them to achieve greater take-off and shorter landing distances. Conversely, on the run-in phase, male and female athletes performed greater step lengths (moderate and large correlations with race result) with shorter contact times indicating a better ability to apply impulse during contact. Split times of the hurdle unit phase, run-in phase and approach run phase (in this order) had the greatest correlation with the race result. The hurdle flight time and the step times along the race were also largely correlated with race result. These results indicate that elite-level athletes were faster than high-level in the three phases of the 60 m hurdles event, specifically in some new spatiotemporal parameters (e.g. step length in the run-in phase) as well as others already studied. Accordingly, coaches and athletes should implement their training programs to have an impact on these key variables.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the Technical University of Madrid. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

PG-F, SV, JM, and EN contributed to conception and design of the study and organized the database. SV and PG-F performed the statistical analysis and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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REFERENCES

Abdel-Aziz, Y. I., and Karara, H. M. (1971). "Direct linear transformation from comparator coordinates into space coordinates in close range photogrammetry" in *Proceedings of the Symposium on close range photogrammetry*. ed. The American Society of Photogrammetry (Falls Church), 1–18.

Allard, P., Blanchi, J. P., and Aíssaqui, R. (1995). "Bases of three-dimensional reconstruction" in *Three dimensional analysis of human movement*. eds. P. Allard, I. A. F. Stokes, and J. P. Bianchi (Champaign, IL: Human Kinetics), 19–40.

Brüggemann, G. P. (1990). Time analysis of the 110 metres and 100 metres hurdles: scientific research project at the games of the XXXIV Olympiad Seoul 1988. *New Stud. Athlet.*, 91–129.

Cala, A., Veiga, S., García, A., and Navarro, E. (2009). Previous cycling does not affect running efficiency during a triathlon world cup competition. *J. Sport Med. Phys. Fitness* 49, 152–158.

Coh, M. (2003). Biomechanical analysis of Colin Jackson's hurdle clearance technique. *New Stud. Athlet.* 18, 37–45.

Coh, M., and Dolenec, A. (1996). Three-dimensional kinematic analysis of the hurdles technique used by Brigita Bukovec. *New Stud. Athlet.* 11, 63–69.

Coh, M., and Iskra, J. (2012). Biomechanical studies of 110 m hurdle clearance technique. *Sport Sci.* 5, 10–14.

Cohen, J. A. (1992). Power primer. *Psychol. Bull.* 112, 155–159. doi: 10.1037/0033-2909.112.1.155

Graubner, R., and Nixdorf, E. (2011). Biomechanical analysis of the Sprint and hurdles events at the 2009 IAAF world championships in athletics. *New Stud. Athlet.* 26, 19–53.

Ho, C. S., Chang, C. Y., and Lin, K. C. (2020). The wearable devices application for evaluation of 110 meter high hurdle race. *J. Hum. Sport Exer.* 15. doi: 10.14198/jhse.2020.151.04 (in press).

Hopkins, W., Marshall, S., Batterham, A., and Hanin, Y. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–13. doi: 10.1249/MSS.0b013e31818cb278

Iskra, J. (1995). The most effective technical training for the 110 metres hurdles. *New Stud. Athlet.* 10, 51–55.

Ito, A., Ichikawa, H., Saito, M., Sagawa, K., Ito, M., and Kobayashi, K. (1998). Relationship between sprint running movement and velocity at full speed phase during 100 m race. *Jpn. J. Phys. Educ.* 43, 260–273.

Ito, A., Ishikawa, M., Isolehto, J., and Komi, P. V. (2006). Changes in the step width, step length, and step frequency of the world's top sprinters during 100 metres. *New Stud. Athlet.* 21, 35–39.

López del Amo, J. L., Rodríguez, M. C., Hill, D. W., and González, J. E. (2018). Analysis of the start to the first hurdle in 110 m hurdles at the IAAF world athletics championships Beijing 2015. *J. Hum. Sport Exer.* 13, 504–517. doi: 10.14198/jhse.2018.133.03

Mann, R., and Herman, J. (1985). Kinematic analysis of Olympic woman 100 m hurdles. *Int. J. Sport Biomech.* 1, 163–173.

McDonald, C. (2002). Hurdles is not sprinting. *Track Coach* 161, 5137–5143.

McDonald, C., and Dapena, J. (1991). Linear kinematics of the men's 110-m and women's 100-m hurdles races. *Med. Sci. Sports Exerc.* 23, 1382–1391.

Muller, H., and Hommel, H. (1997). Biomechanical research project at the VIth world championships in athletics, Athens 1997. *New Stud. Athlet.* 12, 43–73.

Park, Y. J., Ryu, J. K., Ryu, J. S., Kim, T. S., Hwang, W. S., Park, S. K., et al. (2011). Kinematic analysis of hurdle clearance technique for 110-m Mens's hurdlers at IAAF world championships, Daegue 2011. Korean journal of sport. *Biomechanics* 21, 529–540. doi: 10.5103/KJSB.2011.21.2.131

Pollitt, L., Walker, J., Bissas, A., and Merlino, S. (2018a). "Biomechanical report for the IAAF world championships 2017: 110 m hurdles men's" in *2017 IAAF world championships biomechanics research project*. London, UK: International Association of Athletics Federations.

Pollitt, L., Walker, J., Bissas, A., and Merlino, S. (2018b). "Biomechanical report for the IAAF world championships 2017: 100 m hurdles Women's" in *2017 IAAF world championships biomechanics research project*. London, UK: International Association of Athletics Federations.

Rash, G. S., Garret, J., and Voisin, M. (1990). Kinematic analysis of top American female 100-meter hurdles. *Int. J. Sport Biomech.* 6, 386–393.

Ryu, J. K., and Chang, J. K. (2011). Kinematic analysis of the hurdle clearance technique used by world top class Women's hurdler. Korean journal of sport. *Biomechanics* 21, 131–140. doi: 10.5103/KJSB.2011.21.2.131

Salo, A., Grimshaw, P. N., and Marar, L. (1997). 3-D biomechanical analysis of sprint hurdles at different competitive levels. *Med. Sci. Sports Exerc.* 29, 231–237.

Tsiokanos, A., Tsaopoulos, D., Giavroglou, A., and Tsarouchas, E. (2017). Race pattern of Women's 100-m hurdles: time analysis of Olympic hurdle performance. *Int. J. Kinesiol. Sport Sci.* 5, 56–64. doi: 10.7575/aiac.ijkss.v.5n.3p.56

Veiga, S., Cala, A., Mallo, J., and Navarro, E. (2013). A new procedure for race analysis in swimming based on individual distance measurements. *J. Sports Sci.* 31, 159–165. doi: 10.1080/02640414.2012.723130

Walker, J., Pollitt, L., Paradisis, G. P., Bezodis, I., Bissas, A., and Merlino, S. (2019a). *Biomechanical report for the IAAF world indoor championships 2018: 60 metres hurdles men*. Birmingham, UK: International Association of Athletics Federations.

Walker, J., Pollitt, L., Paradisis, G. P., Bezodis, I., Bissas, A., and Merlino, S. (2019b). *Biomechanical report for the IAAF world indoor championships 2018: 60 metres hurdles Women*. Birmingham, UK: International Association of Athletics Federations.

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Differences in Technical Performance of Players From 'The Big Five' European Football Leagues in the UEFA Champions League

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The current study aimed to identify the differences in technical performance between players from clubs of Bundesliga (Germany), La Liga (Spain), Ligue 1 (France), Premier League (England) and Serie A (Italy) when competing in the matches of the UEFA Champions League. Technical performance-related match data of 1,291 players from 1,125 matches (9,799 observations) of the UEFA Champions League (seasons 2009/2010–2017/2018) were collected and analysed. The generalised mixed linear modelling was employed taking the names of the league as the independent variable to predict the count number of 20 technical performance-related match actions and events performed by players belonging to different leagues. The non-clinical magnitude-based inference was used to evaluate the uncertainty in the true effects of the predictor. Results showed that differences in the technical performances between players from La Liga, Premier League and Ligue 1 were all trivial. Bundesliga players made higher numbers of shots than players from La Liga, Premier League and Serie A and achieved more long balls than players from Ligue 1. Serie A players achieved lower numbers of ball touches, passes and lower pass accuracy per match than players from any of the other four leagues. In addition, players from Serie A performed a higher number of long balls per match than Ligue 1 players and lower number of dribbles per match than Premier League players. Non-significant differences in other variables related to passing and organising and all variables related to defending were identified in players between the five leagues. The identified differences in technical performance among leagues could provide a more thorough understanding for practitioners working within the fields of talent identification, player development, player recruitment, coaching and match preparation.

Keywords: performance analysis, match analysis, player profiles, European soccer leagues, playing style

INTRODUCTION

Spanish La Liga, English Premier League, Italian Serie A, German Bundesliga and French Ligue 1 are the top five ranked professional football leagues in the Union of European Football Associations (UEFA)[1] and have been recognised to be the most successful football leagues in the world (Lago-Peñas et al., 2016). The success of 'the big five' leagues from a financial perspective has enabled teams to attract top-level players from all over the world (Littlewood et al., 2011; Oberstone, 2011).

Each of these five leagues is characterised by an idiosyncratic match-play style due to the cultural, historical and social differences existing among countries (Sarmento et al., 2013; Sapp et al., 2018). Thus, players or teams from the same league are often characterised by a specific archetype (Sarmento et al., 2013). Teams from the English Premier League, have tended to be characterised by a direct style with special emphasis upon its importance of the players' physical attributes (e.g., strength, speed, power etc.) (Dellal et al., 2011). The English Premier League is therefore considered as the most aggressive league (Sapp et al., 2018). Italian teams are often characterised by a rigid tactical requirement for defensive organisation (Foot, 2006). Spanish teams are often considered to prioritise ball possession and players' individual technical ability to control the game (Crolley et al., 2000) whilst the German and French Leagues are often considered to fall somewhere between the English tendency for physically able players and the Italian desire for defencive team organisation (Oberstone, 2011; Sapp et al., 2018).

Nevertheless, the playing style observed within each of the leagues has evolved over years (Bloomfield et al., 2005), as a result of the increasing frequency of player and coach labour migration between leagues in modern football (Frick, 2007; Littlewood et al., 2011). Even so, differences between the major European football leagues have been identified from a number of perspectives. For example, a qualitative analysis from Sarmento et al. (2013) demonstrated that the differences exist between La Liga (Spain), the Premier League (England) and Serie A (Italy) regarding culture, preferred strategy and tactics, players' characteristics and coaches' philosophies. Moreover, there have been a number of comparative studies conducted to examine the differences between major European leagues that have focussed upon: anthropometric data (Bloomfield et al., 2005), technical and tactical performance (Dellal et al., 2011; Oberstone, 2011; Alberti et al., 2013; Collet, 2013; Lago-Peñas et al., 2016; Sapp et al., 2018), physical performance (Dellal et al., 2011), injury pattern (Waldén et al., 2005), player recruitment (Frick, 2007; Littlewood et al., 2011) and competitive balance (Brandes and Franck, 2007; Pawlowski et al., 2010). Even though anecdotal attention has been paid to the differences in technical and tactical performance in different leagues, and the effects of situational variables and playing position were also considered, but either limited performance-related variables or a limited number of leagues have previously been analysed. Besides, those comparisons were not properly accounted for the effects of situational variables as players' match performances are varied in different competing contexts (Gómez et al., 2013). Therefore, there is an important empirical and practical gap in our understanding of the differences in match-play between major European leagues.

Methodologically, one of the major obstacles that affects our ability to conduct an objective and accurate assessment of player's match performance is the comparability of match data across leagues due to the inconsistency in data collection and analysis systems (Barros et al., 2007; Di Salvo et al., 2009). Therefore, match data collected from the UEFA Champions League (a cross-league competition), which is standardised for all teams, is an ideal source of data for scientific comparison. In addition, from a data analysis perspective, a methodology is needed to address appropriately the repeated-measured data of players who played in multiple matches (Yi et al., 2018, 2019), which was failed to be considered in previous research (Dellal et al., 2011; Oberstone, 2011; Alberti et al., 2013; Lago-Peñas et al., 2016; Sapp et al., 2018). The generalised mixed linear modelling used in the current study has been proved as a valid method for this issue, and the situational effects can also be controlled by this modelling to identify the similarities and differences between leagues in a more objective way (Yi et al., 2018, 2019).

Consequently, the current study aims to quantify the differences of technical performance of players from five major European leagues (Spanish La Liga, English Premier League, Italian Serie A, German Bundesliga and French Ligue 1) in the UEFA Champions League from season 2009/2010 to 2017/2018. The large sample size allows us to account for the effects of situational variables (game location: home, away and neutral, team and opponent strength: end-of-season UEFA club coefficient, match type: group stage and knockout stage and game result: win, draw and lose) and the effect of players' playing position (central defender, full back, central midfielder, wide midfielder and forward). Using generalised mixed linear modelling, allows us to demonstrate the similarities and differences between leagues with an increased degree of confidence. What is more, an added random effect of player names in the modelling, could process properly the repeated-measured data of a player participating in various matches.

MATERIALS AND METHODS

Data Resource and Reliability

Technical performance-related match data of players in all the 1,125 games throughout nine seasons from 2009–2010 to 2017–2018 in the UEFA Champions League were collected manually from a public-accessed football statistic website named 'whoscored.com'[2]. The original data of this website is provided by OPTA Sportsdata company, whose tracking system (OPTA Client System) has been tested by Liu et al. (2013) to have a high level of reliability (*Kappa* values > 0.90). The current study maintains the anonymity of the players according to European

[1] http://www.uefa.com

[2] https://www.whoscored.com

data protection law, and follows the research ethics standard set out by the local university.

Sample and Variables

The dataset consisted of 9,799 full-match observations of 1,291 players from Spanish La Liga (n = 2,597 observations), English Premier League (n = 2,303), Italian Serie A (n = 1,522), German Bundesliga (n = 2,021) and French Ligue 1 (n = 1,356) played in the UEFA Champions League during the past nine seasons (2009/2010–2017/2018). Only the data of match observations of outfield players who played the entire match were included. Moreover, due to the differences in technical variables between outfield players and goalkeepers, technical performance-related match data of goalkeepers were excluded from the sample.

After the screening based on the availability of data and the review of previous literature (Lago-Peñas et al., 2010; Castellano et al., 2012; Liu et al., 2015, 2016; Yi et al., 2018), 20 technical performance-related match actions and events grouped into four groups were selected as the dependent variables in the analysis (see **Table 1**).

Procedure and Statistical Analysis

Generalised mixed linear modelling was achieved by *Proc Glimmix* in the University Edition of Statistical Analysis System (version SAS Studio 3.6). The fixed effects estimated the effects of league, game location, team and opponent strength, match type and game result, as well as playing position. Player identity was used as the random effect to interpret the repeated-measure data of players from multiple matches. Separate Poisson regressions were run in the model taking the value of each of the 20 technical performance-related variables as the dependent variable.

League, game location, match type, game result and playing position were all included as nominal predictor variables in the model. League was with five levels (Spanish La Liga, English Premier League, Italian Serie A, German Bundesliga and French Ligue 1), game location was with three levels (home, away and neutral), match type was with two levels (matches of group stage and knock-out stage), game result was with three levels (win, draw and loss), and playing position was with five levels (CD, FB, CM, WM and FW). The effect of team and opponent strength was estimated by including the difference in the log of the end-of-season UEFA club coefficient as a predictor (Yi et al., 2018).

Uncertainty in the true effects of the predictors was evaluated using non-clinical magnitude-based inference that referenced *Bayesian* with a dispersed uniform prior which was implemented in the spreadsheet accompanying the package of materials for generalised mixed modelling with SAS Studio (Hopkins, 2016). Estimated magnitudes of difference in means and their 90% confidence limits were presented in standardised units, and were evaluated qualitatively with the following scale: trivial, 0–0.2; small, 0.2–0.6; moderate, 0.6–1.2; large, 1.2–2.0; and very large, >2.0 (Hopkins et al., 2009). The likelihood of the effects to be clear was considered qualitatively as follows: $<0.5\%$, most unlikely; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%,

TABLE 1 | Selected technical performance-related match events and actions.

Groups	Event or action: operational definition
Variables related to goal scoring	Shot: an attempt to score a goal, made with any (legal) part of the body, either on or off target
	Shot on target: an attempt to goal which required intervention to stop it going in or resulted in a goal/shot which would go in without being diverted
Variables related to passing and organising	Touch: a sum of count values of all actions and events where a player touches the ball
	Pass: an intentional played ball from one player to another
	Pass accuracy (%): successful passes as a proportion of total passes
	Key pass: the final pass or cross leading to the recipient of the ball having an attempt at goal without scoring
	Cross: any ball sent into the opposition team's area from a wide position
	Long ball: an attempted pass of 25 yards or more
	Through ball: a pass that split the last line of defence and plays the teammate through on goal
	Aerial won: two players competing for a ball in the air, for it to be an aerial duel both players must jump and challenge each other in the air and have both feet off the ground. The player who wins the duel gets the *Aerial won*, and the player who does not gets an *Aerial lost*
	Dribble: a dribble is an attempt by a player to beat an opponent in possession of the ball. OPTA also log attempted dribbles where the player overruns the ball
	Offside: awarded to the player deemed to be in an offside position where a free kick is awarded. If two or more players are in an offside position when the pass is played, the player considered to be most active and trying to play the ball is given offside
	Fouled: where a player is fouled by an opponent
	Dispossessed: when a player is tackled without attempting to dribble past his opponent
Variables related to defending	Tackle: the action of gaining possession from an opposition player who is in possession of the ball
	Interception: a player intercepts a pass with some movement or reading of the play
	Clearance: attempt made by a player to get the ball out of the danger zone, when there is pressure (from opponents) on him to clear the ball
	Blocked shot: a defensive block, blocking a shot going on target. This must be awarded to the player who blocks the shot
	Foul: any infringement that is penalised as foul play by a referee
	Yellow card: where a player was shown a yellow card by the referee for reasons of foul, persistent infringement, hand ball, dangerous play, etc.

TABLE 2 | Descriptive statistics of technical match performance of players from big five UEFA leagues estimated from the generalised mixed linear model (*n* denotes the number of match observations, results are mean ± between-player standard deviation, units are counts, except for pass accuracy).

Variable	Bundesliga (*n* = 2,021)	La Liga (*n* = 2,597)	Ligue 1 (*n* = 1,356)	Premier League (*n* = 2,303)	Serie A (*n* = 1,522)
Shot	1.19 ± 1.56	0.95 ± 1.40	1.03 ± 1.45	0.93 ± 1.38	0.92 ± 1.38
Shot on target	0.38 ± 0.95	0.30 ± 0.91	0.33 ± 0.92	0.31 ± 0.91	0.30 ± 0.90
Touch	62.33 ± 20.96	61.57 ± 20.79	60.57 ± 20.55	61.34 ± 20.73	55.90 ± 19.45
Pass	45.55 ± 19.62	44.86 ± 19.41	42.85 ± 18.82	43.85 ± 19.12	39.25 ± 17.74
Pass accuracy (%)	81.16 ± 9.59	82.09 ± 9.66	81.17 ± 9.59	81.39 ± 9.61	79.06 ± 9.43
Key pass	0.89 ± 1.39	0.84 ± 1.36	0.85 ± 1.37	0.74 ± 1.29	0.83 ± 1.35
Cross	1.16 ± 2.66	1.04 ± 2.50	1.28 ± 2.82	1.02 ± 2.47	1.08 ± 2.54
Long ball	3.60 ± 3.32	3.38 ± 3.19	3.04 ± 3.00	3.34 ± 3.17	3.64 ± 3.34
Through ball	0.12 ± 0.99	0.15 ± 0.95	0.11 ± 1.02	0.13 ± 0.98	0.13 ± 0.97
Dribble	0.67 ± 1.40	0.70 ± 1.42	0.78 ± 1.50	0.87 ± 1.58	0.66 ± 1.39
Offside	0.11 ± 0.89	0.11 ± 0.90	0.12 ± 0.88	0.13 ± 0.87	0.14 ± 0.86
Aerial won	1.06 ± 1.66	1.04 ± 1.65	1.11 ± 1.70	1.13 ± 1.71	0.99 ± 1.61
Fouled	1.14 ± 1.41	1.22 ± 1.45	1.21 ± 1.44	1.05 ± 1.36	1.29 ± 1.48
Dispossessed	0.80 ± 1.30	0.89 ± 1.37	0.97 ± 1.42	0.98 ± 1.43	0.91 ± 1.38
Tackle	2.03 ± 1.89	1.98 ± 1.87	2.02 ± 1.89	1.86 ± 1.81	1.85 ± 1.81
Interception	1.55 ± 1.69	1.53 ± 1.68	1.72 ± 1.77	1.51 ± 1.67	1.58 ± 1.70
Clearance	1.48 ± 2.17	1.54 ± 2.20	1.45 ± 2.14	1.63 ± 2.27	1.69 ± 2.32
Blocked shot	0.20 ± 0.92	0.27 ± 0.93	0.24 ± 0.92	0.30 ± 0.94	0.29 ± 0.94
Foul	1.34 ± 1.47	1.29 ± 1.44	1.29 ± 1.44	1.34 ± 1.47	1.39 ± 1.49
Yellow card	0.17 ± 0.71	0.19 ± 0.70	0.18 ± 0.70	0.16 ± 0.71	0.20 ± 0.70

possibly; 75–95%, likely; 95–99.5%, very likely; and >99.5%, most likely (Hopkins et al., 2009).

RESULTS

Descriptive statistics (mean ± SD) of the 20 technical performance-related match variables for players from five European football leagues estimated by the generalised mixed linear model controlling the effects of playing position, game location, match type, game result and team and opposition strength are presented in **Table 2**. The estimated true effects (effect size ± 90% confidence interval) of differences within pairwise comparisons between any two of these five leagues are shown in the **Figure 1**.

Regarding the variables related to goal scoring, the number of shots from players of German Bundesliga was clearly higher than that of Spanish La Liga, English Premier League and Italian Serie A, while no substantial differences were observed among shots attempted by players of other four leagues. There were no clear differences ascertained in shot on target between players from all five leagues. No substantial differences were detected between players from Spanish La Liga, English Premier League and German Bundesliga when considering the variables related to passing and organising. However, comparing to the players from other four leagues, players of Italian Serie A performed a lower number of touches, passes and achieved lower pass accuracy. Additionally, players from German Bundesliga and Italian Serie A achieved more long balls than players from French Ligue 1. Players from English Premier League had greater number of dribbles compared with those players from Italian Serie A. Other pairwised comparisons across five leagues regarding variables related to passing and organising did not reveal meaningful differences. Furthermore, trivial differences were also observed between players from all five leagues in all variables related to defending.

DISCUSSION

The current study quantified the differences in technical match performance between players from the 'major five' European football leagues in the UEFA Champions League. The data set presented here was based on one of the largest samples of data published to date (nine seasons). Moreover, our research approach allows us to control the situational effects for the identification of similarities and differences, and the UEFA Champions League and domestic leagues are characterised by specific features. Therefore, the findings from the current study are partly differ from prior studies due to the different methodologies used and the data sources. The current study demonstrated that the differences in players' technical performance between five leagues were smaller than we expected from the stereotypical perspective often portrayed within the media. Differences were mainly focussed on the variables related to goal scoring, passing and organising, whereas differences in variables related to defending were minimal.

Our study suggests that players from La Liga (Spain), the Premier League (England) and Ligue 1 (France) performed similar match actions and no substantial differences were observed across all technical variables. This finding differ from past research that has suggested that players from La Liga

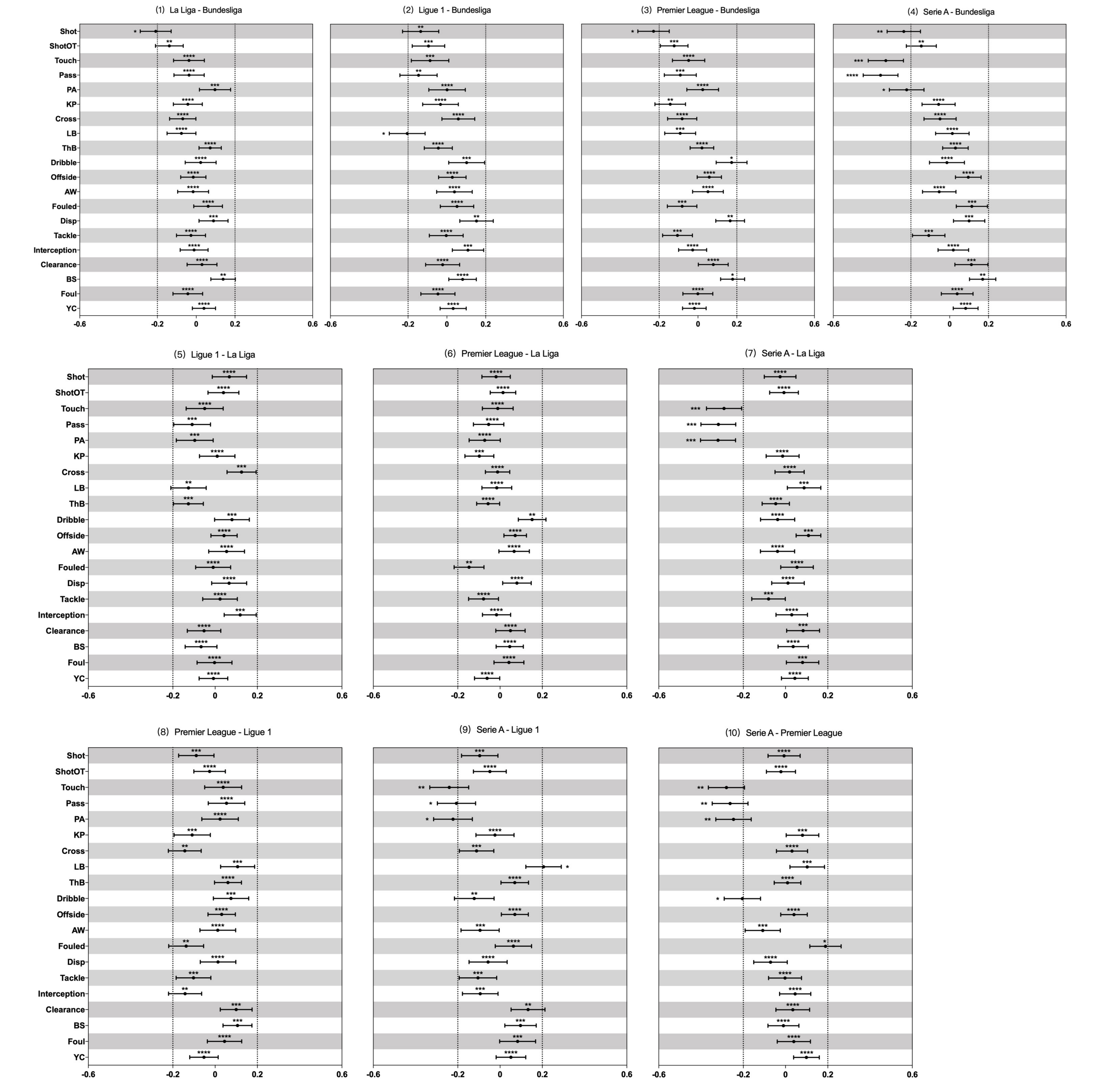

FIGURE 1 | Standardised effects of differences in mean count of each match action or event between five UEFA leagues estimated from the generalised mixed linear modelling. Bars are 90% confidence intervals. Asterisks indicate the likelihood for the magnitude of the true effect as follows: *possible; **likely; ***very likely; ****most likely. Asterisks located in the area between –0.2 and 0.2 denote for trivial differences. ShotOT, shot on target; PA, pass accuracy in %; KP, key pass; LB, long ball; ThB, through ball; AW, aerial won; Disp, dispossessed; BS, blocked shot; YC, yellow card.

(Spain) performed a more elaborated and skilled playing style while players from the Premier League (England) prefer the direct playing style, they performed relatively more tackles and aerial duels and covered greater distances in sprinting (Dellal et al., 2011; Oberstone, 2011; Sarmento et al., 2013). In addition, a previous research from Oberstone (2011) reported that significant differences existed between La Liga (Spain) and the Premier League (England) in variables related to goal scoring and defending. Ligue 1 (France) has received comparatively less attention in existing studies and therefore offers a novel area of exploration. Our findings revealed that when competing in the UEFA Champions League, players from Ligue 1 (France) shared a similar technical performance to players from La Liga (Spain) and the Premier League (England). This finding may reveal a trend that the differences in technical performance among these three leagues has decrease over time, potentially due to increasing levels of player and coach migration (Maguire and Stead, 1998; Maguire and Pearton, 2000; Littlewood et al., 2011; Sarmento et al., 2013). Hence, the teams' style of play and players' technical characteristics had evolved and were assimilated (Maguire and Stead, 1998; Maguire and Pearton, 2000).

Meaningful differences in technical performance between players from the Bundesliga (Germany), La Liga (Spain) and the Premier League (England) were only observed in the number of shots per game. Players from the Bundesliga (Germany) performed the most shots per game, while the differences in shots on target were minimal among these three leagues. This is partly in contrast to the findings of Oberstone (2011), who illustrated that La Liga (Spain) has a higher percentage of shot on target than the Premier League (England). Considering the technical differences between players from the Bundesliga (Germany) and Ligue 1 (France), we only found substantial difference in the number of long balls. Players from the Bundesliga (Germany) performed more long balls than players from Ligue 1 (France). Interestingly, the number of long balls from players from Serie A (Italy) was also substantially higher than those of Ligue 1 (France). Long balls have previously been related to the direct playing style (Fernandez-Navarro et al., 2016; Lago-Peñas et al., 2017). This finding may indicate that direct play is more prevalent in the Bundesliga (Germany) and Serie A (Italy) using long aerial passes more frequently than in the Premier League (England), La Liga (Spain) and Ligue 1 (France).

A prior study from Oberstone (2011) compared the technical performance of players from the Premier League (England), Serie A (Italy) and La Liga (Spain) based on a database of domestic leagues, it was reported that Serie A (Italy) is a league with better passing compared with the Premier League (England) and La Liga (Spain). However, the current study demonstrated that players from Serie A (Italy) showed comparatively greater technical difference during the comparisons between five leagues, especially in the aspect of passing and organising. They achieved the lowest ball touches, passes and pass accuracy comparing to their counterparts from the other four leagues (e.g., the Bundesliga, La Liga, Ligue 1 and the Premier League). This result may indicate that there is no passing superiority for players from Serie A (Italy) when competing in the international competition against the best teams from other leagues. We also found that players from Serie A (Italy) achieved the highest number of long passes, although the meaningful differences only observed in the comparison with players from Ligue 1 (France). This finding combined with their abovementioned weakness support the notion that Italian teams prefer to play counter-attack and are more focussed on the tactical-defensive aspects in the UEFA Champions league. Therefore, the low number of touch and pass were obtained. In addition, long pass is a crucial element during the counter-attack process, the high frequencies of occurrence in long balls could influence the accuracy of pass (Liu et al., 2016).

Given the focus on the perspective of attacking. The popular assumption is that La Liga (Spain) is primarily attacking and trying to control the match with high ball possession, while Serie A (Italy) has been characterised by its rigorous defensive tactics and relatively less developed and worse prepared in offencive aspect (Sarmento et al., 2013). Conversely, the results of the present study showed that limited differences in attacking performances between players from five leagues. The only substantial difference was detected in dribble between players of the Premier League (England) and Serie A (Italy). Dribble is a performance indicator that could reflect the degree of freedom of players during match play (Liu et al., 2016). In the Premier League (England), tactical and strategic aspects have not tended to have been considered with the same importance as in other leagues, while Italian Serie A has a special emphasis on its collective execution in the defensive organisation and plays a conservative game (Sarmento et al., 2013). Therefore, players from English Premier League are given more freedom to perform technical skills (dribble) during the attacking process, mainly due to direct styles of play with more counterattacks (Fernandez-Navarro et al., 2016).

Previously it has been suggested that teams in Italian Serie A are better in defending performance than other European teams (Sarmento et al., 2013). However, one noteworthy finding in this study is that players from all five leagues showed no substantial differences in defensive variables. This may reveal a trend that teams are increasingly aware of the importance of a solid defence for winning a game, trying to keep a good balance between attacking and defending during match play. The introduction of a considerable number of foreign players and coaches may once again account for that why the differences that we expected did not show in the current study. The foreign players that grown up in different youth academy systems have been instilled different conceptions about attacking and defending (Maguire and Stead, 1998; Maguire and Pearton, 2000), there will be an interplay between players from different countries when they play in the same team. Moreover, the migration of players and coaches between leagues may reduce the differences in players' physical abilities and teams' playing style between different leagues (Bloomfield et al., 2005; Sarmento et al., 2013). Therefore, these two factors may explain that the defending variables are no longer the important indicators to differentiate the five leagues. In addition, the evolution of tactics and strategies may also play a role. The diversity of tactics and strategies in modern football enable teams to find a defensive tactic that could be suitable for their playing style in defence.

CONCLUSION

This study identified both similarities and disparities in various aspects of players' technical performance across major five European football leagues in the UEFA Champion League from a long-term perspective. Players from the Bundesliga (Germany) were more advantageous than other leagues for creating scoring opportunities. Serie A (Italy) players did not show their advantage in defending performance but showed the worst performance in passing and organising. Players from La Liga (Spain) and the Premier League (England) have a balance performance in all aspects. However, the superiority of La Liga players in passing and organising was not detected and Premier League players are no longer playing the 'aerial game' as we used to think from the stereotypical perspective. Little attention has been paid on the comparison of players from Ligue 1 (France) with other leagues, while our data suggested that their technical performance were similar to players from La Liga (Spain) and the Premier League (England), but they prefer short pass during the attacking process. These technical differences largely driven by the differences in culture, playing style, players' characteristics and coach's philosophy. Nevertheless, the evolution of tactics and strategies, the migration of players and coaches and the different systems in youth academy may also play a role.

Practical Applications

The differences in technical performance for players from each league have been identified, thus the technical profiles could be created, which can provide a more thorough understanding for stakeholders in talent identification, player development, player recruitment, coaching and the match preparation when against with foreign teams. However, limitations of this study should be noted. This study only compared the technical players' performance from the best teams of each league played in a European competition rather than the whole teams of a domestic league. Therefore, the players' characteristics from a specific league identified in this study cannot represent the general characteristics of that entire league. This is one of the main causes that the disparities of findings between the current study and previous studies. Moreover, only the statistics of technical match actions and events were analysed, while the information of tactical behaviours was failed to consider due to the availability of match data. This may restrict the understanding of players' technical and tactical match performance. Lastly, further studies should account for validity and reliability of the sample used and key performance indicators in soccer as was previously described in basketball (Pérez-Ferreirós et al., 2019). This approach will be extremely useful when studying the minimum (reliable and valid) number of matches or observations from soccer teams and players, respectively.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the Polytechnic University of Madrid. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

QY participated in the study design, data collection, statistical analysis, data interpretation, writing, and revision of the manuscript. RG participated in the revision and proof check of the manuscript. CD participated in the data collection. HL and MG participated in the study design, statistical analysis, data interpretation, and revision of the manuscript.

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REFERENCES

Alberti, G., Iaia, F. M., Arcelli, E., Cavaggioni, L., and Rampinini, E. (2013). Goal scoring patterns in major European soccer leagues. *Sport Sci. Health* 9, 151–153. doi: 10.1007/s11332-013-0154-9

Barros, R. M., Misuta, M. S., Menezes, R. P., Figueroa, P. J., Moura, F. A., Cunha, S. A., et al. (2007). Analysis of the distances covered by first division Brazilian soccer players obtained with an automatic tracking method. *J. Sports Sci. Med.* 6:233.

Bloomfield, J., Polman, R., Butterly, R., and O'Donoghue, P. (2005). Analysis of age, stature, body mass, BMI and quality of elite soccer players from 4 European Leagues. *J. Sports Med. Phys. Fitness* 45, 58–67.

Brandes, L., and Franck, E. (2007). Who made who? An empirical analysis of competitive balance in European soccer leagues. *East. Econ. J.* 33, 379–403. doi: 10.1057/eej.2007.32

Castellano, J., Casamichana, D., and Lago, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *J. Hum. Kinet.* 31, 137–147. doi: 10.2478/v10078-012-0015-7

Collet, C. (2013). The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. *J. Sports Sci.* 31, 123–136. doi: 10.1080/02640414.2012.727455

Crolley, L., Hand, D., and Jeutter, R. (2000). Playing the identity card: stereotypes in European football. *J. Soccer Soc.* 1, 107–128. doi: 10.1080/14660970008721267

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., et al. (2011). Comparison of physical and technical performance in European soccer match-play: FA premier league and La Liga. *Eur. J. Sport Sci.* 11, 51–59. doi: 10.1080/17461391.2010.481334

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., and Drust, B. (2009). Analysis of high intensity activity in premier league soccer. *Int. J. Sports Med.* 30, 205–212. doi: 10.1055/s-0028-1105950

Fernandez-Navarro, J., Fradua, L., Zubillaga, A., Ford, P. R., and McRobert, A. P. (2016). Attacking and defensive styles of play in soccer: analysis of Spanish and english elite teams. *J. Sports Sci.* 34, 2195–2204. doi: 10.1080/02640414.2016.1169309

Foot, J. (2006). *Calcio. A History of Italian Football*. New York, NY: Harper Perennial.

Frick, B. (2007). The football players' labour market: empirical evidence from the major European leagues. *Scott. J. Polit. Econ.* 54, 422–446. doi: 10.1111/j.1467-9485.2007.00423.x

Gómez, M., Lago, C., and Pollard, R. (2013). "Situational variables," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio, (London: Routledge), 259–269.

Hopkins, W. (2016). SAS (and R) for mixed models. Spreadsheet: process poisson and logistic repeated measures. *Sport Sci.* 20:3.

Hopkins, W., Marshall, S., Batterham, A., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–13. doi: 10.1249/mss.0b013e31818cb278

Lago-Peñas, C., Gómez-Ruano, M., Megías-Navarro, D., and Pollard, R. (2016). Home advantage in football: examining the effect of scoring first on match outcome in the five major European leagues. *Int. J. Perform. Anal. Sport* 16, 411–421. doi: 10.1080/24748668.2016.11868897

Lago-Peñas, C., Gómez-Ruano, M., and Yang, G. (2017). Styles of play in professional soccer: an approach of the Chinese soccer super league. *Int. J. Perform. Anal. Sport* 17, 1073–1084. doi: 10.1080/24748668.2018.1431857

Lago-Peñas, C., Lago-Ballesteros, J., Dellal, A., and Gómez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *J. Sports Sci. Med.* 9, 288–293.

Littlewood, M., Mullen, C., and Richardson, D. (2011). Football labour migration: an examination of the player recruitment strategies of the 'big five'European football leagues 2004–5 to 2008–9. *Soccer Soc.* 12, 788–805. doi: 10.1080/14660970.2011.609680

Liu, H., Gómez, M.-A., Gonçalves, B., and Sampaio, J. (2016). Technical performance and match-to-match variation in elite football teams. *J. Sports Sci.* 34, 509–518. doi: 10.1080/02640414.2015.1117121

Liu, H., Hopkins, W., Gómez, A. M., and Molinuevo, S. J. (2013). Inter-operator reliability of live football match statistics from OPTA Sportsdata. *Int. J. Perform. Anal. Sport* 13, 803–821. doi: 10.1080/24748668.2013.11868690

Liu, H., Yi, Q., Giménez, J.-V., Gómez, M.-A., and Lago-Peñas, C. (2015). Performance profiles of football teams in the UEFA champions league considering situational efficiency. *Int. J. Perform. Anal. Sport* 15, 371–390. doi: 10.1080/24748668.2015.11868799

Maguire, J., and Pearton, R. (2000). The impact of elite labour migration on the identification, selection and development of European soccer players. *J. Sports Sci.* 18, 759–769. doi: 10.1080/02640410050120131

Maguire, J., and Stead, D. (1998). Border crossings: soccer labour migration and the European Union. *Int. Rev. Sociol. Sport* 33, 59–73. doi: 10.1177/101269098033001005

Oberstone, J. (2011). Comparing team performance of the english premier league, Serie A, and La Liga for the 2008-2009 season. *J. Quant. Anal. Sports* 7, 1–18.

Pawlowski, T., Breuer, C., and Hovemann, A. (2010). Top clubs' performance and the competitive situation in European domestic football competitions. *J. Sports Econ.* 11, 186–202. doi: 10.1177/1527002510363100

Pérez-Ferreirós, A., Kalén, A., Gómez, M. Á., and Rey, E. (2019). Reliability of Teams' game-related statistics in basketball: number of games required and minimal detectable change. *Res. Q. Exerc. Sport* 90, 297–306. doi: 10.1080/02701367.2019.1597243

Sapp, R. M., Spangenburg, E. E., and Hagberg, J. M. (2018). Trends in aggressive play and refereeing among the top five European soccer leagues. *J. Sports Sci.* 36, 1346–1354. doi: 10.1080/02640414.2017.1377911

Sarmento, H., Pereira, A., Matos, N., Campaniço, J., Anguera, T. M., and Leitão, J. (2013). English premier league, spaiǹs La Liga and Italý s seriés A–What's different? *Int. J. Perform. Anal. Sport* 13, 773–789.

Waldén, M., Hägglund, M., and Ekstrand, J. (2005). UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. *Br. J. Sports Med.* 39, 542–546. doi: 10.1136/bjsm.2004.014571

Yi, Q., Gómez, M. A., Wang, L., Huang, G., Zhang, H., and Liu, H. J. (2019). Technical and physical match performance of teams in the 2018 FIFA World cup: effects of two different playing styles. *J. Sports Sci.* 37, 2569–2577. doi: 10.1080/02640414.2019.1648120

Yi, Q., Jia, H., Liu, H., and Gómez, M. Á (2018). Technical demands of different playing positions in the UEFA Champions league. *Int. J. Perform. Anal. Sport* 18, 926–937. doi: 10.1080/24748668.2018.1528524

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Strength, Jumping, and Change of Direction Speed Asymmetries Are Not Associated With Athletic Performance in Elite Academy Soccer Players

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The aims of the present study were 2-fold: (1) to measure interlimb asymmetries from a battery of fitness tests in youth soccer players and (2) to determine the association between asymmetry and measures of athletic performance. Sixteen elite youth soccer players (14.7 ± 0.2 years) performed a single-leg Abalakov test (ABK), change of direction (COD) test over 10 m (5 + 5) and 20 m (10 + 10), and an iso-inertial power test. Subjects also performed 10-, 20-, and 30-m sprints and a bilateral countermovement jump, which were correlated with all ABK, COD, and iso-inertial asymmetry scores. A one-way repeated-measures analysis of variance showed significant differences between interlimb asymmetry scores across multiple tests ($p < 0.05$), with the iso-inertial power test presenting the greatest magnitude of asymmetry, whereas individual data highlighted substantially greater interindividual differences in each test. Pearson r correlations showed no significant relationships ($p > 0.05$) between the different interlimb asymmetry scores, and between asymmetry scores and athletic performance. These findings show the test-specific nature of asymmetries in youth soccer players, with the iso-inertial power test being the most sensitive in detecting asymmetry. Moreover, the results obtained suggest that inherent asymmetry in young soccer players did not negatively impact their performance.

Keywords: fitness testing, interlimb differences, performance reduction, power, youth

INTRODUCTION

For team sport athletes, the majority of high-intensity actions occur unilaterally (e.g., sprinting, changing direction, kicking, and jumping) (Gonzalo-Skok et al., 2017; Bishop et al., 2018a). A recent study noted that these actions were unlikely to occur in an equal amount on each limb in professional soccer players (Bishop et al., 2019a); thus, the presence of interlimb asymmetry is to be somewhat expected. This is further supported in previous research from Hart et al. (2016), who showed that asymmetry is a by-product of playing sport, noting that positional differences are a contributing factor to the prevalence of asymmetry as well. However, the prevalence of asymmetry alone does little to inform practitioners about whether targeted training interventions are required from an injury reduction or performance enhancement perspective.

Recently, there has been a rise in studies investigating the association between interlimb asymmetry and measures of athletic performance. For example, Bishop et al. (2018b) showed that jump height asymmetries from the unilateral countermovement jump (CMJ) were associated with slower 5-m (r = 0.49), 10-m (r = 0.52), and 20-m (r = 0.59) sprint times in elite youth female soccer players. Additionally, in elite academy soccer players of multiple age groups, ranging from younger than 16 to younger than 23 years old, Bishop et al. (2019b) showed that jump height asymmetry (again from the unilateral CMJ) was associated with slower times in 5- (r = 0.60–0.86), 10- (r = 0.54–0.87), 20-m (r = 0.56–0.79) sprints, and it also affected performance in the 5-0-5 test in either limb (r = 0.61–0.85). In contrast, Lockie et al. (2014) reported jump height and distance asymmetries during the unilateral CMJ (10.4%), lateral jump (5.1%), and broad jump (3.3%) tests in male collegiate athletes. No significant relationships were reported with linear speed or change of direction (COD) speed tests. Similarly, Dos'Santos et al. (2017) reported distance asymmetries of 5 to 6% for the single and triple hop for distance tests in male collegiate athletes and found no significant relationships between the two COD speed tests. Hence, in lieu of the available evidence, results demonstrate inconclusive findings when aiming to determine the association between interlimb asymmetry and measures of athletic performance. Thus, further research in this area is warranted.

In addition to this conflicting evidence, there is a paucity of studies investigating the relationship between strength/power asymmetry and performance tests. Previous research supports the notion that strength asymmetry is negatively correlated with jump performance (Bailey et al., 2013), speed and COD speed (Coratella et al., 2018), and kicking accuracy (Hart et al., 2014). However, these studies analyzed the strength asymmetry scores through the concentric phase of the movement, or even with isometric contractions, despite the fact that most of the sportive actions occur by combining concentric and eccentric contractions (i.e., the stretch-shortening cycle) (Nuñez and Sáez de Villarreal, 2017). An interesting alternative for the assessment of asymmetry would be to use flywheel devices, because these allow to apply load during both phases of the movement (i.e., concentric and eccentric) (Beato et al., 2019). In addition, to the authors' knowledge, only one previous study has analyzed whether asymmetries observed in an iso-inertial power test influence the athletic performance (Madruga-Parera et al., 2019), showing no significant relationships between them. However, the authors used specific tests (i.e., shuffle lateral and crossover steps) in youth tennis players, and no research has studied the relationship between the level of the asymmetry obtained in an iso-inertial soccer-related test (i.e., lateral squat) and the performance in elite young soccer players.

Therefore, the aims of the present study were 2-fold: (1) to measure interlimb asymmetries from a battery of fitness tests in youth soccer players and (2) to determine the association between asymmetry and measures of athletic performance. Owing to the conflicting evidence, developing a logical hypothesis was challenging, however, it was thought that larger asymmetries would be associated with reduced athletic performance.

MATERIALS AND METHODS

Participants

Sixteen elite U15 male soccer players (age = 14.7 ± 0.2 years, height = 169.1 ± 8.3 cm, body mass = 56.6 ± 9.7 kg, body mass index = 20.1 ± 1.8 kg/m^2) volunteered to participate in the study (*post hoc* statistical power >0.80). The players played in the highest division corresponding to their age-category level in Spain. Prior to participating in the study, each player completed a questionnaire about their medical and injury history. Goalkeepers were excluded from the study sample, and players who did not complete all tests were omitted in the subsequent statistical analysis. The inclusion criteria were to complete all the tests and to not have been injured during the last month before the investigation. Prior to initiating the study, participants were fully informed about the protocol to follow, and their assent was collected. Additionally, their parents/legal guardians filled out informed consents as they were younger than 18 years. All participants were free to leave the study at any time without any penalty. The study followed the guidelines set out in the Declaration of Helsinki (2013) and was approved by the university's research ethics.

Procedures

All data collection sessions were scheduled before the regular soccer sessions with testing taking place over 2 weeks. A familiarization period took place during the first weeks (two sessions), in order to avoid any learning effects (Castillo et al., 2019), while during the second week, the participants performed the two data collection sessions with 48 h of separation between sessions. Participants were required to complete the jump and power test during the first data collection session, and the linear and COD sprint test in the second one. This order was agreed with the clubs as it was deemed to minimize the accumulation of fatigue and therefore most likely to maximize performances across all tests. During the experimental period, the concerned players were instructed to have their last meal 3 h before the beginning of the tests, not to drink any caffeinated beverages or to perform intense physical exercise. All tests were performed at the same time, in the field of artificial grass where the team had their training session, with the training gear and footwear normally used by the player in the training. In addition, all these sessions were supervised by the accredited strength and conditioning coaches, who verbally discussed with each participant to ensure both parties were satisfied with requirements before data collection. Before each data collection session, a standardized warm-up was performed, consisting of 3 min of continuous, low-intensity running;

FIGURE 1 | The iso-inertial power test.

joint mobility exercises; and jump and sprint actions over distances of 10 to 30 m.

Vertical Jump Tests

After the standardized warm-up, the players performed three bilateral CMJ and three unilateral Abalakov jumps (ABK) with each limb, separated by 45 s of passive recovery (Núñez et al., 2018). During the CMJ, all participants were instructed to place their hands on their hips, which was followed by a vertical jump at maximal effort and landing in a vertical position, with their knees being flexed after landing (Sáez de Villarreal et al., 2015). However, during ABK, the swinging of the arms was allowed. All the jumps were performed on a platform with infrared rays (Optojump Next; Microgate®, Bolzano, Italy), and the jump height (cm) was recorded. The best of the performances of each test was selected for the subsequent statistical analysis.

Iso-Inertial Power Test

Following the jump test, the power test was conducted using a flywheel device (K-Box 3; Exxentric®, Stockholm, Sweden). All players performed 2 sets of 6 repetitions of the lateral squat exercise (**Figure 1**) with each leg (inertia 0.10 kg/m^2), allowing a rest of 4 min between each attempt (Sabido et al., 2017). Mean and peak power were measured by means of a rotary encoder (SmartCoach™ Power Encoder; SmartCoach Europe AB, Stockholm, Sweden) using its associated software (v5.6.0.8) in both concentric and eccentric phases, being the sum of both values calculated. The inertial load used for this assessment was chosen because previous studies have shown that power values are higher with lower loads (Sabido et al., 2017). To avoid possible fatigue effects, 50% of the participants started with their right limb, and the other 50% started with their left limb. The best result obtained in each test was selected for the subsequent statistical analysis.

Linear Sprint Test

Participants were assessed over 30 m with split times on 10 and 20 m. Four pairs of photoelectric cells (Polifemo Light Radio; Microgate®) were used to record the sprint times. The starting position was placed 0.5 m before the first timing gate, and players started when ready eliminating reaction time. Two trials with a rest of 2 min between each sprint were completed, and the fastest time was considered for the subsequent statistical analysis.

Change of Direction Sprint Test

After the linear sprint test, participants performed a total of four sprints with a COD involved. There were two sprints of 10 m (5 + 5 m) and two sprints of 20 m (10 + 10 m) with a COD of 90° (**Figure 2**). Each set of sprints was repeated so that the player changed direction to the right twice and changed direction to the left twice (Hader et al., 2015), and 50% of the participants started with their right limb, and the other 50% started with their left limb. A recovery time of 2 min was allowed between each sprint. At the beginning of each sprint, the front foot was placed 0.5 m before the first photocell (Polifemo Light Radio; Microgate®). For the subsequent statistical analysis, the fastest time of each test was chosen.

Statistical Analysis

Results are presented as mean ± standard deviations. All the dependent variables obtained from the tests were tested for normality using the Shapiro-Wilk test, and all the variables obtained were normally distributed. Within-session reliability of test measures was computed using the intraclass correlation coefficient (ICC) with absolute agreement and the coefficient of variation (CV). Interpretation of ICC and the 95% confidence interval were calculated and categorized as excellent (0.90–1.00), good (0.75–0.9), moderate (0.50–0.75), or poor (<0.50) (Koo and Li, 2016), considering CV values lower than 10% as acceptable (Cormack et al., 2008). In each unilateral test, the limb where a higher score was obtained was determined as the stronger limb, and the other limb was denoted as the weaker limb, and subsequently, interlimb asymmetries were calculated using a standard percentage difference equation for all the tests: (score in stronger limb − score in weaker limb)/(score in stronger limb) × 100 (Impellizzeri et al., 2007). When depicting interlimb differences individually, the use of an "IF function" in Microsoft Excel was added to the end of the formula: *IF (left < right, 1,−1) (Bishop et al., 2018a), in order to show the direction of asymmetry (i.e., which leg produced the larger score) without altering the magnitude. A one-way repeated-measures analysis of variance was conducted to determine the systematic bias between mean asymmetry scores, with statistical significance set at $p < 0.05$. Pearson r correlations were conducted to establish the relationship between interlimb asymmetries and fitness test scores, with statistical significance set at $p < 0.05$. The following scale of magnitudes was used to interpret the correlation coefficients: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and >0.9, nearly perfect (Hopkins et al., 2009). All statistical tests were performed using the software package SPSS version 24.0 (SPSS Inc., Chicago, IL, United States).

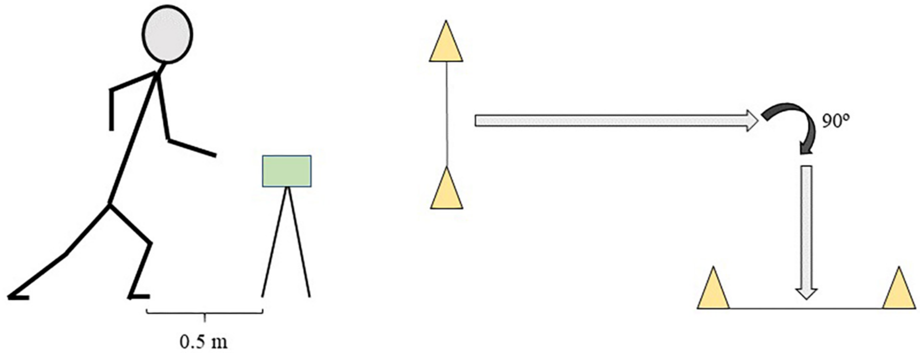

FIGURE 2 | Schematic representation of change of direction tests configuration.

RESULTS

Within-session reliability data are presented in **Table 1** and show that all data reported an excellent reliability except for 10-m linear speed (ICC = 0.75), whereas acceptable CV for all the tests (<10%) was obtained. In addition, significantly higher values ($p < 0.05$) were observed in ABK, mean power, and peak power interasymmetry scores in comparison to COD5 and COD10, without differences between the other tests.

Individual asymmetry values for each player are presented in **Figures 3–5** for jump height (ABK), COD (i.e., 5 and 10), and power (i.e., mean and peak). Individual asymmetry values ranged from 5.86 to 24.65% in ABK, 0.37 to 8.46% in COD5, 0.48 to 8.13% in COD10, 0.30 to 46.40% in mean power, and 0.14 to 57.37% in peak power.

Pearson r correlations between interlimb asymmetry scores across tests are shown in **Table 2**; no significant relationships were present between tests. Pearson r correlations between interlimb asymmetry scores and fitness tests are shown in **Table 3**. No significant relationships were found between interlimb asymmetry scores and either speed or jump performance.

DISCUSSION

The aims of the present study were to measure interlimb asymmetries from a battery of fitness tests in youth soccer players and to determine the association between asymmetry and measures of athletic performance. Results showed varying magnitudes of asymmetry across tests, the largest of which was during the iso-inertial power tests. Abalakov test and iso-inertial power tests showed larger asymmetry scores when comparing to the COD tests, and the correlations between asymmetry indexes were not significant. In addition, no significant relationship between asymmetry scores and athletic performance was observed.

TABLE 1 | Mean test scores ± standard deviations (SDs), test reliability (95% CIs), and mean interlimb asymmetry values.

Fitness test	Mean ± SD	ICC (95% CI)	CV (95% CI)	Mean asymmetry (%)
ABK-S (cm)	24.54 ± 3.61	0.96 (0.93–0.98)	2.8 (2.1–4.3)	11.95 ± 5.82*
ABK-W (cm)	21.55 ± 2.86	0.96 (0.92–0.98)	3.2 (2.4–4.9)	
COD5-S (s)	2.58 ± 0.12	0.94 (0.86–0.97)	1.2 (0.9–1.8)	4.60 ± 2.51
COD5-W (s)	2.46 ± 0.12	0.95 (0.89–0.98)	1.3 (1.0–2.0)	
COD10-S (s)	4.04 ± 0.14	0.96 (0.91–0.98)	0.9 (0.7–1.4)	3.02 ± 1.74
COD10-W (s)	4.17 ± 0.14	0.93 (0.85–0.97)	0.8 (0.6–1.3)	
Lateral squat:				
Mean power-S (W)	301.70 ± 114.86	0.98 (0.95–0.99)	3.9 (2.9–6.0)	21.27 ± 15.55*
Mean power-W (W)	241.60 ± 114.19	0.99 (0.97–1.00)	2.3 (1.8–3.5)	21.68 ± 18.85*
Peak power-S (W)	524.83 ± 198.13	0.97 (0.92–0.99)	7.3 (5.4–11.2)	
Peak power-W (W)	416.41 ± 202.41	0.99 (0.98–1.00)	2.9 (2.2–4.5)	
Speed:				
10 m (s)	1.76 ± 0.07	0.75 (0.48–0.88)	2.3 (1.7–3.5)	—
20 m (s)	3.09 ± 0.11	0.93 (0.85–0.97)	1.1 (0.8–1.6)	—
30 m (s)	4.31 ± 0.17	0.97 (0.93–0.99)	0.7 (0.5–1.0)	—
Countermovement jump (cm)	37.23 ± 4.98	0.96 (0.92–0.98)	3.4 (2.5–5.2)	—

**Higher interlimb asymmetry scores in comparison to COD tests ($p < 0.05$). ICC, intraclass correlation coefficient; CV, coefficient of variation; CI, confidence interval; ABK, Abalakov test; S, strong; W, weak; COD, change of direction.*

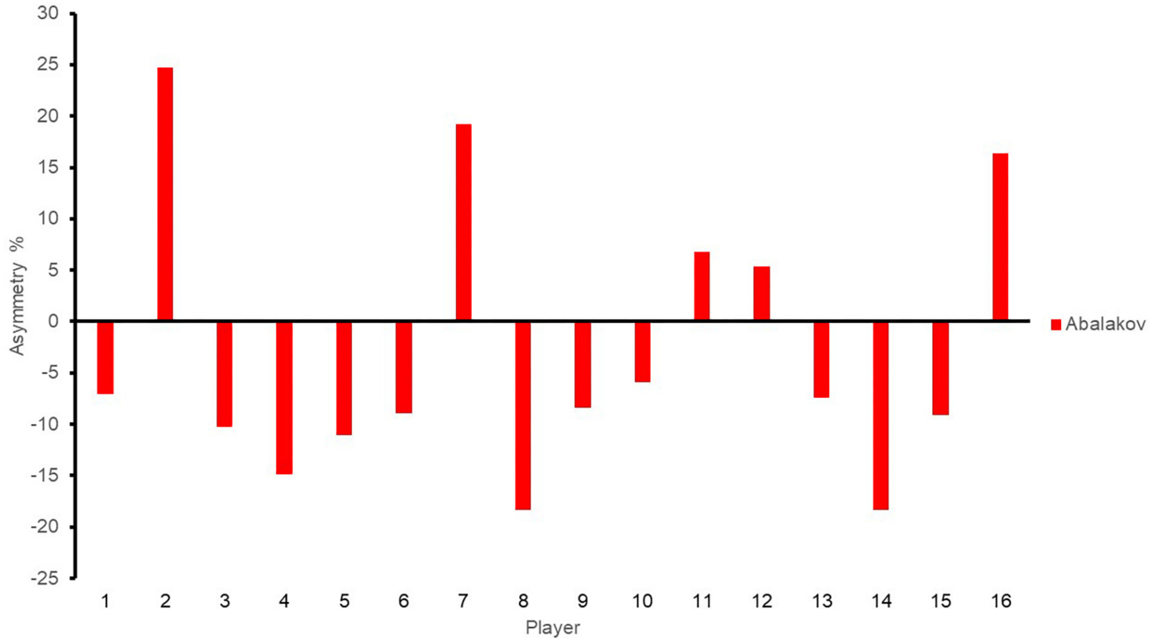

FIGURE 3 | Individual asymmetry data for Abalakov test. Above the line indicates raw score is greater on the right limb, and below the line indicates raw score is greater on the left limb. ABK, Abalakov test.

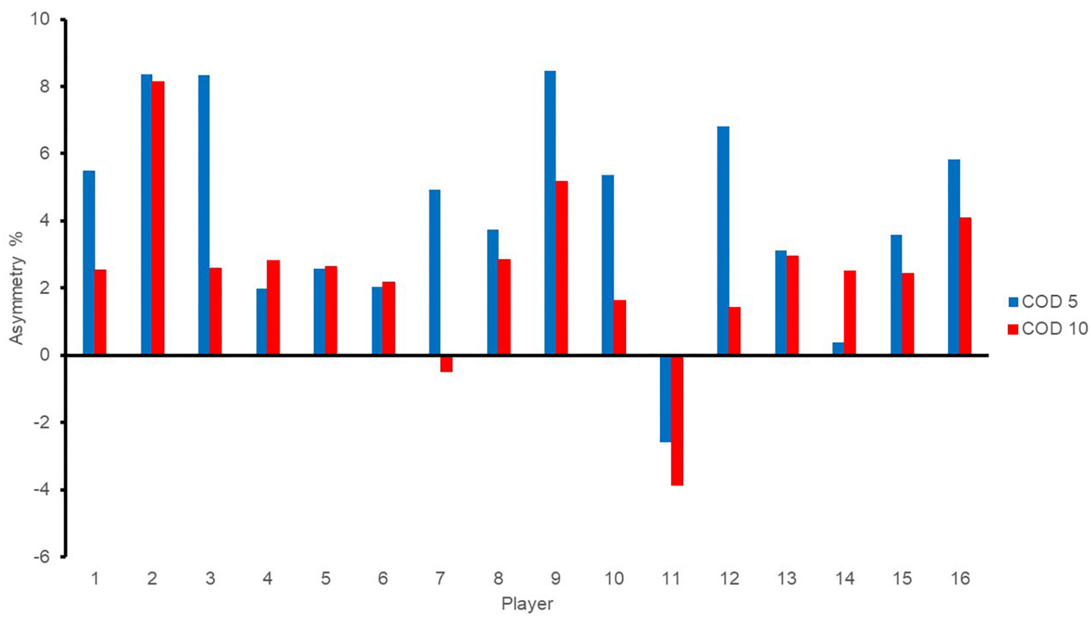

FIGURE 4 | Individual asymmetry data for change of direction tests. Above the line indicates raw score is greater on the right limb, and below the line indicates raw score is greater on the left limb. COD, change of direction.

All tests showed excellent reliability, except for 10 m, which showed an acceptable variability (<10%). These findings suggest the data being presented in this article can be interpreted with confidence for further analysis (Turner et al., 2015). Previous research supports that the level of experience and the structured strength and conditioning training (inclusive of speed and jump training) performed during the season seem to contribute to the good reliability of the data (Bishop et al., 2019a). Regarding the asymmetry scores observed in the present study, iso-inertial power tests showed the largest asymmetries in both mean and peak power (21.27% ± 15.55% and 21.68% ± 18.85%, respectively) across the different proposed tests, whereas the

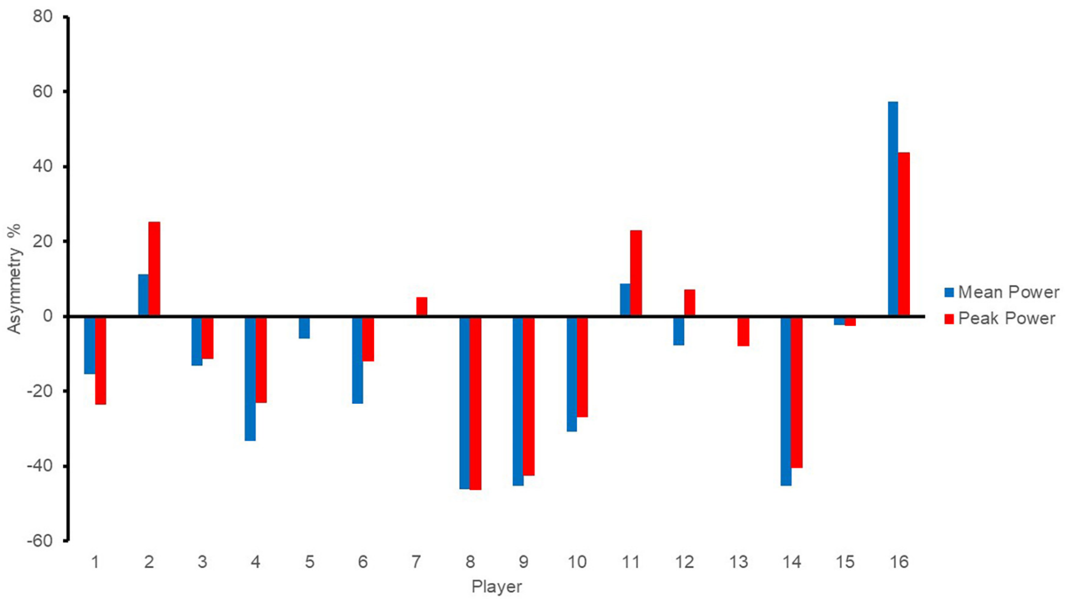

FIGURE 5 | Individual asymmetry data for iso-inertial power test. Above the line indicates raw score is greater on the right limb, and below the line indicates raw score is greater on the left limb.

COD test showed a lower magnitude of asymmetry (COD5: 4.60% ± 2.51% and COD10: 3.02% ± 1.74%) in comparison to the jump and iso-inertial power tests, which is in agreement with previous research (Fort-Vanmeerhaeghe et al., 2015; Dos'Santos et al., 2018; Madruga-Parera et al., 2019). The COD tests' inability to detect asymmetries could be due to two reasons: first, there is a strong linear speed component during COD, mainly in COD10 (Madruga-Parera et al., 2019), and second, sprint times are far more replicable than power outputs during jump (Bishop et al., 2019a) or iso-inertial tests.

No significant relationships were present between asymmetry scores, highlighting the independent nature of the selected tests in elite youth male soccer players (**Table 2**). This finding is supported by previous studies (Loturco et al., 2018; Bishop et al., 2019c), which stated a lack of relationships between different asymmetry scores in both female and male elite senior soccer players. Furthermore, in a recent study, Bishop et al. (2018a) observed that when comparing asymmetry scores across multiple tests levels of agreement were typically poor. This information suggests that asymmetries are independent of each other, reflecting the necessity to introduce different tests to provide a holistic picture of the asymmetries in the soccer players, as well as to preclude the use of a single test to screen for interlimb asymmetry. Given similar findings have been shown across multiple populations (Bishop et al., 2018a, 2019a; Loturco et al., 2018), it seems prudent to suggest that the lack of association between asymmetry in different tasks has less to do with youth male soccer players, but more to do with the variable nature of asymmetry itself.

As the interlimb asymmetry scores vary according to the test used, not all players respond equally to the same test in terms of asymmetry. Regarding this, some authors (Bishop et al., 2018a) have postulated that individual asymmetry analysis is key, owing to the high variability for the mean asymmetry scores (**Table 1**). In this sense, the largest mean asymmetry value for the analyzed test ranged from 3.02 to 21.68%, however, it is clear from **Figures 3–5** that many individual asymmetry values greatly surpassed this. In addition, individual analysis provides information about which asymmetry values favor the left limb (as represented by negative scores) and which favor the right

TABLE 2 | Pearson *r* correlations (95% confidence intervals) between the different interlimb asymmetry scores.

Tests	ABK	COD5	COD10	MP
COD5	0.01 (±0.43)	–		
COD10	0.40 (±0.37)	0.40 (±0.37)	–	
MP	0.34 (±0.39)	0.09 (±0.42)	0.40 (±0.37)	–
PP	0.26 (±0.40)	−0.03 (±0.43)	0.19 (±0.41)	0.90 (±0.09)*

**Statistical significance at $p < 0.01$. ABK, Abalakov test; COD, change of direction; MP, mean power; PP, peak power.*

TABLE 3 | Pearson *r* correlations (95% confidence intervals) between the different interlimb asymmetry scores and speed and jump tests.

Asymmetry	S10	S20	S30	CMJ
ABK	−0.14 (±0.42)	−0.15 (±0.42)	−0.19 (±0.41)	0.17 (±0.42)
COD5	−0.43 (±0.36)	−0.38 (±0.38)	−0.32 (±0.39)	0.42 (±0.36)
COD10	−0.19 (±0.41)	−0.24 (±0.41)	−0.24 (±0.41)	0.04 (±0.43)
MP	0.17 (±0.42)	0.22 (±0.41)	0.16 (±0.42)	0.26 (±0.40)
PP	0.29 (±0.40)	0.31 (±0.39)	0.22 (±0.41)	−0.15 (±0.42)

ABK, Abalakov test; COD, change of direction; MP, mean power; PP, peak power.

limb (positive asymmetry outcome) for each player, highlighting how a limb may be favored over the other from task to task (Bishop et al., 2018a). This individual information seems to be critical to perform specific training interventions, in order to reduce optimally interlimb asymmetries, because thresholds of greater than 10% are to be accepted as cutoffs where reduced performance (Bishop et al., 2018c) and increased risk of injury are present (Rohman et al., 2015). Therefore, to deepen in the interlimb asymmetry knowledge, the athlete profile should present the individual data as well as mean values.

It is well documented that in this sport several high-intensity actions occur unilaterally, not being equal the implication of both limbs (Sabido et al., 2017), which lead to the presence of asymmetries in soccer players (Bishop et al., 2019a). Attending to this, previous studies performed with soccer players have reported that jump asymmetry impacts negatively in athletic performance (Bishop et al., 2019a,b). Conversely, in the present study, no significant relationships were observed between interlimb asymmetries from ABK and either speed or jump performance. These differences could be due to the different jump test used in previous studies (i.e., drop jump), which is characterized by the presence of a braking action with an immediate requirement to transition into high propulsive forces straight, something that does seem to affect COD performance (Jones et al., 2009). According to this, no significant correlations were presented between COD asymmetry and athletic performance. Although we hypothesized that the asymmetry scores obtained in the iso-inertial power test could influence athletic performance, our results revealed a lack of significant relationships. In this sense, only one previous study has used an iso-inertial device to assess interlimb asymmetries and its relationship with jump performance (Madruga-Parera et al., 2019), obtaining similar results. Given that asymmetries have no detrimental impact in young soccer players' performance, even using iso-inertial devices for the assessment, it seems pertinent to assume that reducing asymmetry scores is not a relevant strategy to improve the performance in this specific population. Further studies should analyze the relationship between asymmetry and external match load (i.e., distance covered, high-speed running, etc.) in order to understand the relevance of asymmetry on match performance in young soccer players.

This study is not without limitations. The main one is that maturation stages have not been considered in this study; thus, an assumption was made that players were no longer circa peak height velocity, which may have influenced the results obtained in this study. Additionally, a small sample size of 16 subjects was used, so the results obtained should be taken with caution. Therefore, future research should aim to use a larger cohort of soccer players, as well as to include the maturation status of the participants.

CONCLUSION

The findings from this study highlight that asymmetries vary across commonly used tests without significant relationships between each other, suggesting the necessity to apply a fitness test battery for youth soccer players in order to provide a holistic picture of the asymmetries in the soccer players. On the other hand, individual asymmetry scores were vastly different from mean values for all metrics, so practitioners should always consider the individual nature of asymmetries to perform specific training interventions on a more individual level. In addition, iso-inertial power test appears to be a highly sensitive test to detect asymmetries. However, this power test had no detrimental association with sprint and jumping abilities. These findings suggest that the reduction of interlimb asymmetries should not be expected to impact player performance in youth soccer players.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Universidad Isabel I. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JR-G conceived the research idea, collected the sample data, analyzed the data, and statistically interpreted the findings. JR-G, CB, SV, PG-P, and AN prepared the manuscript. All authors critically revised the manuscript, read, and approved the final version.

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REFERENCES

Bailey, C., Sato, K., Alexander, R., Chiang, C.-Y., and Stone, M. H. (2013). Isometric force production symmetry and jumping performance in collegiate athletes. *J. Trainol.* 2, 1–5. doi: 10.17338/trainology.2.1_1

Beato, M., McErlain-Naylor, S. A., Halperin, I., and Dello Iacono, A. (2019). Current evidence and practical applications of flywheel eccentric overload exercises as postactivation potentiation protocols: a brief review. *Int. J. Sports Physiol. Perform.* [Epub ahead of print].

Bishop, C., Berney, J., Lake, J., Loturco, I., Blagrove, R., Turner, A., et al. (2019a). Bilateral deficit during jumping tasks. *J. Strength Cond. Res.* [Epub ahead of print].

Bishop, C., Brashill, C., Abbott, W., Read, P., Lake, J., and Turner, A. (2019b). Jumping asymmetries are associated with speed, change of direction speed, and jump performance in elite academy soccer players. *J. Strength Cond. Res.* [Epub ahead of print].

Bishop, C., Lake, J., Loturco, I., Papadopoulos, K., Turner, A., and Read, P. (2018a). Interlimb asymmetries: the need for an individual approach to data analysis. *J. Strength Cond. Res.* [Epub ahead of print].

Bishop, C., Read, P., McCubbine, J., and Turner, A. (2018b). Vertical and horizontal asymmetries are related to slower sprinting and jump performance in elite youth female soccer players. *J. Strength Cond. Res.* [Epub ahead of print].

Bishop, C., Turner, A., Maloney, S., Lake, J., Loturco, I., Bromley, T., et al. (2019c). Drop jump asymmetry is associated with reduced sprint and change-of-direction speed performance in adult female soccer players. *Sports* 7:E29. doi: 10.3390/sports7010029

Bishop, C., Turner, A., and Read, P. (2018c). Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J. Sports Sci.* 36, 1135–1144. doi: 10.1080/02640414.2017.1361894

Castillo, D., Domínguez, R., Rodríguez-Fernández, A., and Raya-González, J. (2019). Effects of caffeine supplementation on power performance in a flywheel device: a randomised, double-blind cross-over study. *Nutrients* 11:255. doi: 10.3390/nu11020255

Coratella, G., Beato, M., and Schena, F. (2018). Correlation between quadriceps and hamstrings inter-limb strength asymmetry with change of direction and sprint in U21 elite soccer-players. *Hum. Mov. Sci.* 59, 81–87. doi: 10.1016/j.humov.2018.03.016

Cormack, S. J., Newton, R. U., McGuigan, M. R., and Doyle, T. L. A. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *Int. J. Sports Physiol. Perform.* 3, 131–144. doi: 10.1123/ijspp.3.2.131

Dos'Santos, T., Thomas, C., Jones, P. A., and Comfort, P. (2018). Assessing asymmetries in change of direction speed performance; application of change of direction deficit. *J. Strength Cond. Res.* 33, 2953–2961. doi: 10.1519/JSC.0000000000002438

Dos'Santos, T., Thomas, C. A., Jones, P., and Comfort, P. (2017). Asymmetries in single and triple hop are not detrimental to change of direction speed. *J. Trainology* 6, 35–41. doi: 10.17338/trainology.6.2-35

Fort-Vanmeerhaeghe, A., Montalvo, A. M., Sitjà-Rabert, M., Kiefer, A. W., and Myer, G. D. (2015). Neuromuscular asymmetries in the lower limbs of elite female youth basketball players and the application of the skillful limb model of comparison. *Phys. Ther. Sport.* 16, 317–323. doi: 10.1016/j.ptsp.2015.01.003

Gonzalo-Skok, O., Tous-Fajardo, J., Suarez-Arrones, L., Arjol-Serrano, J. L., Casajús, J. A., and Mendez-Villanueva, A. (2017). Single-leg power output and between-limbs imbalances in team-sport players: unilateral versus bilateral combined resistance training. *Int. J. Sports Physiol. Perform.* 12, 106–114. doi: 10.1123/ijspp.2015-0743

Hader, K., Palazzi, D., and Buchheit, M. (2015). Change of direction speed in soccer: how much braking is enough? *Kinesiology* 47, 67–74.

Hart, N. H., Nimphius, S., Spiteri, T., and Newton, R. U. (2014). Leg strength and lean mass symmetry influences kicking performance in Australian football. *J. Sports Sci. Med.* 13, 157–165.

Hart, N. H., Nimphius, S., Weber, J., Spiteri, T., Rantalainen, T., Dobbin, M., et al. (2016). Musculoskeletal asymmetry in football athletes. *Med. Sci. Sport. Exerc.* 48, 1379–1387. doi: 10.1249/MSS.0000000000000897

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sport. Exerc.* 41, 3–13. doi: 10.1249/MSS.0b013e31818cb278

Impellizzeri, M., Rampinini, E., Maffiuletti, N., and Marcora, S. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Med. Sci. Sport. Exerc.* 39, 2044–2050. doi: 10.1249/mss.0b013e31814fb55c

Jones, P., Bampouras, T. M., and Marrin, K. (2009). An investigation into the physical determinants of change of direction speed. *J. Sports Med. Phys. Fit.* 49, 97–104.

Koo, T. K., and Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J. Chiropr. Med.* 15, 155–163. doi: 10.1016/j.jcm.2016.02.012

Lockie, R. G., Callaghan, S. J., Berry, S. P., Cooke, E. R. A., Jordan, C. A., Luczo, T. M., et al. (2014). Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team-sport athletes. *J. Strength Cond. Res.* 28, 3557–3566. doi: 10.1519/JSC.0000000000000588

Loturco, I., Pereira, L. A., Kobal, R., Abad, C. C. C., Komatsu, W., Cunha, R., et al. (2018). Functional screening tests: interrelationships and ability to predict vertical jump performance. *Int. J. Sports Med.* 39, 189–197. doi: 10.1055/s-0043-122738

Madruga-Parera, M., Bishop, C., Fort-Vanmeerhaeghe, A., Beltran-Valls, M. R., Skok, O. G., and Romero-Rodríguez, D. (2019). Interlimb asymmetries in youth tennis players. *J. Strength Cond. Res.* [Epub ahead of print].

Nuñez, F. J., and Sáez de Villarreal, E. (2017). Does flywheel paradigm training improve muscle volume and force? A meta-analysis. *J. Strength Condition. Res.* 31, 3177–3186. doi: 10.1519/JSC.0000000000002095

Núñez, F. J., Santalla, A., Carrasquila, I., Asian, J. A., Reina, J. I., and Suarez-Arrones, L. J. (2018). The effects of unilateral and bilateral eccentric overload training on hypertrophy, muscle power and COD performance, and its determinants, in team sport players. *PLoS One* 13:e0193841. doi: 10.1371/journal.pone.0193841

Rohman, E., Steubs, J. T., and Tompkins, M. (2015). Changes in involved and uninvolved limb function during rehabilitation after anterior cruciate ligament reconstruction: implications for Limb Symmetry Index measures. *Am. J. Sports Med.* 43, 1391–1398. doi: 10.1177/0363546515576127

Sabido, R., Hernández-Davó, J. L., Botella, J., Navarro, A., and Tous-Fajardo, J. (2017). Effects of adding a weekly eccentric-overload training session on strength and athletic performance in team-handball players. *Eur. J. Sport Sci.* 17, 530–538. doi: 10.1080/17461391.2017.1282046

Sáez de Villarreal, E., Suarez-Arrones, L., Requena, B., Haff, G. G., and Ferrete, C. (2015). Effects of plyometric and sprint training on physical and technical skill performance in adolescent soccer players. *J. Strength Cond. Res.* 29, 1894–1903. doi: 10.1519/JSC.0000000000000838

Turner, A., Brazier, J., Bishop, C., Chavda, S., Cree, J., and Read, P. (2015). Data analysis for strength and conditioning coaches. *Strength Cond. J.* 37, 76–83. doi: 10.1519/SSC.0000000000000113

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CORRECTION
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Corrigendum: Strength, Jumping, and Change of Direction Speed Asymmetries Are Not Associated With Athletic Performance in Elite Academy Soccer Players

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In the original article, the specific contributions of the authors Santiago Veiga and Pedro Gómez-Piqueras were not included in the Author Contributions statement. The corrected Author Contributions Statement appears below.

AUTHOR CONTRIBUTIONS

JR-G conceived the research idea, collected the sample data, analyzed the data, and statistically interpreted the findings. JR-G, CB, SV, PG-P, and AN prepared the manuscript. All authors critically revised the manuscript, read, and approved the final version.

The authors apologize for this error and state that this does not change the scientific conclusions of the article in any way. The original article has been updated.

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ORIGINAL RESEARCH
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Influence of Strength, Power, and Muscular Stiffness on Stroke Velocity in Junior Tennis Players

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Objective: The main aim of this study was to establish the relationship between strength, power characteristics, individual muscle stiffness, international tennis number (ITN), and stroke velocity (StV) in junior tennis players.

Methods: Twenty one junior male tennis players (mean ± SD; age, 17.0 ± 0.8 years; height, 1.8 ± 0.1 m; body mass, 72.3 ± 5.8 kg; BMI 22.1 ± 1.5 kg/m^2), with an ITN ranging from 2 to 4, performed measurements regarding muscle stiffness of selected muscles involved in tennis strokes. StV (serve, forehand, and backhand), strength (maximum isometric strength) and power (medicine ball throws, squat jump, countermovement jump, and bench press) measurements were also performed (ICC = 0.803–0.998; CV = 0.3–6.4).

Results: Moderate inverse correlations were found between serve velocity (SV) and ITN ($r = -0.43$; $p = 0.05$), and large positive correlations were observed between pectoralis majoris stiffness (PMStiff) ($r = 0.53$; $p = 0.01$), isometric wrist flexion ($r = 0.58$; $p = 0.006$) and ITN, respectively. PMStiff was moderately inversely correlated to forehand velocity (FV) ($r = -0.45$; $p = 0.03$) and gastrocnemius (GStiff) and infraspinatus stiffness (IStiff) positively to SV ($r = 0.45$; $p = 0.04$; $r = 0.42$; $p = 0.05$). No significant correlations were found regarding strength and power measurements.

Conclusion: Greater stiffness values may enhance StV, especially when transferring power from lower to upper body. On the other hand, high scores could interfere in technical parameters that are key for velocity production in complex tennis strokes. Strength and power values proved to correlate poorly to StV in this particular sample of junior tennis players, possibly due to the multifactorial nature of tennis strokes and the possibility that they become more important as age and level increase.

Keywords: serve, forehand, backhand, speed, testing

INTRODUCTION

Today's tennis is considered as a fast-paced, explosive and highly dynamic sport (Roetert et al., 2009b; Fernández-Fernández et al., 2014). High hitting velocities, specifically in the serve, can decide the game and are directly related to the tennis player's level (Gillet et al., 2009; Ulbricht et al., 2016). This action has been considered the most important shot, due to the possibilities to dominate the rally or win the point directly through an ace (Gillet et al., 2009; Kovacs and Ellenbecker, 2011). On the other hand, groundstroke velocity has received less attention by literature, although some data on the matter suggest an increased hitting velocity when comparing professional and youth high-performance players (Landlinger et al., 2012). Achieving higher velocity production in strokes could be an important factor on which players may benefit in order to improve performance and achieve higher competitive levels. Moreover, tennis strokes are considered highly complex motor skills which require force production and the ability to transfer these forces throughout the entire body in what is known as the kinetic chain (Kibler, 2009, 2014). Thus, further knowledge around specific determinants of stroke velocities and how they influence performance could be of interest for practitioners.

Because of the aforementioned characteristics, it is commonly been accepted that these strokes are affected by several parameters such as technique (Roetert et al., 2009a,b), anthropometrics (Söğüt, 2014; Bonato et al., 2015), strength, power (Baiget et al., 2016; Fett et al., 2018; Palmer et al., 2018) biological (Sanchís-Moysi et al., 2010), and range of movement (ROM) characteristics (Palmer et al., 2018), making the action of a multi-factorial nature. Several studies have focused on biomechanical and kinematic factors influencing hitting performance (Elliott et al., 1995; Roetert et al., 2009a,b), establishing the speed of the racquet head, internal rotation of the upper arm, wrist flexion and moment of ball impact as some of the major contributors to generate velocity (Elliott et al., 1995). Also, anthropometrics such as height and body mass have been related positively with serve speed in professional and young players (Söğüt, 2014; Bonato et al., 2015; Fett et al., 2018). Regarding strength values, literature traditionally has focused on analyzing isokinetic data at certain joint positions and degrees that mimic the serve action (Ellenbecker and Roetert, 2003), obtaining moderate positive correlations especially on those positions that resemble the serve motion. More recently, investigations have also aimed to assess strength values adding maximal isometric strength testing to experimental methods, especially in the shoulder complex (Cools et al., 2014; Baiget et al., 2016; Fett et al., 2018; Hayes et al., 2018). When assessing SV, it has been accepted as a contributor to velocity production, but few investigations have aimed to the relationship between maximal isometric strength and forehands or backhands. Further research regarding groundstrokes could be of interest as previous studies have shown a strong relationship between isometric strength and performance (Baiget et al., 2016). When focusing on dynamic strength, some interesting data has recently been analyzed, indicating upper body strength and power as important contributors of the junior tennis player's serve (Fett et al., 2018; Palmer et al., 2018). Nevertheless, as the majority of investigations have established strength and power as contributors to SV in elite players, it seems interesting to further focus on these measurements regarding young competitive players and especially analyzing the groundstrokes. Taking into account these actions as determinant factors differentiating elite from sub-elite players (Landlinger et al., 2012), it seems important to study associations between strength and power characteristics and groundstrokes, as we find regarding SV in literature.

Furthermore, the influence of complex neuromuscular factors has hardly been studied in relation to any tennis specific stroke. Enhanced values of mechanical stiffness, that can be defined as the resistance of an object or body to deformation or change in length (Brughelli and Cronin, 2008), have been suggested as beneficial for actions that rely on the stretch shorten cycle (SSC) such as jumping, sprinting or agility (Brughelli and Cronin, 2008). Due to the greater capacity of a compliant structure to absorb and re-use rapidly greater amounts of elastic energy for a given force (Kalkhoven and Watsford, 2018), this quality could be beneficial or have influence on tennis strokes, as they are complex skills that involve SSC actions in the entire kinetic chain. On the other hand, an increased or non-sufficient level of the mentioned stiffness could interpose technical aspects or the capacity to produce velocity to the stroke (Brazier et al., 2017). Because of this, studies have started to investigate neuromechanical factors such as individual muscle stiffness and their contribution to performance aspects (Sheehan et al., 2018). The majority of investigations on stiffness have aimed at actions involving the lower body (Pruyn et al., 2014; Kalkhoven and Watsford, 2018), making this phenomenon still unclear when speaking of how it affects predominantly upper body motions. Added to this, investigations have aimed to establish specific predictors of tennis actions, yet to the best of our knowledge, none concerning the relationship between muscle stiffness characteristics and stroke velocity (StV), especially on groundstrokes and junior tennis players.

In short, the influence of specific strength and power parameters on StV, especially groundstrokes, and how muscle mechanical properties affect dynamic actions seems of importance for professionals. Therefore, the aim of this study was to examine the relationship between strength and power characteristics, individual muscle stiffness values, international tennis number (ITN) and StV in competitive junior tennis players. Our working hypothesis was that a strong positive association will exist between strength and power characteristics, ITN and all strokes, as seen previously in SV (Baiget et al., 2016; Fett et al., 2018; Hayes et al., 2018; Palmer et al., 2018). Also, due to the beneficial effects of enhanced stiffness in explosive actions (Brughelli and Cronin, 2008), a higher level of this property in the muscle groups tested will correlate to faster StV.

MATERIALS AND METHODS

Participants

Twenty-one junior male tennis players (mean ± SD; age, 17.0 ± 0.8 years; height, 1.8 ± 0.1 m; body mass, 72.3 ± 5.8 kg; BMI 22.1 ± 1.5 kg/m^2) with an ITN ranging from 2 to 4 (advanced level) participated in this study. *A priori* power analysis for a Pearson correlation was conducted in G*power to estimate a sufficient sample size. With the alpha level set at 0.05, using a large target effect size (ES) of 0.6, a power of 0.80 and two tails, it was determined that 19 subjects would be needed. The player's ITN was established by the consensus of three coaches accredited with RPT (Registro Profesional de Tenis) level 3, following the ITN Description of Standards (ITN, 2019). Subjects had a weekly volume of training of 25 h/week^{-1} of which 5 accounted for fitness training and 20 for technical and tactical sessions. The mean training background of the players was 10.1 ± 1.7 years, which focused on tennis-specific training (i.e., technical and tactical skills), aerobic and anaerobic training (i.e., on- and off-court exercises), and strength training. Inclusion criteria for all subjects required each participant to have a minimum of 1 year experience in strength training and 5 years of tennis training and competition. Participants were excluded from the study if they had history of upper extremity surgery, shoulder, back or knee pain and/or rehabilitation for the past 12 months. All subjects were informed in advance about the characteristics of the study and, before their participation, the participants or their legal tutors, in the case of being underage, voluntarily signed an informed consent. The study was conducted following the ethical principles for biomedical research with human beings, established in the Declaration of Helsinki of the AMM (2013) and approved by the Ethics Committee of the Catalan Sports Council (26/2018/CEICEGC).

Experimental Design

This was a cross-sectional laboratory study with uninjured participants. The collection of data took place in May during a normal in-season training week in groups of 4 or 5 players and on 4 separate testing sessions, executed from 8 a.m. to 2 p.m. approximately, before the player's afternoon normal technical-tactical training. On session 1, participants were assessed for 1 repetition maximum (1RM) on the bench press exercise. On session 2, participants were assessed for individual muscle stiffness (Stiff) via muscle natural oscillation. On session 3, participants were assessed for maximal StV on the forehand, backhand and serve actions. On session 4, participants were assessed using strength tests including bench press peak power (Wmax), maximal isometric strength (IsoMax) in 5 different positions, squat jump (SJ), countermovement jump (CMJ), and medicine ball overhead throw (MBT), following that order. Sessions 2, 3, and 4 were separate 2 h apart and session 1 was executed 24 h before. Players performed one tennis technical-tactical training session of 90 min between sessions 1 and 2 and ceased activity for at least 14 h before resuming the testing protocol. The use of pain-relieving strategies (e.g., foam rolling, massage, ice baths, etc.) was not allowed during testing in order to avoid interferences with the results. Players were allowed to consume water *ad libitum*. Isotonic and energetic drinks were not allowed during the tests. The order of the sessions was established this way with the intention of avoiding the influence of stiffness, strength and power testing on the StV protocol. In order to ensure a better precision and reproducibility of singles measurements, the intra-session reliability of stiffness, strength, power and StV values was determined using a test-retest design. Thus, the same testing procedure that was carried out in the current study was repeated twice in the strength and power (1RM, Wmax, IsoMax, SJ, CMJ, and MBT), three times in the StV (forehand, backhand, and serve) and five times in stiffness measurements in all tennis players. Two familiarization sessions of all the strength and power tests were completed during the 2 weeks prior to the application of the protocol.

Procedures

1-Repetition Maximum Estimation

Maximum dynamic strength was estimated in session 1 using the load-velocity relationship via a progressive load test (Jidovtseff et al., 2011). All subjects were tested in four progressive loads in the bench press exercise. The number of series performed were executed in the following manner; eight repetitions with 20 kg of load; eight repetitions with 30 kg; eight repetitions with 35 kg, and eight repetitions with 40 kg. Participants had 5 min rest between sets. For each load, players were indicated to raise the bar as quickly as possible without releasing it. If eight repetitions were not performed, as many as the subject performed were recorded. The test recorded only the concentric phase of the exercise so the bar had an initial position of 3 cm above the nipple line. During the whole movement, the subjects had their backs on the bench and their hips flexed at 90°. The best repetition was recorded for the analysis of the maximum speed achieved. 1RM was estimated using a regression line plotted through the known load (X) and average velocity (Y). From this linear regression, the slope, theoretical average velocity at 0 kg, and theoretical load at 0 m/s^{-1} were calculated by means of a linear transducer (CLTP, Chronojump Boscosystem®, Barcelona, Spain) (Jidovtseff et al., 2011). This encoder has been previously validated showing it has a valuable and reliable system for measuring movement velocity and for estimating power in strength and conditioning training exercises (Garnacho-Castaño et al., 2014).

Contractile Properties Measurement

In session 2, individual muscle stiffness was recorded on the dominant side of the body using a hand-held myometer (Myoton-Pro, Myoton AS, Tallinn, Estonia). The dominant extremity or side of the body was established based on upper body dominance. Before the assessment, body marks were established for the nine measurement points using the SENIAM electrode placement guides (Freriks et al., 1999; Konrad, 2005; **Figure 1**). The muscle groups chosen were those mostly involved in the hitting actions (Girard et al., 2005) attending to the whole kinetic chain; pectoralis major (PM); biceps brachii (B); infraspinatus (I); deltoids (D); rectus abdominis (RA), the rectus femoris (RF); vastus medialis (VM); biceps femoris (BF), and the lateral head of the gastrocnemius (G). The measurements were made with a state of muscle relaxation and the subjects lying down (RA), seated (PM, B, I, D) or in anatomical position (RF, VM, BF, G), depending on the test point. The tip of the Myoton-Pro was placed perpendicular to all measurement zones sampling at 15 ms with a force of 0.58 N and measured the damped natural oscillations cause by the probe impact. The device's accelerometers operated

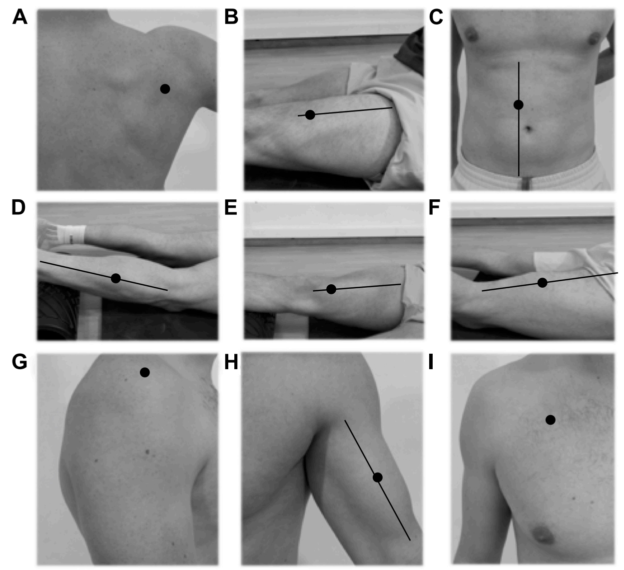

FIGURE 1 | Mechanical muscle stiffness measurement spots. Myoton-Pro® tip placement. **(A)** Infraspinatus. **(B)** Rectus femoris. **(C)** Rectus abdominis. **(D)** Gastrocnemius. **(E)** Vastus medialis. **(F)** Biceps femoris. **(G)** Deltoids. **(H)** Biceps brachii. **(I)** Pectoralis majoris.

at 3,200 Hz, offering an average value of five consecutive measurements. The Myoton-Pro reliability is expressed in **Table 1**, and shows excellent test-retest values (ICC = 0.95–0.99; CV = 0.3–0.9) as shown previously in other investigations (Zinder and Padua, 2013).

Maximum Hitting Velocity

In session 3, subjects performed a standardized warm-up that included mobility exercises, 5 min of free rallies and 5–10 progressive serves. Each subject executed a series of 6 flat services on each side of the court with 60 s of rest between sets and 12 forehands and 12 backhands (crossed-court) without alternating strokes. Only the serves that were in the serve box and the groundstrokes that landed in the court were counted. StV was determined using a hand-held radar gun [Stalker ATS II, United States, frequency: 34.7 GHz (Ka-Band) ± 50 MHz] and peak velocity was registered for further analysis. The radar was positioned in the center of the baseline, 2 m behind the line and at an approximate height of 2 m for the serves and behind the player following the trajectory of the ball for groundstrokes. Hitting as hard and precise as possible to the "T" was indicated when serving and cross-court when hitting groundstrokes. Immediate feedback was provided to the subjects to encourage maximum effort. To avoid variability performing groundstrokes, balls were fed by a ball-throwing machine (Pop-Lob Airmatic 104, France) at a constant speed (68.6 ± 1.9 km $^{h-1}$).

Strength and Power Measurements

In session 4, the participants were asked to perform five maximum isometric tests following a protocol similar to that offered by Baiget et al. (2016). The different positions tested were: internal shoulder rotation with the elbow and shoulder flexed 90° (IsoIR), horizontal shoulder abduction (IsoAbd), horizontal shoulder adduction (IsoAdd), wrist flexion (IsoWrF), and extension (IsoWrE). The test was performed sitting on an Ercolina machine (Technogym Company®, Cesena, Italy). The participants sat in a position with a 90° hip flexion and the back resting on a bench. All the participants were fastened with a harness on the chest to avoid unwanted movements. Only the dominant extremity was evaluated. The maximum isometric force peak was recorded using a strain gauge sampling at 80 Hz (Chronojump, Boscosystem®, Barcelona, Spain). Positions were established before each test using a goniometer. Subjects performed three maximal voluntary contractions for 3–6 s and spaced by 1-min rest between attempts. Regarding upper body, peak power (Wmax) was assessed with a linear transducer (CLTP, Chronojump, Boscosystem®, Barcelona, Spain) and analyzed with Chronojump Software (v1.8) using a load based on each participant's 1RM. Each subject performed eight repetitions on the bench press exercise without verbal encouragement given. Following the literature (Soriano et al., 2017) the load was set at 50% of the 1RM since it seems closest to optimal for the development of the peak power in the bench press. Only the propulsive concentric phase of the exercise was analyzed. During the whole movement, the subjects had their backs on the bench and their hips flexed at 90°. No bouncing or arching the back was allowed. MBT were evaluated using 3 external loads of 1, 2, and 3 kg. The participants placed themselves behind a line and performed three throws with each of the balls, spaced by 1 min of rest between them. Throws had to be performed with both hands, above the head, without jumping or taking advantage of the momentum of the legs or falling with the feet in front of the throwing line. MBT seem to be useful for testing tennis players as they show high external validity, because they involve the coordination of body segments (i.e., kinetic chain) (Fernández-Fernández et al., 2014). Regarding lower body, CMJ and SJ in order to assess lower body power were performed on a contact platform (Chronojump, Boscosystem®, Barcelona, Spain). Each participant executed three maximum jumps spaced by 45 s of passive rest. The best trial (i.e., highest jump height) was used for the subsequent analysis.

Statistical Analyses

The values presented are expressed as mean ± SD and 95% confidence intervals (95% CI). The normality of the distributions and homogeneity of variances were assessed with the Shapiro–Wilk test, all variables showed normal distributions except for ITN. The reliabilities of test measurements were assessed using intraclass correlation coefficients (ICCs), the standard error of measurements (SEM), and the coefficient of variation (CV). All of stiffness, strength, power and serve, forehand, and backhand velocity measurements reached an acceptable level of reliability and are presented in **Table 1**. Pearson correlation coefficients were used to examine the relations between serve, forehand and backhand velocity and strength, power, and stiffness variables. Strength, power and stiffness

TABLE 1 | Reliability of test measurements.

	ICC (95% CI)	CV (%)	SEM
SJ (cm)	0.889 (0.720–0.956)	3.1	2.3
CMJ (cm)	0.916 (0.787–0.967)	0.5	2.5
1 kg MBT (m)	0.870 (0.693–0.980)	3.1	0.9
2 kg MBT (m)	0.979 (0.956–0.991)	0.4	0.3
3 kg MBT (m)	0.976 (0.950–0.989)	1.3	0.3
WmaxBP (W)	0.915 (0.843–0.961)	3.5	46.1
IsoIR (N)	0.815 (0.544–0.925)	6.4	21.2
IsoAbd (N)	0.923 (0.811–0.969)	2.9	13.4
IsoAdd (N)	0.870 (0.681–0.947)	1.6	21.5
IsoWrF (N)	0.947 (0.869–0.978)	2.5	11.2
IsoWrE (N)	0.935 (0.847–0.973)	1.4	8.6
SV ($km \cdot h^{-1}$)	0.803 (0.183–0.986)	1.1	9.3
FV ($km \cdot h^{-1}$)	0.937 (0.829–0.987)	3.4	7.6
BV ($km \cdot h^{-1}$)	0.900 (0.672–0.988)	1.1	6.5
AbdStiff ($N \cdot m^{-1}$)	0.996 (0.993–0.998)	0.9	6.1
BStiff ($N \cdot m^{-1}$)	0.981 (0.965–0.991)	0.3	3.2
DStiff ($N \cdot m^{-1}$)	0.991 (0.983–0.996)	0.9	5.3
PMStiff ($N \cdot m^{-1}$)	0.992 (0.985–0.996)	0.4	3.6
IStiff ($N \cdot m^{-1}$)	0.956 (0.920–0.979)	0.3	6.5
BFStiff ($N \cdot m^{-1}$)	0.996 (0.992–0.998)	0.5	5.3
RFStiff ($N \cdot m^{-1}$)	0.994 (0.988–0.997)	0.8	4.5
VMStiff ($N \cdot m^{-1}$)	0.988 (0.978–0.994)	0.5	3.3
GStiff ($N \cdot m^{-1}$)	0.998 (0.996–0.999)	0.4	6.2

ICC, intraclass correlation coefficient; CI, confidence interval; CV, coefficient of variation. SEM, standard error of measurement; StV, stroke velocity; SV, serve velocity; FV, forehand velocity; BV, backhand velocity; ITN, international tennis number; IsoIR, maximum isometric internal rotation strength; IsoAdd, maximum isometric adduction strength; IsoAbd, maximum isometric abduction strength; IsoWrF, maximum isometric wrist flexion strength; IsoWrE, maximum isometric wrist extension strength; WmaxBP, peak power bench press; MBT, medicine ball throw; SJ, squat jump; CMJ, countermovement jump; BStiff, biceps stiffness; PMStiff, pectoral majoris stiffness; DStiff, deltoids stiffness; IStiff, infraspinatus stiffness; AbdStiff, rectus abdominis stiffness; BFStiff, biceps femoris stiffness; RFStiff, rectus femoris stiffness; VMStiff, vastus medialis stiffness; GStiff, gastrocnemius stiffness.

variables were correlated with the ITN of the players using Spearman rank order correlation. Correlations were classified as trivial (0–0.1), small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), nearly perfect (0.9), and perfect (1.0) (Hopkins et al., 2009). Statistical significance was accepted at an alpha level of $p \leq 0.05$. All statistical analyses were performed using IBM SPSS Statistics 23.0 (SPSS, Inc., Chicago, IL, United States).

RESULTS

The correlation coefficients between strength, power and StV), and ITN are presented in **Table 2**. Correlations between muscle stiffness values, StV and ITN are presented in **Table 3**. Moderate inverse correlations were found between serve velocity (SV) and ITN ($r = -0.43$; $p = 0.05$), and large positive correlations between ITN and pectoralis majoris stiffness (PMStiff) ($r = 0.53$; $p = 0.01$) and isometric wrist flexion (IsoWrF) ($r = 0.58$; $p = 0.006$). Also, moderate inverse and positive correlations were observed between PMStiff and forehand velocity (FV) ($r = -0.45$; $p = 0.03$) and between gastrocnemius/infraspinatus stiffness (GStiff/IStiff) and SV ($r = 0.45$; $p = 0.04$, $r = 0.42$; $p = 0.05$), respectively. Regarding strength and power values, no significant correlations were found between upper or lower body values and hitting velocities.

TABLE 2 | Strength and power variables and correlation coefficients (r) between maximal stroke velocity and competitive level ($n = 21$).

Variable	Mean performance	Maximal StV§			Competitive level‡
		SV (r)	FV (r)	BV (r)	ITN (r)
SV ($Km \cdot h^{-1}$)	179.5 ± 12	1	0.49†	0.31	−0.43†
FV ($Km \cdot h^{-1}$)	154.3 ± 11.6	0.49†	1	0.15	0.01
BV ($Km\ h^{-1}$)	136.5 ± 7.8	0.31	0.15	1	−0.35
IsoIR (N)	176.8 ± 36.5	0.005	0.003	0.36	0.27
IsoAbd (N)	139.7 ± 33.4	0.15	−0.23	−0.10	0.19
IsoAdd (N)	209.8 ± 47.8	0.31	−0.06	0.16	−0.16
IsoWrF (N)	259.9 ± 68.2	−0.06	0.07	−0.18	0.58†
IsoWrE (N)	161.3 ± 53.1	−0.02	0.06	−0.19	0.28
WmaxBP (W)	503.6 ± 92.6	0.11	0.11	0.04	−0.08
1 kg MBT (m)	12.9 ± 1.5	0.24	0.001	0.16	−0.02
2 kg MBT (m)	9.4 ± 1.4	0.12	−0.05	0.04	0.01
3 kg MBT (m)	7.8 ± 1.2	0.21	0.002	0.01	0.03
SJ (cm)	27.4 ± 5.1	0.15	−0.05	0.30	−0.07
CMJ (cm)	30.1 ± 6.3	0.04	−0.003	0.28	0.35

Values are mean ± SD. § Pearson product moment correlations. ‡Spearman correlation coefficients. StV, stroke velocity; SV, serve velocity; FV, forehand velocity; BV, backhand velocity; ITN, international tennis number; IsoIR, maximum isometric internal rotation strength; IsoAdd, maximum isometric adduction strength; IsoAbd, maximum isometric abduction strength; IsoWrF, maximum isometric wrist flexion strength; IsoWrE, maximum isometric wrist extension strength; WmaxBP, peak power bench press; MBT, medicine ball throw; SJ, squat jump; CMJ, countermovement jump. †$p < 0.05$.

TABLE 3 | Individual muscle stiffness variables and correlation coefficients (r) between maximal stroke velocity and competitive level ($n = 21$).

Variable	Mean performance	Maximal StV§			Competitive level‡
		SV (r)	FV (r)	BV (r)	ITN (r)
BStiff	207.1 ± 21.5	−0.14	−0.21	−0.13	0.31
PMStiff	235.6 ± 39.4	−0.29	−0.45†	−0.16	0.53†
DStiff	223.0 ± 53.4	−0.01	−0.38	−0.16	−0.16
IStiff	246.2 ± 51.1	0.42	0.15	0.16	0.19
AbdStiff	329.6 ± 87.8	−0.11	0.11	−0.10	−0.17
BFStiff	394.9 ± 79.6	0.17	−0.12	0.24	−0.04
RFStiff	318.2 ± 50.5	0.14	−0.07	0.10	−0.07
VMStiff	218.9 ± 30.7	−0.10	−0.22	−0.01	0.03
GStiff	31.5 ± 198.9	0.45†	0.02	−0.06	−0.08

Values are mean ± SD. § Pearson product moment correlations. ‡Spearman correlation coefficients. StV, stroke velocity; SV, serve velocity; FV, forehand velocity; BV, backhand velocity; ITN, international tennis number; BStiff, biceps stiffness; PMStiff, pectoral majoris stiffness; DStiff, deltoids stiffness; IStiff, infraspinatus stiffness; AbdStiff, rectus abdominis stiffness; BFStiff, biceps femoris stiffness; RFStiff, rectus femoris stiffness; VMStiff, vastus medialis stiffness; GStiff, gastrocnemius stiffness. †$p < 0.05$.

DISCUSSION

This study aimed to analyze strength (maximum isometric strength) and power (medicine ball throws, SJ, CMJ, and bench press peak power) characteristics alongside ITN as possible determinants of StV, including serve and groundstrokes, in junior tennis players. The main finding was that an increased gastrocnemius (GStiff), infraspinatus (IStiff), and decreased pectoralis majoris stiffness (PMStiff) may have some positive influence over performance in serve (SV) and forehand velocity (FV) respectively. Also, SV was inversely correlated to ITN. Moreover, strength and power values proved to be weak predictors of StV in this particular sample of junior tennis players. These results indicate that players of these characteristics that are able to reach higher velocity production in the serve and groundstrokes don't specifically rely on the assessed strength and power characteristics.

In other investigations it has been shown that physical aspects such as strength and power are determinant for producing ball velocity (Fett et al., 2018; Palmer et al., 2018), also when comparing players of different levels (Girard et al., 2005; Ulbricht et al., 2016). Non-significant positive results have been found between some physical indicators such as isokinetic strength and SV (Ellenbecker, 1991) but recent findings restate the importance of strength and power characteristics for velocity production on both, national young tennis players (Fett et al., 2018) and highly competitive players (Baiget et al., 2016). These differences in results with the present study could be explained by the variance of the analyzed subjects. The cited investigations carried out assessments with highly skilled players that respond to elite population (Baiget et al., 2016; Fett et al., 2018). Added to the fact that the players participating in this study where of a different level (ITN 2/4 vs. 1/2) than those present in other investigations (Baiget et al., 2016), there could also be an influence due to the age (17.0 ± 0.8 vs. 9.4–17.9 age range) (Fett et al., 2018) of the subjects for contrary results. Younger players may still rely more thoroughly on technique and coordinative skills while serving or hitting rather than on strength values that may become more important as both age and level increases. As suggested in literature, this may indicate that although SV is highly related to tennis performance, velocity production may depend more importantly on strength and power parameters as the player grows and the performance level raises (Girard, 2009).

Studies focused on SV have generally established positive results between MBT and velocity production in young tennis players (Fett et al., 2018). MBT have even been established as fundamental indicators of whole-body explosive power regardless of throwing technique (Fernández-Fernández et al., 2014). Surprisingly, no correlations were found between the overhead MBT and StV in this study. Leaving aside the lack of positive results between MBT and SV, results regarding FV and BV may be explained by methodological issues. MBT testing focused on the overhead motion only, and, although the conducted test assessed three different loads (1, 2, and 3 kg), it did not contemplate mimicking the forehand or the backhand motion (i.e., throwing the medicine ball with one or two hands from the side of the body), as previously studied and found positively correlated with SV (Ulbricht et al., 2016; Fett et al., 2018). On the other hand, consistent with findings in other studies (Kraemer et al., 2003), poor correlations were found for the bench press exercise and either groundstrokes or SV. This, most likely, is explained by the lack of movement similarity and, unlike the MBT testing, the low specificity of the action. Also, muscle involvement in the bench press exercise is reduced to fewer groups than in tennis specific strokes.

Regarding maximal isometric values, no correlations with any of the actions measured were found besides results indicating a positive association between maximal isometric wrist flexion and a higher ITN score. Previous studies have positively correlated isometric strength values with throwing (Ferragut et al., 2011; Freeston et al., 2016) or even tennis specific motions in both, upper and lower body (Fett et al., 2018; Hayes et al., 2018). The findings in this investigation are consistent with those present in other works that found no relation between isometric measurements and tennis actions (Bonato et al., 2015). However, and given that the positions measured are rather different than those focused on the grip, results are surprising. Due to the similarity of the positions tested and those present and involved in the kinetic chain at the wrist, elbow and shoulder, it was expected to obtain certain positive relations between both variables. As literature points out, increased levels of maximal isometric strength, evaluated during multi-joint actions, are likely to be positively related to dynamic performances (Juneja et al., 2010) such as the serve and groundstrokes (Baiget et al., 2016). However, the discrepancy could be explained by the fact that the participants were similar in age but not in level (ITN 1–2 vs. ITN 2–4 or high-performance vs. elite) to those present in other studies (Baiget et al., 2016; Hayes et al., 2018). It would be possible that these players still rely more on coordinative aspects while serving or hitting rather than on strength values that may increase with age and level (Girard, 2009). Moreover, the ability to apply a high amount of force in a short time (i.e., rate of force development) could be of greater importance over absolute values of strength when referring to explosive dynamic actions such as the analyzed strokes.

Lower body power variables analyzed (i.e., SJ and CMJ) did not correlate with any of the StV variables. Although the contribution of the legs is considered widely as one of the main parameters supporting the effectiveness of the kinetic chain (Kibler, 2009), these results indicate that strength values such as explosiveness and power may not be as determinant as coordinative aspects involved in tennis strokes (Bonato et al., 2015; Dossena et al., 2018). Strong consistency has been found in other investigations stating vertical jumps as predictors of sprinting times and lower body strength/power values in tennis players (Kraemer et al., 2003; Girard et al., 2005). Nevertheless, regarding actions such as strokes, this does not seem as clear. As predominantly lower body actions could benefit from enhanced strength and power values, regarding upper body actions such as serves and groundstrokes, legs might provide a coordinative and timing contribution to velocity-production (Bonato et al., 2015; Dossena et al., 2018; Fett et al., 2018).

Regarding muscle stiffness, results indicate moderate positive correlations between GStiff, IStiff and SV, PMStiff, and ITN, and inverse correlations between PMStiff and FV. As far as we know, no previous studies have attempted to correlate individual stiffness values and StV, although in other investigations, some findings indicate the importance of stiffness when we refer to actions that rely on the SSC (Brughelli and Cronin, 2008; Pruyn et al., 2014; Kalkhoven and Watsford, 2018; Sheehan et al., 2018). Generally, literature has found positive evidence linking greater stiffness values to enhanced sprinting or jumping, mainly lower body actions (Brughelli and Cronin, 2008; Kalkhoven and Watsford, 2018). This happens because of the athlete's capacity to store more elastic energy during ground contact and generate greater force output at push-off, increasing jump height and running speed (Brazier et al., 2017). On the other hand, in predominantly upper body motions as tennis strokes, research is scarce. The study carried out by Sheehan et al. (2018), found a strong relationship between vertical stiffness assessed via a unilateral leg hop test and the club head speed in male golfers. When analysing upper body muscle groups, no significant results regarding pectoralis majoris, latissimus dorsi, flexor carpi ulnaris, and club head speed were found. No measurements of vertical stiffness were included in the study design of this investigation, limiting the findings regarding the influence of muscle stiffness of the lower body and its relation to velocity production. Nevertheless, the strong and consistent correlations between stiffness and dynamic performance observed in other investigations (Sheehan et al., 2018), may indicate that greater stiffness values in lower body muscles could be beneficial for performance in motions taking place predominantly in the upper body. In this line, the fact that a higher level of stiffness of the gastrocnemius benefits SV could follow the same idea, as energy storage and transfer from lower to upper body is key for tennis actions (Kibler, 2009). Regarding purely upper body muscle stiffness values, results are similar to those seen in other studies (Sheehan et al., 2018), observing small correlations with StV. Greater levels of PMStiff seem to have a certain negative influence on FV and ITN, suggesting that a greater level of stiffness in the upper body, far from being beneficial could interpose velocity production in junior tennis players. This matches findings in literature (Sheehan et al., 2018), suggesting that tendencies for compliancy might be favorable for motions involving the SSC in the upper body. As complex motor skills such as the tennis groundstrokes rely, among other aspects, on the principle of coordination of individual impulses and an effective kinetic chain (Kibler, 2009, 2014), high levels of upper body stiffness could be counterproductive for these particular actions, affecting execution. Moreover, tightness and increased external rotation when compared to the non-dominant side have been well established as contributors of shoulder internal rotation deficit (Marcondes et al., 2013), which generally can lead to shoulder injury in overhead athletes (Moreno-Pérez et al., 2015). It could be, as it appears when speaking of lower body actions, that an increased or non-sufficient level of stiffness could contribute to a greater injury risk, due to increased shock, peak forces and reduced ROM (Brazier et al., 2017). As a general idea, stiffness values may be beneficial to reduce electromechanical delay and enhance rate of force development, as could be the case of moderate positive correlations found here between IStiff and SV. On the other hand, stiffness could interfere in technical parameters that are key for velocity production in complex tennis strokes and increase injury likelihood due to restrictions in ROM. In any case, this is speculative and additional work is required to state a conclusion on the matter. The fact that stiffness measures were collected individually and in a relaxed state that differs highly with that present during competition may be a reason for generally poor correlations found in this study. Therefore, future investigations may explore upper body stiffness in a more "global" manner, as it has generally been done concerning lower body (i.e., hopping tests) and try to measure muscle stiffness in different contraction regimes.

This study showed some limitations. Maximal speed measurements, especially in groundstrokes, don't take into account technical and tactical aspects on which skilled players may rely on in order to reach greater performance (i.e., spin or shot placement).

PRACTICAL APPLICATIONS

As specific values of stiffness remain unclear, this study suggests practitioners include control and evaluation of stiffness as it may have influence in performance or injury risk. Moreover, due to multiple aspects affecting StV, designing programs that include technical and tactical assessment alongside strength and power enhancement, coordinative training and biomechanical aspects seems essential to enhance velocity production. Performance in these actions are affected by several aspects and the influence of them over StV may vary depending on the athlete's age and level.

CONCLUSION

In conclusion, an increased GStiff and IStiff seem to correlate to greater SV and high values of PMStiff affect negatively the player's FV. Greater stiffness values of the gastrocnemius may enhance StV, possibly supporting power transfer from lower to upper body. On the other hand, enhanced levels in muscles surrounding the shoulder complex could interfere in technical parameters that are key for velocity production in complex tennis strokes. Also, SV is inversely correlated to ITN, indicating that players with a higher number in this rating seem to serve faster. Moreover, strength and power values proved to correlate poorly to StV in this particular sample of junior tennis players. Results indicate that athletes of these characteristics that are able to reach higher velocity production in the serve and groundstrokes don't specifically rely on the assessed strength and power characteristics, possibly due to the multifactorial nature of tennis strokes and the possibility that they become more important as age and level increase.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Catalan Sports Council Research Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JC, EB, and FC contributed to the conceptualization, methodology, and review. EB contributed to the statistical analysis. JC contributed to the writing of the original draft preparation.

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REFERENCES

Baiget, E., Corbi, F., Fuentes, J. P., and Fernández-Fernández, J. (2016). The relationship between maximum isometric strength and ball velocity in the tennis serve. *J. Hum. Kinet.* 53, 63–71. doi: 10.1515/hukin-2016-0028

Bonato, M., Maggioni, M. A., Rossi, C., Rampichini, S., La Torre, A., and Merati, G. (2015). Relationship between anthropometric or functional characteristics and maximal serve velocity in professional tennis players. *J. Sports Med. Phys. Fit.* 55, 1157–1165.

Brazier, J., Maloney, S., Bishop, C., Read, P., and Turner, A. (2017). Lower extremity stiffness: considerations for testing, performance enhancement, and injury risk. *J. Strength Cond. Res.* 33, 1156–1166. doi: 10.1519/JSC.0000000000002283

Brughelli, M., and Cronin, J. (2008). A review of research on the mechanical stiffness in running and jumping: methodology and implications. *Scand. J. Med. Sci. Sport* 18, 417–426. doi: 10.1111/j.1600-0838.2008.00769.x

Cools, A. M., Palmans, T., and Johansson, F. R. (2014). Age-related, sport-specific adaptions of the shoulder girdle in elite adolescent tennis players. *J. Athl. Train* 49, 647–653. doi: 10.4085/1062-6050-49.3.02

Dossena, F., Rossi, C., La Torre, A., and Bonato, M. (2018). The role of lower limbs during tennis serve. *J. Sports Med. Phys. Fit.* 58, 210–215. doi: 10.23736/S0022-4707.16.06685-8

Ellenbecker, T., and Roetert, E. P. (2003). Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *J. Sci. Med. Sport* 6, 63–70. doi: 10.1016/s1440-2440(03)80009-9

Ellenbecker, T. S. (1991). A total arm strength isokinetic profile of highly skilled tennis players. *Isokinet Exerc. Sci.* 1, 9–21. doi: 10.3233/ies-1991-1103

Elliott, B. C., Marshall, R. N., and Noffal, G. J. (1995). Contributions of upper limb segment rotations during the power serve in tennis. *J. Appl. Biomech.* 11, 433–442. doi: 10.1123/jab.11.4.433

Fernández-Fernández, J., Ulbricht, A., and Ferrauti, A. (2014). Fitness testing of tennis players: how valuable is it? *Br. J. Sports Med.* 48(Suppl. 1), i22–i31. doi: 10.1136/bjsports-2013-093152

Ferragut, C., Vila, J. A., Abraldes, F., Argudo, F., Rodriguez, N., and Alcaraz, P. E. (2011). Relationship among maximal grip, throwing velocity and anthropometric parameters in elite water polo players. *J. Sports Med. Phys. Fit.* 51, 26–32.

Fett, J., Ulbricht, A., and Ferrauti, A. (2018). Impact of physical performance and anthropometric characteristics on serve velocity in elite junior tennis players. *J. Strength Cond. Res.* 34, 192–202. doi: 10.1519/JSC.0000000000002641

Freeston, J. L., Carter, T., Whitaker, G., Nicholls, O., and Rooney, K. B. (2016). Strength and power correlates of throwing velocity on subelite male cricket players. *J. Strength Cond. Res.* 30, 1646–1651. doi: 10.1519/jsc.0000000000001246

Freriks, B., Hermens, H., Disselhorst-Klug, C., and Rau, G. (1999). The recommendations for sensors and sensor placement procedures for surface electromyography. *Seniam* 8, 13–54.

Garnacho-Castaño, M. V., López-Lastra, S., and Maté-Muñoz, J. L. (2014). Reliability and validity assessment of a linear position transducer. *J. Sport Sci. Med.* 14, 128–136.

Gillet, E., Leroy, D., Thouvarecq, R., and Stein, J. F. (2009). A notational analysis of elite tennis serve and serve-return strategies on slow surface. *J. Strength Cond. Res.* 23, 532–539. doi: 10.1519/JSC.0b013e31818efe29

Girard, O. (2009). Physical determinants of tennis performance in competitive teenage players. *J. Strength Cond. Res.* 29, 1867–1872. doi: 10.1519/JSC.0b013e3181b3df89

Girard, O., Micallef, J. P., and Millet, G. P. (2005). Lower-limb activity during the power serve in tennis: effects of performance level. *Med. Sci. Sports Exerc.* 37:1021.

Hayes, M. J., Spits, D. R., Watts, D. G., and Kelly, V. G. (2018). The relationship between tennis serve velocity and select performance measures. *J. Strength Cond. Res.* 10. doi: 10.1519/JSC.0000000000002440 [Epub ahead of print].

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41, 3–12.

ITN, (2019). *International Tennis Federation Description of Standards*. Available from: www.tennisplayandstay.com/media/131801/131801.pdf (accessed October 30, 2019).

Jidovtseff, B., Harris, N. K., Crielaard, J. M., and Cronin, J. B. (2011). Using the load-velocity relationship for 1RM prediction. *J. Strength Cond. Res.* 25, 267–270. doi: 10.1519/JSC.0b013e3181b62c5f

Juneja, H., Verma, S. K., and Khanna, G. L. (2010). Isometric strength and its relationship to dynamic performance: a systematic review. *JESP* 6, 60–69.

Kalkhoven, J. T., and Watsford, M. L. (2018). The relationship between mechanical stiffness and athletic performance markers in sub-elite footballers. *J. Sports Sci.* 36, 1022–1029. doi: 10.1080/02640414.2017.1349921

Kibler, B. (2009). The 4000-watt tennis player: power development for tennis. *Med. Sci. Tennis* 14, 5–8.

Kibler, B. (2014). Understanding the kinetic chain. *Aspetar. Sport Med. J.* 3, 492–497.

Konrad, P. (2005). *The ABC of EMG. A Practical Introduction to Kinesiological Electromyography*. Scottsdale, AZ: Noraxon INC.

Kovacs, M., and Ellenbecker, T. (2011). An 8-stage model for evaluating the tennis serve: implications for performance enhancement and injury prevention. *Sports Health* 3, 504–513. doi: 10.1177/1941738111414175

Kraemer, W. J., Hakkinen, K., Triplett-Mcbride, N. T., Fry, A. C., Koziris, L. P., Ratamess, N. A., et al. (2003). Physiological changes with periodized tennis players. *Med. Sci. Sports Exerc.;* 35, 157–168.

Landlinger, J., Stöggl, T., Lindinger, S., Wagner, H., and Müller, E. (2012). Differences in ball speed and accuracy of tennis groundstrokes between elite and high-performance players. *Eur. J. Sport Sci.* 12, 301–308. doi: 10.1080/17461391.2011.566363

Marcondes, F. B., Jesus, J. F., de Bryk, F. F., Vasconcelos, R. A., and Fukuda, T. Y. (2013). Posterior shoulder tightness and rotator cuff strength assessments in painful shoulders of amateur tennis players. *Brazi. J. Phys. Ther.* 17, 185–193. doi: 10.1590/S1413-35552012005000079

Moreno-Pérez, V., Moreside, J., Barbado, D., and Vera-Garcia, F. J. (2015). Comparison of shoulder rotation range of motion in professional tennis players with and without history of shoulder pain. *Man Ther.* 20, 313–318. doi: 10.1016/j.math.2014.10.008

Palmer, K., Jones, D., Morgan, C., and Zeppieri, G. (2018). Relationship between range of motion, strength, motor control, power, and the tennis serve in competitive-level tennis players: a pilot study. *Sports Health* 10, 462–467. doi: 10.1177/1941738118785348

Pruyn, E., Watsford, M., and Murphy, A. (2014). The relationship between lower-body stiffness and dynamic performance. *Appl. Physiol. Nutr. Metab.* 39, 1144–1150. doi: 10.1139/apnm-2014-0063

Roetert, E. P., Ellenbecker, T. S., and Reid, M. (2009a). Biomechanics of the tennis serve: implications for strength training. *Strength Cond J.* 31, 35–40. doi: 10.1519/ssc.0b013e3181af65e1

Roetert, E. P., Kovacs, M., Knudson, D., and Groppel, J. (2009b). Biomechanics of the tennis groundstrokes: implications for strength training. *Strength Cond. J.* 31, 41–49. doi: 10.1519/ssc.0b013e3181aff0c3

Sanchís-Moysi, J., Olmedillas, H., Guadalupe-Grau, A., Alayón, S., Carreras, A., Dorado, C., et al. (2010). The upper extremity of the professional tennis player: muscle volume, fiber-type distribution and muscle strength. *Scand. J. Med. Sci. Sports* 20, 524–534. doi: 10.1111/j.1600-0838.2009.00969.x

Sheehan, W. B., Watsford, M. L., and Pickering Rodriguez, E. C. (2018). Examination of the neuromechanical factors contributing to golf swing performance. *J. Sports Sci.* 37, 458–466. doi: 10.1080/02640414.2018.1505185

Söğüt, M. (2014). Ball speed during the tennis serve in relation to skill level and body height. *Pamukkale J. Sport Sci.* 7, 51–57.

Soriano, M. A., Suchomel, T. J., and Marín, P. J. (2017). The optimal load for maximal power production during upper-body resistance exercises: a meta-analysis. *Sport Med.* 47, 757–768. doi: 10.1007/s40279-016-0626-6

Ulbricht, A., Fernandez-Fernandez, J., Mendez-Villanueva, A., and Ferrauti, A. (2016). Impact of fitness characteristics on tennis performance in elite junior tennis players. *J. Strength Cond. Res.* 30, 989–998. doi: 10.1519/JSC.0000000000001267

Zinder, S. M., and Padua, D. A. (2013). Reliability, validity, and precision of a handheld myometer for assessing in vivo muscle stiffness. *J. Sport Rehabil.* 20, 1–8.

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Evolutionary Trends of Players' Technical Characteristics in the UEFA Champions League

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The current study aimed to investigate the evolutionary trends of players' technical performances in the UEFA Champions League. Match statistics of 18 technical performance indicators from 1,125 matches (2,489 players, 16,247 full match observations) from the group and knockout stages of the UEFA Champions League (season 2009/2010 to 2017/2018) were analysed. Separate Poisson regression models were run in the generalised mixed linear modelling to compare the differences in technical performances among seasons, and the autocorrelation function was used to identify the correlations within technical variables. Results demonstrated that players' match performances in variables of shots and shots on target showed trivial changes over the nine seasons. The defending related variables showed either downward trends or negligible changes, and the passing- and attacking-related variables showed different evolving paths throughout the course of the nine seasons. These findings may indicate that European teams are now more focussed on the control of match play, creating offensive space by increasing passing frequency and accuracy rather than crossing the ball from the wings into the penalty box. The significant autocorrelations were only detected in the attacking- and passing-related variables of crossing, though ball and aerial wins, they displayed persistence patterns among the nine seasons.

Keywords: football, soccer, performance analysis, technical evolution, UEFA Champions League

INTRODUCTION

Football matches are characterised by high dynamicity (Garganta, 2009) where the players' adapt their behaviours in the continuous performer–environment interactions (Barreira et al., 2015; Aquino et al., 2017b). Thus, the variability of players' match performances can be observed and assessed between matches (Bush et al., 2015a; Liu et al., 2016a). The within-season variation was observed at a low level (Morgans et al., 2014), but when putting it in a larger timeframe, the playing patterns of football matches have undergone substantial changes over the past seasons and will continue to evolve due to the interaction of external factors (Bush et al., 2015b) and intrinsic variation within the human movement (Gonçalves et al., 2014). The modification of playing rules, the innovation of tactics, and the advancement of technical and physical preparation have been reported as the main external contributors of the longitudinal performance changes (Barnes et al., 2014; Wallace and Norton, 2014). Nevertheless, in addition to the causes of performance evolution, it is also important to figure out how the playing patterns evolve during a given period. The patterns of match play can be described by a selection of match actions and events that could be valid measurements of various aspects of match performance (O'Donoghue, 2009; McGarry et al., 2013). Naturally, tracking the longitudinal changes of performance parameters may provide a valid way to interpret and quantify the evolution of playing patterns. Furthermore, technical parameters have been identified to be related to the match outcome (Castellano et al., 2012; Liu et al., 2016b). Therefore, the investigation of the evolutionary trends of technical parameters allows the understanding of how coaches find the secret to succeed in a match.

To date, literature about the evolution of technical parameters is well documented. Williams et al. (1999) reported that players from the top tier of English football performed more passes, dribbles, and crosses during the period of season 1991/1992 and 1997/1998. Subsequent research from Barnes et al. (2014) in the English Premier League found that the total number of passes made by players per match increased by 40% and the number of short and medium passes increased, but long passes varied little across the timeframe of the study (season 2006/2007–2012/2013). Furthermore, more detailed research has also been conducted that attempts to identify the long-term trends of the technical characteristics in European domestic leagues considering the effects of playing positions (Bush et al., 2015b), team quality (Bradley et al., 2016), player identity (Bush et al., 2017), and match outcome (Konefał et al., 2019). However, each national league was characterised by different specificities and behaviours of match play (Dellal et al., 2011; Oberstone, 2011). Thus, the identified evolutionary dynamics of the match performance in a specific domestic league cannot represent all evolving trends of match play in modern football. A previous study Wallace and Norton (2014) analysed the evolution of match play in an international competition (FIFA World Cup) over a 44 year period. The research focussed on the longitudinal changes of the game structure, speed, and play patterns rather than the evolution of technical parameters.

However, limited technical performance parameters were analysed in the abovementioned literature, and the studies were mainly focussed on passing related parameters. These findings may provide limited information of the overall evolutionary process of players and teams' performance. Furthermore, in addition to the comparison of technical performance among seasons, the evolving trends of match play could also be identified by the measure of the correlations of technical match actions and events among seasons (Yi et al., 2019a). The autocorrelation function (ACF) has been reported as a valid measure (temporal series) to assess the dynamic correlations among a time series (Prieto et al., 2016). This dynamic time-dependent approach may provide a novel insight to assess the temporal relationships within technical variables in a specific period of time.

The UEFA Champions League is considered to be one of the top international competitions and the participating teams are top squads from all over Europe, leading the latest trends in modern football (Liu et al., 2015). Coaches and performance analysts from these teams have been devoted to the innovation of tactics and strategies in order to improve the players' match performance (Memmert and Rein, 2018). The results from the previous studies revealed the temporal changes over a specific period, but the playing patterns of football matches evolve over time; more recent changes need to be identified based on the latest database to describe the contemporary trends of the football match. Therefore, the current study aims to explore the evolutionary trends of players' technical parameters in the UEFA Champions League from season 2009/2010 to 2017/2018 and provide a comprehensive understanding of how the technical characteristics evolve in modern football incorporating the match performance of players from different European countries in goal scoring, attacking, passing, and defending aspects.

MATERIALS AND METHODS

Data Source and Reliability

Technical match performance data of players in the UEFA Champions League across nine consecutive seasons (2009/2010–2017/2018) were acquired from a public-accessed football statistic website called "whoscored.com,[1]" whose data have been considered highly reliable and were used in previous studies (Liu et al., 2015; Yi et al., 2019b), as the data provider is the OPTA Sports. The inter-operator reliability of the tracking system (OPTA Client System) has been previously verified (*Kappa* values > 0.90) with high consistency when repeatedly coding the match actions and events (Liu et al., 2013). The study design and procedures were in accordance with the Declaration of Helsinki and approved by the ethics committee of the local university.

Sample and Technical Parameters

The sample of this study comprises the technical match statistics of 125 matches per season (total matches analysed = 1,125 matches; 2,489 players; and 16,247 players' observations) in the group stage and knockout stage of the UEFA Champions League from season 2009/2010 to 2017/2018 (n = 1,808; n = 1,832; n = 1,796; n = 1,800; n = 1,793; n = 1,796; n = 1,809; n = 1,803; and n = 1,810 players' observations, respectively). Only the outfield players that played at least one full match were included for further analysis to make sure that match observations could be analysed upon the same time dimension. Eighteen technical performance-related actions and events were analysed and classified into three groups of variables (goal scoring, attacking and passing, and defending) in the analysis referring to the previous studies (Lago-Peñas et al., 2010; Liu et al., 2015; Yi et al., 2019b). The grouping information and operational definitions of these technical variables are in **Table 1**.

Statistical Analysis

Separate Poisson regressions were run in the generalised mixed linear modelling performing with *Proc Glimmix* in the University Edition of Statistical Analysis System (version SAS Studio 3.6) used to examine both the differences in technical variables

[1] https://www.whoscored.com

TABLE 1 | Selected technical performance-related match events and actions.

Groups	Event or action: operational definition
Variables related to goal scoring	Shot: an attempt to score a goal, made with any (legal) part of the body, either on or off target
	Shot on target: an attempt to goal which required intervention to stop it going in or resulted in a goal/shot which would go in without being diverted
Variables related to passing and organising	Touch: a sum of count values of all actions and events where a player touches the ball
	Pass: an intentional played ball from one player to another
	Pass accuracy (%): successful passes as a proportion of total passes
	Key pass: the final pass or cross leading to the recipient of the ball having an attempt at goal without scoring
	Cross: any ball sent into the opposition team's area from a wide position
	Long ball: an attempted pass of 25 yards or more
	Through ball: a pass that split the last line of defense and plays the teammate through on goal
	Dribble: a dribble is an attempt by a player to beat an opponent in possession of the ball. OPTA also log attempted dribbles where the player overruns the ball
	Aerial won: two players competing for a ball in the air, for it to be an aerial duel both players must jump and challenge each other in the air and have both feet off the ground. The player who wins the duel gets the *Aerial won*, and the player who does not gets an *Aerial lost*
	Fouled: where a player is fouled by an opponent
	Offside: awarded to the player deemed to be in an offside position where a free kick is awarded. If two or more players are in an offside position when the pass is played, the player considered to be most active and trying to play the ball is given offside.
Variables related to defending	Tackle: the action of gaining possession from an opposition player who is in possession of the ball
	Interception: a player intercepts a pass with some movement or reading of the play
	Clearance: attempt made by a player to get the ball out of the danger zone, when there is pressure (from opponents) on him to clear the ball
	Foul: any infringement that is penalised as foul play by a referee
	Yellow card: where a player was shown a yellow card by the referee for reasons of foul, persistent infringement, hand ball, dangerous play, etc.

between seasons and the localised differences verified. The value of each of the 18 technical performance-related variables was selected as the dependent variable (Yi et al., 2019c). The fixed effects estimated the effects of match location (home, away, and neutral), competition stage (group stage and knock-out stage), match outcome (win, draw, and loss) and playing position (central defender, full back, central midfielder, wide midfielder, and forward), as well as the team and opponent strength estimated by including the difference in the log of the end-of-season UEFA club coefficient as a predictor (Yi et al., 2018). The player identity was employed as the random effect to account for the repeated-measure data acquired from players in multiple matches across seasons.

Autocorrelation function was employed to quantify the correlations of a technical variable among a time series of nine seasons with its own values (Yi et al., 2019a). The statistical software IBM SPSS version 25 for Windows (IBM Corp., Armonk, NY, United States) was used for the analysis. The ACF was calculated with a lag length of one season, and seven lags were chosen according to the length of the time series. There was no time-offset if lag = 0. The magnitude of the absolute value of ACF was assessed qualitatively with the following scales: <0.1 trivial, 0.1–0.3 small, 0.3–0.5 moderate, 0.5–0.7 large, 0.7–0.9 very large, >0.9 nearly perfect (Hopkins, 2002). Statistical significance was set at $P \leq 0.5$.

Uncertainty in the true effects of the predictors was evaluated by a combination of null hypothesis significance testing (P-value) and non-clinical magnitude-based inference. An implemented spreadsheet accompanying the package of materials for generalised mixed modelling with SAS Studio was used for the evaluation (Hopkins, 2016). The magnitude of meaningful difference and the 90% confidence limit were expressed in standardised units, and a standardised effect of 0.2 and −0.2 were assumed to be the smallest worthwhile differences. Effect were considered clear if the 90% confidence limit of the effect size did not affect the smallest worthwhile differences of 0.2 and −0.2 simultaneously. Estimated magnitudes of effect sizes were quantified by the following scales: <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, and 1.2–2.0 large (Hopkins et al., 2009), along with a qualitative likelihood of the clear effects: <0.5%, most unlikely; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; and >99.5%, most likely (Hopkins et al., 2009).

RESULTS

Goal Scoring Related Variables

The number of shots and shots on target showed trivial differences across nine seasons ($p < 0.9685$; effect size (ES) = −0.16, 0.1; likelihood: likely-most likely); shots on target observed a relatively greater fluctuation (see **Figure 1**). There were no clear correlations for these variables over the same period of time (ACF = -0.072 ± 0.215, -0.068 ± 0.191; $P = 0.52$, 0.575) (see **Table 2**).

Attacking and Passing Related Variables

Similar changing trends were observed among touches, passes, and pass accuracy (%) during the timeframe of this study. There were simultaneous increases between season 2009/2010 and 2010/2011 (52.76 ± 18.01vs. 56.03 ± 18.76, 36.02 ± 16.32 vs. 39.54 ± 17.36, 77.96 ± 9.87 vs. 79.37 ± 9.99; $P < 0.0001$; ES = 0.18, 0.21, 0.14; likelihood: possibly, possibly, and very likely), which then remained relatively steady until season 2016/2017, where the significant increases were appealed again peaking at season 2017/2018 (64.06 ± 20.56, 45.20 ± 19.01, 81.59 ± 10.16), although trivial increases for pass and pass accuracy were observed between season 2015–2016 and 2016–2017 (40.99 ± 17.79 vs. 42.45 ± 18.21, 79.74 ± 10.03 vs. 80.41 ± 10.07; $P = 0.0033$ and 0.147; ES = 0.08, 0.05; likelihood:

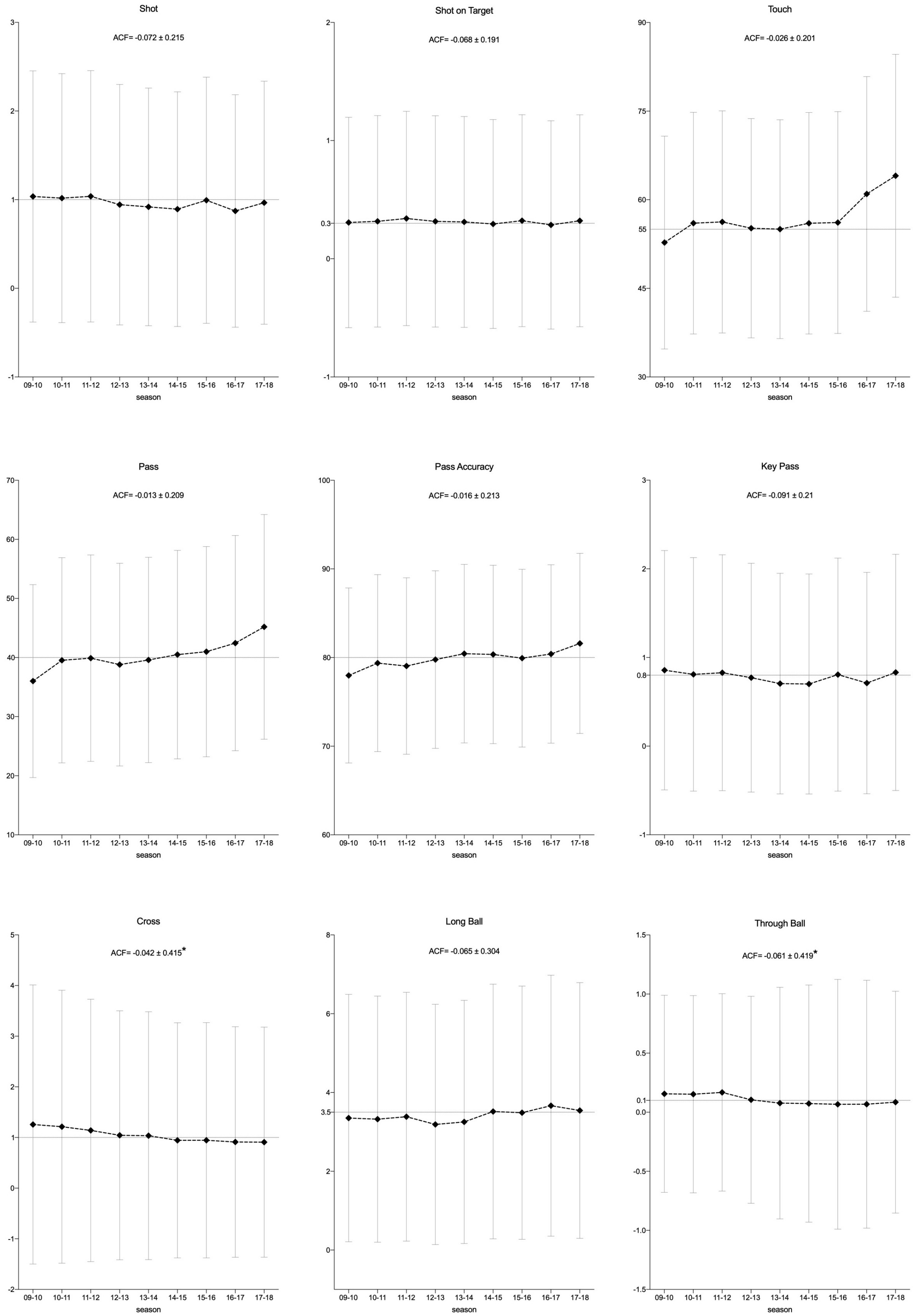

FIGURE 1 | Continued

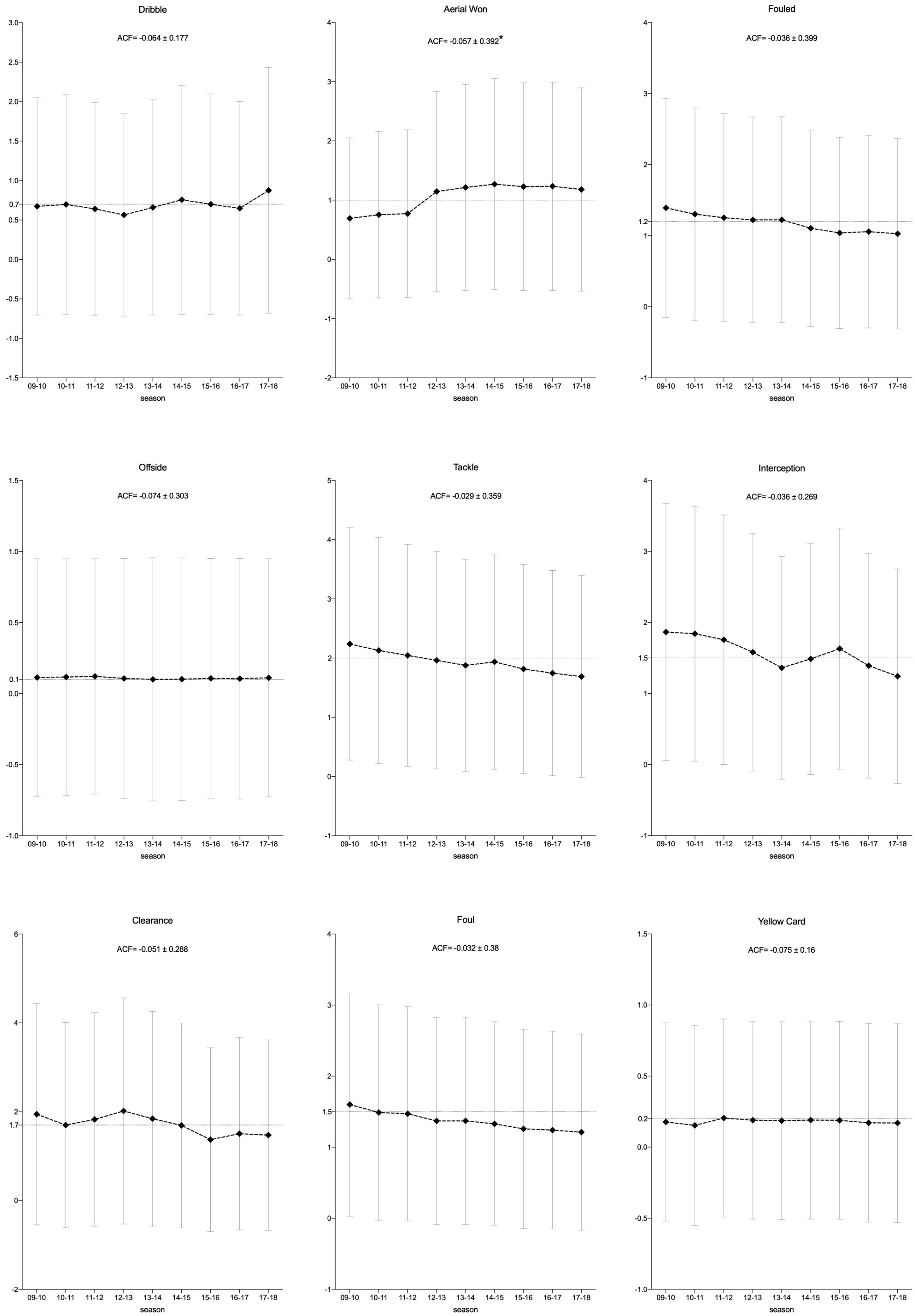

FIGURE 1 | Temporal changes of each technical performance indicators from season 2009/2010 to 2017/2018. Black dot and error bar indicate the mean value and standard deviation, respectively. Value of ACF is presented as mean value of 7 lags with the form of mean ± standard deviation. Asterisk indicate the statistical significance.

TABLE 2 | Descriptive statistics of technical match performance of players in the UEFA Champions League from season 2009/10 to 2017/18.

Variable	**Season**									**Total**
	2009–2010 (*n* = 1,808)	**2010–2011 (*n* = 1,832)**	**2011–2012 (*n* = 1,796)**	**2012–2013 (*n* = 1,800)**	**2013–2014 (*n* = 1,793)**	**2014–2015 (*n* = 1,796)**	**2015–2016 (*n* = 1,809)**	**2016–2017 (*n* = 1,803)**	**2017–2018 (*n* = 1,810)**	**(*n* = 16,247)**
Shot	1.04 ± 1.42	1.02 ± 1.41	1.04 ± 1.42	0.94 ± 1.36	0.92 ± 1.34	0.89 ± 1.32	0.99 ± 1.39	0.87 ± 1.31	0.97 ± 1.37	1.15 ± 1.54
Shot on Target	0.31 ± 0.89	0.32 ± 0.89	0.34 ± 0.91	0.32 ± 0.89	0.31 ± 0.89	0.29 ± 0.88	0.32 ± 0.90	0.29 ± 0.88	0.32 ± 0.90	0.40 ± 0.79
Touch	52.76 ± 18.01	56.03 ± 18.76	56.25 ± 18.81	55.19 ± 18.57	55.02 ± 18.53	56.02 ± 18.75	56.13 ± 18.78	60.97 ± 19.87	64.06 ± 20.56	62.15 ± 22.18
Pass	36.02 ± 16.32	39.54 ± 17.36	39.90 ± 17.47	38.80 ± 17.14	39.59 ± 17.38	40.50 ± 17.64	40.99 ± 17.79	42.45 ± 18.21	45.20 ± 19.01	46.27 ± 21.41
Pass Accuracy (%)	77.98 ± 9.87	79.37 ± 9.99	79.04 ± 9.96	79.78 ± 10.02	80.44 ± 10.07	80.35 ± 10.06	79.94 ± 10.03	80.41 ± 10.07	81.59 ± 10.16	81.50 ± 10.28
Key Pass	0.86 ± 1.35	0.81 ± 1.32	0.83 ± 1.33	0.77 ± 1.29	0.71 ± 1.24	0.70 ± 1.24	0.81 ± 1.32	0.71 ± 1.25	0.83 ± 1.33	0.89 ± 1.22
Cross	1.26 ± 2.75	1.21 ± 2.69	1.14 ± 2.59	1.04 ± 2.46	1.04 ± 2.45	0.94 ± 2.32	0.95 ± 2.32	0.91 ± 2.28	0.91 ± 2.27	1.76 ± 2.59
Long Ball	3.35 ± 3.14	3.32 ± 3.13	3.38 ± 3.16	3.19 ± 3.05	3.25 ± 3.09	3.52 ± 3.23	3.49 ± 3.21	3.67 ± 3.31	3.54 ± 3.25	4.58 ± 3.78
Through Ball	0.16 ± 0.83	0.15 ± 0.83	0.17 ± 0.84	0.11 ± 0.88	0.08 ± 0.98	0.07 ± 1.00	0.07 ± 1.06	0.07 ± 1.05	0.08 ± 0.94	0.22 ± 0.62
Dribble	0.67 ± 1.38	0.70 ± 1.40	0.64 ± 1.35	0.56 ± 1.28	0.66 ± 1.36	0.76 ± 1.45	0.70 ± 1.40	0.65 ± 1.35	0.88 ± 1.56	0.85 ± 1.34
Aerial Won	0.69 ± 1.36	0.75 ± 1.40	0.77 ± 1.42	1.15 ± 1.69	1.22 ± 1.74	1.27 ± 1.78	1.23 ± 1.75	1.24 ± 1.76	1.18 ± 1.72	1.18 ± 1.50
Fouled	1.39 ± 1.54	1.30 ± 1.49	1.25 ± 1.46	1.22 ± 1.45	1.22 ± 1.45	1.11 ± 1.38	1.04 ± 1.35	1.06 ± 1.36	1.03 ± 1.34	1.16 ± 1.27
Offside	0.11 ± 0.84	0.12 ± 0.83	0.12 ± 0.83	0.11 ± 0.84	0.10 ± 0.86	0.10 ± 0.85	0.11 ± 0.84	0.11 ± 0.85	0.11 ± 0.84	0.20 ± 0.58
Tackle	2.24 ± 1.96	2.13 ± 1.91	2.05 ± 1.87	1.96 ± 1.84	1.88 ± 1.80	1.94 ± 1.82	1.82 ± 1.77	1.75 ± 1.73	1.69 ± 1.71	2.07 ± 1.78
Interception	1.86 ± 1.81	1.84 ± 1.79	1.76 ± 1.76	1.58 ± 1.67	1.36 ± 1.57	1.49 ± 1.63	1.63 ± 1.70	1.39 ± 1.58	1.24 ± 1.51	1.89 ± 1.72
Clearance	1.94 ± 2.49	1.70 ± 2.31	1.83 ± 2.41	2.02 ± 2.55	1.84 ± 2.42	1.69 ± 2.31	1.37 ± 2.07	1.50 ± 2.17	1.47 ± 2.14	2.67 ± 3.04
Foul	1.60 ± 1.57	1.49 ± 1.52	1.47 ± 1.51	1.37 ± 1.46	1.37 ± 1.46	1.33 ± 1.44	1.26 ± 1.40	1.24 ± 1.39	1.21 ± 1.38	1.27 ± 1.26
Yellow Card	0.18 ± 0.70	0.15 ± 0.70	0.20 ± 0.70	0.19 ± 0.70	0.19 ± 0.70	0.19 ± 0.70	0.19 ± 0.70	0.17 ± 0.70	0.17 ± 0.70	0.18 ± 0.38

n denotes the number of players' observations. Results are presented as the form of mean ± standard deviation, representing the average value that players achieved in a full match. Units are counts, except for pass accuracy. The average value was calculated dividing the total number of actions by the number of players' observations.

most likely and most likely). The players' match performances in crosses and fouls presented downward trends over the nine seasons. Even though the differences among most of the seasons were trivial, the number of crosses and fouls of players obtained per match decreased from 1.26 ± 2.75 and 1.39 ± 1.54 in 2009/2010 to 0.91 ± 2.27 and 1.03 ± 1.34 in 2017/2018 ($P < 0.0001$; ES = −0.21, −0.32; likelihood: possibly, most likely). The longitudinal changes in through ball and aerial wins showed opposite trends; there was a pronounced decrease for through ball and an increase for aerial wins in season 2012/2013 compared to season 2011/2012 (0.17 ± 0.84 vs. 0.11 ± 0.88, 0.77 ± 1.42 vs. 1.15 ± 1.69; $P < 0.0001$; ES = −0.20, 0.29; likelihood: possibly, most likely). Afterwards, both showed negligible changes over following seasons. The number of dribbles varied little within season 2009/2010 and 2016/2017, while it significantly increased by 35% between season 2016/2017 and 2017/2018 (0.65 ± 1.35 vs. 0.88 ± 1.56; $P < 0.0001$; ES = 0.20; likelihood: possibly). Players' match performances in key passes, long balls, and offsides varied by trivial magnitudes across the nine seasons ($P < 0.9916$; ES = −0.16, 0.16; likelihood: likely-most likely).

Concerning the inter-variable correlations among the nine seasons, the statistical significance was only observed in cross, through ball, and aerial wins (ACF = −0.042 ± 0.415, −0.061 ± 0.419, −0.057 ± 0.392; P = 0.036, 0.021, 0.033) showing trivial negative correlations among seasons.

Defending Related Variables

Continued momentum of decline can be found in the number of tackles and fouls of players performed per match, declining from 2.24 ± 1.96, 1.60 ± 1.57 in season 2009/2010 to 1.69 ± 1.71, 1.21 ± 1.38 in season 2017/2018 ($P < 0.0001$; ES = −0.36, −0.32; likelihood: most likely, most likely). Although there were also general declining trends in interception and clearance, they experienced fluctuations during the nine seasons. Players achieved more interceptions and clearances ($P < 0.0001$; ES: −0.47, −0.26; likelihood: most likely, likely) in season 2009/2010 (1.86 ± 1.81; 1.94 ± 2.49) compared to season 2017/2018 (1.24 ± 1.51; 1.47 ± 2.14), peaking at season 2009/2010 (1.86 ± 1.81) and 2012/2013 (2.02 ± 2.55), respectively. Players showed a relatively stable match performance in yellow cards among these nine seasons ($P < 0.9875$; ES = −0.10, −0.13; likelihood: very likely-most likely). All defending related variables showed non-clear correlations during the studied period of time (ACF = −0.075 ± 0.16 to −0.029 ± 0.359; P = 0.079–0.784).

DISCUSSION

The current study quantified the long-term trends of technical performance indicators among seasons aiming to identify the contemporary evolution of players' technical characteristics based on the latest nine seasons of the UEFA Champions League. The evolutional process of 18 technical performance related indicators regarding goal scoring, attacking and passing, and defending aspects have been demonstrated. The effects of situational factors and positional roles were controlled by the modelling to deal with the intrinsic variation within matches.

Coaches and performance analysts have been trying to find ways to increase the scoring opportunities and improve the efficiency over years, so the increase in relevant match statistics, therefore, might be expected. However, our research on the players from the UEFA Champions League demonstrated that their match performances in variables of shots and shots on target showed trivial changes over the last nine seasons. This finding is in line with a study on the English Premier League from Barnes et al. (2014) in which the evolutionary trends of players' technical performance were identified based on a period of seven consecutive seasons. Nevertheless, opposite changes were observed in Germany's Bundesliga, the number of total shots decreased among playing positions during season 2014/2015 to 2016/2017 (Konefał et al., 2019). This disparity may be due to the relatively smaller database used (three seasons); the identified longitudinal performance characteristics cannot be compared with the seven-season and nine-season period studies. The results among studies may be more consistent by expanding the timeframe of the study on the German Bundesliga.

Although the number of shots and shots on target varied little, the number of touches and passes players performed per match increased over the last nine seasons. This trend partly contrasts with the research by Tenga et al. (2010) who argued that longer passing sequences could produce more shots per possession. This may indicate that the increase in the frequency of passes cannot directly bring more scoring opportunities, the ability of creating offensive space and sending the ball into the scoring area may play an important role (Collet, 2013). This statement could be supported by the changes of key pass and through balls as these two match performance indicators can describe the key situations during match play. The evolving technical characteristics of the increase of passing frequency may possibly be driven by the prevalence of possession play (Aquino et al., 2017a; Yi et al., 2019b), whereas how to decrease unwanted passes and improve offensive efficiency are key issues for teams that employ this tactical approach to consider during the coaching process (Alves et al., 2019). These evolving trends are further supported by the changes in the number of crosses and long balls. These variables showed a relentless decline and a limited fluctuation, respectively, among nine seasons, which means that players performed more short passes and medium passes, so the pass accuracy was increased accordingly. Similar findings were reported in a previous study on the English Premier League (Barnes et al., 2014). This indicates that the passing tempo increased during the period of nine seasons and teams tended to play a more elaborate match.

The changes of passing actions may also influence players' performance in attacking behaviours. The players' stable performance in offside could be considered as a result of the minimal changes of the key pass and through balls over the same period, as these two technical performance indicators are usually associated with the offside situations. The number of key passes fluctuated within a narrow range, and the mean number of through balls players achieved per match remained at a relatively low level, although there was a clear decrease in season 2012/2013. Combining this result with the feature of the occurrence rate of offsides during a match may explain the low variation of offsides over the nine seasons. Another concern is that the number of crosses continuously decreased and the number of long balls slightly changed among the period of nine seasons, while the percentage of the aerial wins observed a significant increase, especially from the season 2012/2013. This result is in line with the study of Konefał et al. (2019) on the German Bundesliga. As the aerial duels usually occurred from crosses and long balls (Liu et al., 2016a), our findings may indicate that the decrease of the crosses has a negative impact on the appearance of the aerial duels. However, this finding should be interpreted with caution, because the underlying causes need to be verified and more insight is needed to interpret the substantial increase in the last six seasons.

The occurrence frequency of dribbling was relatively stable in the first eight seasons and then suddenly increased in the last season. This finding is not in accordance with the research made by Williams et al. (1999), who reported that the incidence of dribbling in the English league increased from season 1991/1992 to 1997/1998. Future research is needed given that dribbling is an important performance indicator explaining players' technical characteristics and tactical roles during match play. Another interesting finding of our analysis is that the number of players who were fouled during a match showed a steady decline during the timeframe of the current study. Together with the findings in defensive performance indicators, the number of tackles and fouls also showed a similar downward trend and the number of yellow cards remained stable among the nine seasons. These findings support the notion of Oberstone (2011) that players played football more cleanly. The modification of rules could be one of the potential reasons for this data. The rules of the game are being tweaked over time as the lawmakers continue to figure out the best way to regulate the behaviour of players on the pitch, especially in controversial and confrontational situations involving opponents or match officials. The downward trends could also be found in the number of interceptions and clearances, even though fluctuations were seen. These findings may reflect the way teams' defence has changed over time, rather than the retrogress of players' defensive abilities. The defensive manners of teams are evolving in the direction of joint actions, which can improve the effectiveness of the defence.

Autocorrelation functions of technical variables provide important understanding from another perspective to depict how playing patterns evolve. A prior study investigated the long-term trends of the variation of technical variables in the UEFA Champions League and reported that the variation of through balls displayed trivial negative autocorrelation throughout a time period of eight seasons (2009/2010–2016/2017) (Yi et al., 2019a). This finding was also identified in the current study, where crosses, through balls, and aerial wins showed substantial negative correlations among nine seasons, while the temporal relationships within other variables have not been detected. The lower ACF value indicates less persistence among a time series (Prieto et al., 2017). However, the magnitudes of the autocorrelations were trivial, which may still provide useful insights about the patterns of these three variables to describe the dynamic trends of technical performances. These findings may mean that the more unstable the performance of the players in the form of crosses, through balls, and aerial duels won in a season, the more stable the performance could be of these variables in the following season. Thus, these susceptible variables should be treated by coaches with care.

CONCLUSION

The current study investigated the evolving patterns of players' technical performance indicators based on a dataset of nine seasons from the UEFA Champions League. Disparities exist in the evolutionary patterns between technical performance indicators of goal scoring, passing, organising, and defending. Players performed an increasing number of passes per match, especially short passes, with no change in the number of shots and shots on target. Teams are now more focussed on controlling the match and creating offensive space by increasing the passing frequency and accuracy, rather than crossing the ball from the wings into the penalty box. However, the progression of the ability of creating scoring opportunities was not observed and the success rate of aerial duel increased. We also found that all defending related indicators did not show upward trends during the nine seasons. The number of players who were fouled decreased during the match and teams organised their defence collectively in a group-tactical way to enhance the effectiveness of defensive actions. Besides, only the attacking and passing related variables of crosses, through balls, and aerial wins demonstrated a certain degree of persistence over the nine seasons.

Practical Applications

We tracked the temporal trends of the technical match performances of contemporary elite football and the longitudinal changes were quantified across a period of nine seasons. We provided important evidence to explain how and why the technical aspect of match-play evolve. The identified evolving characteristics could provide a holistic understanding for coaches and performance analysts to fine-tune their performance knowledge about the matches in the UEFA Champions League. The key performance indicators such as shots on target, key passes, and through balls should be treated with care; special interventions are needed to improve players' match performance towards these indicators. Teams could also diagnose and optimise their tactics and strategies according to the identified trends. For example, the current study reported that the number of passes increased while the number of crosses decreased, which may provide references for teams in the disposition of defensive tactics. However, this study failed to consider the effects of playing positions and situational variables, thus some important information was masked as the differences exist in players' tactical roles and duties and in the technical behaviours when playing in different situations. Future research regarding the investigation of evolving trends of technical indicators should take players' positions on the pitch and the competing situations into account, which may contribute to more practical insights. Moreover, further research is needed to explore the causative factors underlying the temporal changes in players' technical performance. The modification of rules, the improvement of skill execution, and the innovation of tactics may help to explain the dynamic changes.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Shanghai University of Sport. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

QY, M-ÁG, and HL: conceptualisation and methodology. HL: software. QY: data collection, writing – original draft preparation, visualisation, and funding acquisition. HL, GN, and M-ÁG: writing – review and editing and supervision.

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REFERENCES

Alves, D. L., Osiecki, R., Palumbo, D. P., Moiano-Junior, J. V., Oneda, G., and Cruz, R. (2019). What variables can differentiate winning and losing teams in the group and final stages of the 2018 FIFA World Cup? *Int. J. Perform. Anal. Sport* 19, 248–257. doi: 10.1080/24748668.2019.1593096

Aquino, R., Manechini, J. P., Bedo, B. L., Puggina, E. F., and Garganta, J. (2017a). Effects of match situaional variables on possession: the case of England Premier League season 2015/16. *Motriz* 23:3.

Aquino, R., Puggina, E. F., Alves, I. S., and Garganta, J. (2017b). Skill-related performance in soccer: a systematic review. *Hum. Mov.* 18, 3–24.

Barnes, C., Archer, D. T., Hogg, B., Bush, M., and Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *Int. J. Sports Med.* 35, 1095–1100. doi: 10.1055/s-0034-1375695

Barreira, D., Garganta, J., Castellano, J., Machado, J., and Anguera, M. T. (2015). How elite-level soccer dynamics has evolved over the last three decades?: input from generalizability theory. *Cuadernos Psicol. Deporte* 15, 51–62. doi: 10.4321/s1578-84232015000100005

Bradley, P. S., Archer, D. T., Hogg, B., Schuth, G., Bush, M., Carling, C., et al. (2016). Tier-specific evolution of match performance characteristics in the English Premier League: it's getting tougher at the top. *J. Sports Sci.* 34, 980–987. doi: 10.1080/02640414.2015.1082614

Bush, M., Archer, D. T., Barnes, C., Hogg, B., and Bradley, P. S. (2017). Longitudinal match performance characteristics of UK and non-UK players in the English Premier League. *Sci. Med. Football* 1, 2–9. doi: 10.1080/02640414.2016.1233347

Bush, M., Archer, D. T., Hogg, R., and Bradley, P. S. (2015a). Factors influencing physical and technical variability in the English Premier League. *Int. J. Sports Physiol. Perform.* 10, 865–872. doi: 10.1123/ijspp.2014-0484

Bush, M., Barnes, C., Archer, D. T., Hogg, B., and Bradley, P. S. (2015b). Evolution of match performance parameters for various playing positions in the English Premier League. *Hum. Mov. Sci.* 39, 1–11. doi: 10.1016/j.humov.2014.10.003

Castellano, J., Casamichana, D., and Lago, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *J. Hum. Kinet.* 31, 137–147. doi: 10.2478/v10078-012-0015-7

Collet, C. (2013). The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. *J. Sports Sci.* 31, 123–136. doi: 10.1080/02640414.2012.727455

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., et al. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *Eur. J. Sport Sci.* 11, 51–59. doi: 10.1080/17461391.2010.481334

Garganta, J. (2009). Trends of tactical performance analysis in team sports: bridging the gap between research, training and competition. *Rev. Portuguesa Ciências Desporto* 9, 81–89. doi: 10.5628/rpcd.09.01.81

Gonçalves, B. V., Figueira, B. E., Maçãs, V., and Sampaio, J. (2014). Effect of player position on movement behaviour, physical and physiological performances during an 11-a-side football game. *J. Sports Sci.* 32, 191–199. doi: 10.1080/02640414.2013.816761

Hopkins, W., Marshall, S., Batterham, A., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* 41:3. doi: 10.1249/mss.0b013e31818cb278

Hopkins, W. G. (2002). A scale of magnitudes for effect statistics. A new view of statistics *Am. J. Sports Sci. Med.* 5, 21–26.

Hopkins, W. G. (2016). SAS (and R) for mixed models. *Sportscience* 20.

Konefał, M., Chmura, P., Zając, T., Chmura, J., Kowalczuk, E., and Andrzejewski, M. (2019). Evolution of technical activity in various playing positions, in relation to match outcomes in professional soccer. *Biol. Sport* 36:181. doi: 10.5114/biolsport.2019.83958

Lago-Peñas, C., Lago-Ballesteros, J., Dellal, A., and Gómez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *J. Sports Sci. Med.* 9:288.

Liu, H., Gómez, M.-A., Gonçalves, B., and Sampaio, J. (2016a). Technical performance and match-to-match variation in elite football teams. *J. Sports Sci.* 34, 509–518. doi: 10.1080/02640414.2015.1117121

Liu, H., Hopkins, W. G., and Gómez, M.-A. (2016b). Modelling relationships between match events and match outcome in elite football. *Eur. J. Sport Sci.* 16, 516–525. doi: 10.1080/17461391.2015.1042527

Liu, H., Hopkins, W., Gómez, A. M., and Molinuevo, S. J. (2013). Inter-operator reliability of live football match statistics from OPTA Sportsdata. *Int. J. Perform. Anal. Sport* 13, 803–821. doi: 10.1080/24748668.2013.11868690

Liu, H., Yi, Q., Giménez, J.-V., Gómez, M.-A., and Lago-Peñas, C. (2015). Performance profiles of football teams in the UEFA Champions League considering situational efficiency. *Int. J. Perform. Anal. Sport* 15, 371–390. doi: 10.1080/24748668.2015.11868799

McGarry, T., O'Donoghue, P., and Sampaio, J. (2013). *Routledge Handbook of Sports Performance Analysis*. Abingdon: Routledge.

Memmert, D., and Rein, R. (2018). Match analysis, big data and tactics: current trends in elite soccer. *German J. Sports Med.* 69, 65–72. doi: 10.5960/dzsm.2018.322

Morgans, R., Adams, D., Mullen, R., McLellan, C., and Williams, M. D. (2014). Technical and physical performance over an English championship league season. *Int. J. Sports Sci. Coach.* 9, 1033–1042. doi: 10.1260/1747-9541.9.5.1033

Oberstone, J. (2011). Comparing team performance of the English premier league, Serie A, and La Liga for the 2008-2009 season. *J. Quant. Anal. Sports* 7, 1–18.

O'Donoghue, P. (2009). *Research Methods for Sports Performance Analysis.* Abingdon: Routledge.

Prieto, J., García, J., and Ibáñez, S. J. (2017). Scoring coordination patterns in basketball international championships of national teams. *Rev. Psicol. Deporte* 26, 27–32.

Prieto, J., Gómez, M. -Á, and Sampaio, J. (2016). Game-scoring coordination in handball according to situational variables using time series analysis methods. *Int. J. Perform. Anal. Sport* 16, 40–52. doi: 10.1080/24748668.2016.11868869

Tenga, A., Ronglan, L. T., and Bahr, R. (2010). Measuring the effectiveness of offensive match-play in professional soccer. *Eur. J. Sport Sci.* 10, 269–277. doi: 10.1080/17461390903515170

Wallace, J. L., and Norton, K. I. (2014). Evolution of World Cup soccer final games 1966–2010: game structure, speed and play patterns. *J. Sci. Med. Sport* 17, 223–228. doi: 10.1016/j.jsams.2013.03.016

Williams, A., Lee, D., and Reilly, T. (1999). *A Quantitative Analysis of Matches Played in the 1991–92 and 1997–98 Seasons*. London: The Football Association.

Yi, Q., Gómez, M. -Á, Liu, H., and Sampaio, J. (2019a). variation of match statistics and football teams'match performance in the group stage of the UEFA champions league from 2010 to 2017. *Kinesiology* 51, 170–181. doi: 10.26582/k.51.2.4

Yi, Q., Gómez, M. A., Wang, L., Huang, G., Zhang, H., and Liu, H. (2019b). Technical and physical match performance of teams in the 2018 FIFA World Cup: effects of two different playing styles. *J. Sports Sci.* 37, 2569–2577. doi: 10.1080/02640414.2019.1648120

Yi, Q., Groom, R., Dai, C., Liu, H., and Gomez Ruano, M. A. (2019c). Differences in technical performance of players from'the big five'European football leagues in the UEFA Champions League. *Front. Psychol.* 10:2738. doi: 10.3389/fpsyg.2019.02738

Yi, Q., Jia, H., Liu, H., and Gómez, M. Á (2018). Technical demands of different playing positions in the UEFA Champions League. *Int. J. Perform. Anal. Sport* 18, 926–937. doi: 10.1080/24748668.2018.1528524

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Diverse Effects of Thermal Conditions on Performance of Marathon Runners

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Heat exposure affects human performance in many ways. Both physiological (i.e., glycogen sparing, oxygen uptake, thermoregulation) and biomechanical mechanisms (i.e., contact time, knee flexion, muscle activity) are affected, hence reducing performance. However, the exposure affects persons differently. Not all athletes necessarily experience an identical thermal condition similarly, and this point has been overlooked to date. We analyzed endurance performances of the top 1000 runners for every year during the last 12 New York City Marathons. Thermal conditions were estimated with wet-bulb globe temperature (WBGT) and universal thermal climate index (UTCI). Under identical thermal exposure, the fastest runners experienced a larger decline in performance than the slower ones. The empirical evidence offered here not only shows that thermal conditions affect runners differently, but also that some groups might consistently suffer more than others. Further research may inspect other factors that could be affected by thermal conditions, as pacing and race strategy.

Keywords: performance, marathon, heat stress, wet-bulb globe temperature, universal thermal climate index

INTRODUCTION

The negative effects of heat exposure are widely known. Labor productivity is negatively impacted by heat exposure in the workplace (Dunne et al., 2013; Cheung et al., 2016; Chavaillaz et al., 2019). Previous research regarding heat exposure focuses on the effects between low- and high-risk labor (Hsiang et al., 2017), the amount of time individuals are exposed (Hancock et al., 2007), and degrees of work stress (Kjellstrom et al., 2018). A point that has been overlooked is that groups of workers within the same labor activity might experience the impacts of identical heat exposure differently (Dear, 2018).

Heat exposure and global warming have many socioeconomic impacts (Watts et al., 2018), including increased death rates (Hsiang et al., 2017; Mora et al., 2017), occupational injuries (Spector et al., 2016; Varghese et al., 2018), reduced economic production (Burke et al., 2015; Fishman et al., 2019; Martinich and Crimmins, 2019), and loss of labor productivity (Dunne et al., 2013; Zare et al., 2015; Chavaillaz et al., 2019). A broad literature exists discussing the negative impacts on labor productivity (Flouris et al., 2018). Physiological effects (Ladell, 1955; Hellon et al., 1956; Liu et al., 2017) are mainly associated with declines in productivity as a consequence of heat stress, but external elements such as clothing (Kampmann et al., 2012), work patterns (Yi and Chan, 2015; Takakura et al., 2017), leisure (Dyble et al., 2019), cooling systems (Tanabe et al., 2015), lifestyle (Trezza et al., 2015), and physical activity (Zander et al., 2015) can also restrain these effects.

Research has examined the impacts of global warming and heat exposure on labor productivity at different geographic levels: global (Ely et al., 2007; Dell et al., 2012; Dunne et al., 2013; Burke et al., 2015; Chavaillaz et al., 2019), national (Cheung et al., 2016; Hsiang et al., 2017; Fishman et al., 2019; Martinich and Crimmins, 2019), and regional (Barreca et al., 2016). Additionally, authors have examined these effects between gender groups (Witterseh et al., 2004), industries, income classes (Zander et al., 2015), indoor vs. outdoor conditions (Cheung et al., 2016), work risk groups (Hsiang et al., 2017), and degrees of heat stress (Kjellstrom et al., 2018). Contemporary research offers adaptation options (Day et al., 2019), limits (Sherwood and Huber, 2010), and recommendations (Watts et al., 2018) on how to cope with global warming and heat exposure.

The negative effects of heat exposure have been extensively researched in sports settings as well. Coris et al. (2004) emphasize heat and humidity as significant risk factors for human exercise. Armstrong et al. (2007) find that heat stress causing organ system dysfunction and failure is a relevant cause for athletes to withdraw from their activities. Tyler et al. (2016) find that heat adaptation is beneficial, however, they state that it depends on the duration of the training (in days). Périard et al. (2015) find, in addition to Tyler et al. (2016), that heat adaptation depends on the kind of heat (e.g., dry or humid hear) and several other factors, such as intensity or frequency. Brotherhood (2008) broadly examines the impacts of heat stress in exercise and sports. Such negative impacts are reported in such diverse sports as cycling (Tatterson et al., 2000), triathlon (Massimino, 1988; Gosling et al., 2008), baseball (Kurakake et al., 1988), and football (Mohr et al., 2012).

Being an outdoor endurance event, marathon running is a sport that researchers have examined carefully for the impacts of heat exposure. Indeed, there is robust evidence of negative effects of weather on performance of marathon runners. Numerous researchers (e.g., Trapasso and Cooper, 1989; Suping et al., 1992; Ely et al., 2007; Montain et al., 2007; Maughan, 2010; Roberts, 2010; Vihma, 2010; Miller-Rushing et al., 2012; Del Coso et al., 2013; Maffetone et al., 2017; Knechtle et al., 2018, 2019; and Nikolaidis et al., 2019b) have found that higher temperatures result in slower finishing times for both elite and amateur runners.

Although the negative impact of heat exposure is well known, it is plausible to assume that not all individuals react similarly to heat. Indeed, Dear (2018) indicates that heterogeneity among workers may result in diverse productivity under similar heat exposure. Although sport is a plausible setting in which heat exposure could have diverse effects, this important element has not been extensively studied in the previous literature. In the context of marathon running, the topic has been discussed by Ely et al. (2007), Montain et al. (2007), and Vihma (2010). They emphasize that slower runners experience larger reductions in performance than elite runners. However, their main argument is that slower runners experience more heat stress because they run for longer periods than faster runners. Our hypothesis, on the other hand, is that even though top runners run for shorter periods, they perform the task (the race) more intensely than slower runners. Hence, they could suffer more from a performance penalty than slower runners.

MATERIALS AND METHODS

We analyze runner performance in the same, constant setting (New York City Marathon) over twelve events (from 2006 to 2018 – the marathon was canceled in 2012). The New York City Marathon takes place at the first Sunday of November. All information regarding race course, rules, and results can be found at https://www.nyrr.org/tcsnycmarathon. Marathon runners are especially prone to heat stress (Roberts, 2010; Smith et al., 2016) as a consequence of the particular characteristics of a marathon, a highly physiologically demanding activity (Ely et al., 2007).

The present setting allows for an appropriate identification of impacts from thermal conditions for the following reasons: (1) goals and outputs are clear: runners seek to be as fast as they can and are ranked according to their performance; (2) similar circumstances: (2.1) all competitors run the same distance and course: 42.195 km (26.219 miles) in New York City over a period of 12 years; (2.2) all athletes are under identical thermal conditions at the same event; (2.3) no seasonal bias – every event happens on the first Sunday of November; and (2.4) no dressing bias – all runners wear similar uniforms. Previous works inspecting the impact of weather on runners analyzed different events at the same time, which undermines the identification of heat exposure effects (Ely et al., 2007; Montain et al., 2007), used air temperature and precipitation as weather conditions (Roberts, 2010; Vihma, 2010), or examined smaller samples each season (Trapasso and Cooper, 1989; Suping et al., 1992; Maffetone et al., 2017; Knechtle et al., 2018) than the current work.

Model and Variables

We examine the impact of heat exposure on performance (p) by multiple linear modeling as follows:

$$p_{it} = \beta_0 + \beta_1 C_{jt} w_t + \beta_2 C_{jt} w_t^2 + \upsilon W_{it} + \varepsilon_i$$

where p is performance, measured by the finishing time in seconds; i is an individual runner; t is a year; C is a matrix of clusters j = 1, 2, 3, or 4; w is thermal condition, measured by WBGT or UTCI, both in Celsius scale (°C), at the beginning of each marathon; $\boldsymbol{W}$ is a vector of control variables. The control variables are age, gender, nationality, number of previous participations, the defined clusters, and start corral dummy (since 2008). An alternative model inspecting a quadratic age effect (cf., Lara et al., 2014; Nikolaidis et al., 2019a) is also carried out but both terms – first and second order – shows insignificant effect and does not influence the results. Start corral was established in the New York Marathon in 2008 with the aim to offer safer conditions for runners by an ordered and smooth flow. It is currently the standard start approach in most major marathon events worldwide. The variables of interest are two interaction terms in each equation: interactions between a heat exposure index (WBGT or UTCI) and its squared term and the defined clusters. It aims to capture the nonlinear impact that heat exposure might have on productivity, as observed by Burke et al. (2015). We use temperature in Celsius degrees throughout the paper. Fahrenheit degrees are related as follows: F =°C * 1.8000+ 32.00.

Thermal condition is calculated by the WBGT and the UTCI at the start time of each marathon. WBGT is the most popular measure of heat exposure (Epstein and Moran, 2006; Kjellstrom et al., 2009; Lemke and Kjellstrom, 2012) and is currently an ISO standard (ISO, 2017). UTCI is a more recent index that affords a slightly different measure of thermal perception (Zare et al., 2018). Brocherie and Millet (2015) discuss some potential limitations regarding WBGT by measuring the severity of the thermal conditions on sport practice. They indicate that UTCI is more appropriate for sport heat stress modeling. However, most of the recent literature still uses WBGT as a bioclimatic index. Therefore, we decided to include both. Both indexes incorporate temperature, solar radiation, wind speed, and humidity, but differ in their calculations. Specifically, WBGT is calculated as follows:

$$WBGT = 0.7 * T_w + 0.2 * T_b + 0.1 * T_d$$

where T_w is wet-bulb temperature; T_b is black globe temperature; and T_d ambient temperature (Epstein and Moran, 2006). UCTI is calculated as follows:

$$UTCI = f\,(T_a;\, T_{mrt};\, va;\, RH) = T_a + Offset(T_a;\, T_{mrt};\, va;\, RH)$$

where T_a is air temperature; T_{mrt} is air mean radiant temperature; va is wind speed; and RH is relative humidity (Błażejczyk et al., 2013). Air temperature, solar radiation, wind speed, and humidity are the inputs in our calculations. Brocherie and Millet (2015) suggest these basic weather elements for WBGT calculation. Both indexes were automatically calculated using the heat stress calculator available at http://www.climatechip.org.

The data comprises the top-1000 overall runners for each event. This sample represents about 2% of total participants for each year. Of these, 89.70% completed the race in less than 3 h – the slowest runner in the sample finished in 3:04:43. Previous work habitually uses subjective criteria to separate runners into groups (e.g., top-3, top-10, top-50, and top-100). Nevertheless, such an arbitrary definition is bound to lead to misspecifications. For instance, the 11th place in a year might be more similar to the runners of the top-10 *group* than compared to the top-50 group. Therefore, to appropriately examine whether groups experience thermal conditions differently, runners were clustered by their performance on each event. The hierarchical clustering through the average linkage method was used to establish the clusters. This method is chosen because of the hierarchical, top-down distribution of runners according to finishing times. The method clusters the data by considering the distance between two clusters as equal to the average distance from any members of both clusters (Ward, 1963; Rokach and Maimon, 2005). There are 222 observations (1.85%) in Cluster 1; 600 observations (5.00%) in Cluster 2; 2192 observations (18.27%) in Cluster 3; and 8985 observations (74.88%) in Cluster 4. **Figure 1** shows the percentage of runners for every cluster for every year. Reasons for changes could be, e.g., the (non-)participation of some runners in specific years, the increase (decrease) in their performances, injuries prior or during the events, or several other external elements that we cannot capture with our data.

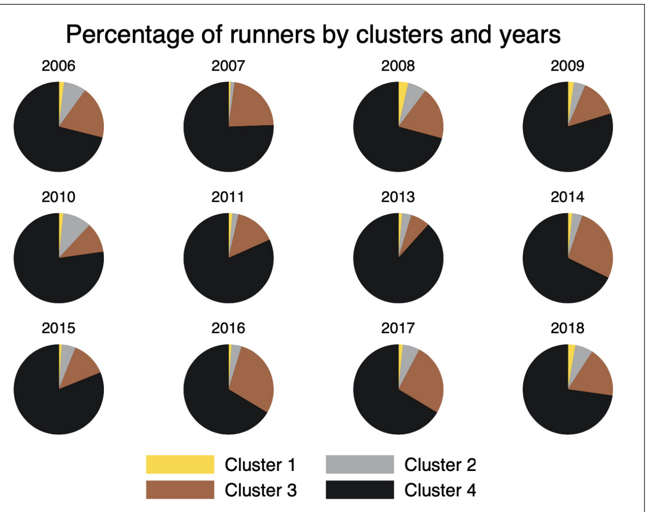

FIGURE 1 | Percentage of runners by clusters and years.

RESULTS AND DISCUSSION

The output of the regressions is given in **Table 1**. All control variables show the expected coefficients. The results also confirm the nonlinear effects of thermal conditions on performance (Burke et al., 2015). In line with previous findings, higher temperatures reduced the performance of runners. However, the results show that each cluster reacts to identical thermal conditions differently. **Figures 2**, **3** show the predictive marginal effects of WBGT (°C) and UCTI (°C) by each cluster. We choose the range of values of temperature (x-axis) from the minimum valid value of WBGT and UTCI in our sample (+3°C and −5°C, respectively) up to the maximum "Do not start" (DNS) temperature for a marathon (+20°C WBGT) (Roberts, 2010).

The general result is that higher temperatures reduce performance in marathons, corroborating previous findings (Ely et al., 2007; Roberts, 2010; El Helou et al., 2012; Miller-Rushing et al., 2012; Del Coso et al., 2013; Cheung et al., 2016; Maffetone et al., 2017; Knechtle et al., 2018). The tipping point of productivity (about +8°C WBGT) is similar to what has been found before. Montain et al. (2007) showed a progressive decrease in performance in temperatures above 5–10°C WBGT, while Knechtle et al. (2018) observed reduced performances of runners under air temperatures higher than +8°C.

However, the current work refutes earlier research that suggests that faster runners suffer less than slower runners (Ely et al., 2007, Montain et al., 2007; Vihma, 2010). In earlier research, the argument was made that slower runners are exposed to heat stress for longer periods and hence suffer more. However, we assume that when analyzing all participants in a marathon, the slower runners (mainly amateurs) tend to have lower performances under higher temperatures not only because of the time exposed, but also due to their inferior level of training and weaker physiological adaptations and metabolic rates than elite runners. Therefore, a comparison among a relatively more homogeneous group of runners, as performed in the current

TABLE 1 | Effects of WBGT and UTCI on performance by clusters of runners.

Variables	Dependent variable: Performance	
	(*w* = WBGT)	**(*w* = UTCI)**
Cluster 1*Heat Index	−141.7***	−19.58***
	(40.83)	(7.60)
Cluster 2*Heat Index	−202.9***	−12.89**
	(23.54)	(5.24)
Cluster 3*Heat Index	−138.3***	−22.56***
	(12.63)	(2.06)
Cluster 4*Heat Index	−58.75***	−21.82***
	(6.55)	(1.22)
Cluster 1*Heat Index^2	9.16***	1.23*
	(2.74)	(0.73)
Cluster 2*Heat Index^2	13.03***	0.48
	(1.58)	(0.51)
Cluster 3*Heat Index^2	9.25***	1.50***
	(0.84)	(0.22)
Cluster 4*Heat Index^2	3.79***	1.10***
	(0.44)	(0.12)
Cluster 2	967.1***	794.7***
	(148.3)	(33.13)
Cluster 3	1,457***	1,486***
	(136.0)	(30.74)
Cluster 4	2,007***	2,298***
	(131.4)	(29.73)
Previous Participations	−23.47***	−23.36***
	(1.66)	(1.63)
Age	5.27***	5.02***
	(0.35)	(0.34)
Gender	51.61***	47.17***
	(10.16)	(10.01)
Start Corral	−77.97***	−90.81***
	(7.15)	(6.77)
Constant	8,893***	8,539***
	(294.6)	(261.8)
Nationality	Yes	Yes
Observations	11,999	11,999
Adjusted R-squared	0.80	0.81

*Standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.*

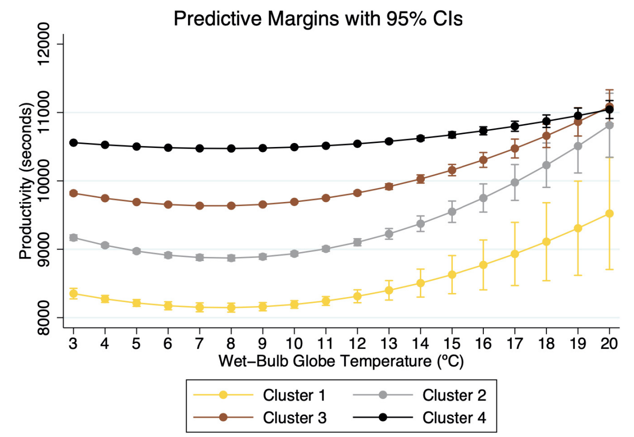

FIGURE 2 | Marginal Impact of WBGT on performance by clusters.

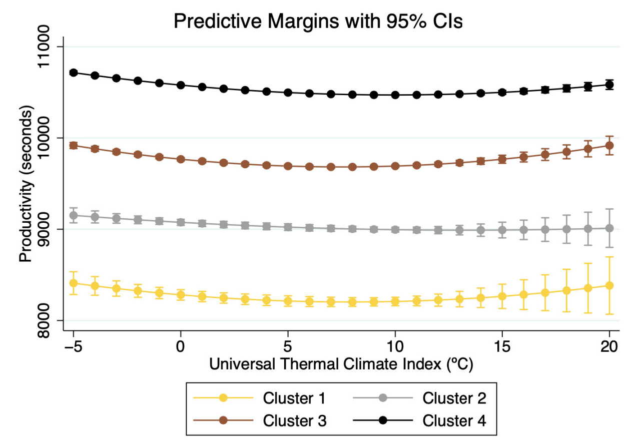

FIGURE 3 | Marginal Impact of UTCI on performance by clusters.

work, is needed to understand whether thermal conditions impact them differently as well.

Our results indicate that top runners suffer higher decreases in performances than slower ones. As shown in **Figures 2, 3**, when comparing finishing times under optimal (+8°C WBGT) and DNT temperatures (+20°C WBGT), the present results indicate an average decrease of about 1,376 s (16.89%), 1,942 s (21.89%), 1,149 s (15.04%), and 569 s (5.44%) for groups 1, 2, 3, and 4, respectively. Faster runners perform the same task at a higher intensity than slower ones, and therefore thermal conditions affect their performance more than the slower groups. Del Coso et al. (2013) previously suggested that runners with higher levels of fatigue could not sustain their habitual pace, and accordingly their performance deteriorates. Therefore, although less skilled runners spend longer periods under heat exposure, their relatively less intense activity explains, to some extent, the reduced negative impact from higher temperatures when compared to top runners.

Psychological elements would also be associated with such performance penalties for faster runners. World-class and elite runners – the fastest in a major marathon – are in a highly competitive situation: pressure to win, earning places in other major events, or achieving certain results because of financial incentives from sponsors. These performance pressures in sports usually result in injuries (Strauss and Curry, 1983) and in some cases may drive top athletes to behave unethically (Volkwein, 1995; Barroso et al., 2008). Donahue et al. (2006) shows that intrinsic and extrinsic motivations are appropriate to prevent elite athletes from unethical behaviors, but they do not eliminate the pressure for good results. Therefore, top-level runners would try to surpass their physiological limits to cope with the negative effects of heat stress, and hence may suffer a bigger performance penalty than slower runners under identical conditions. Unfortunately, our data does not allow us to investigate this matter further, but additional studies are encouraged that focus on these types of questions.

Further research could also exploit the limitations of this paper. Doherty et al. (2020) assess the effect of many training elements on marathon performance but, because of a lack of data availability, they were not included in the present research. Indeed, certain training patterns might help coping with negative effects of heat stress. Pacing and other race strategies are also important elements in marathoners' performance, but were not available for the current research. Further research could examine how heat exposure influences pacing for different groups of athletes as well as analyze optimal strategies that handle certain environmental conditions during marathons. Studies focusing on thermal impacts on gender and age groups are also encouraged. Finally, the variation of thermal conditions during a marathon is an interesting factor that certainly impacts race performance and that should be examined as well. Understanding these elements is essential to maximize sports performance as well as assure the safety of runners.

Several practical implications from this research are already reported in the literature. However, our output is very relevant supporting previous recommendations. Marathons should happen under temperatures around +8°C WBGT, assuring higher levels of performance and safety for all participants. Additionally, organizers should avoid competitions with thermal conditions over +20°C WBGT. The marginal effects presented here can help runners to adjust their training sessions considering the thermal conditions. We may assume that the negative impacts might be similar for both training and competition and, therefore, runners should be aware of these performance penalties not only on the race day, but also during their whole preparation. Finally, the evidence that faster runners suffer from a greater performance penalty than slower ones under identical thermal conditions suggests an opportunity for performance' optimization for top-runners. Researchers and athletes together have to search for ways to maximize performance under such conditions.

The results here are important for future research regarding the impact of thermal conditions on performance. We demonstrate that marathon runners suffer from thermal conditions in different ways: under identical thermal conditions, top runners experience a substantially greater performance decrement than slower runners. This finding, which contradicts previous research, is the key contribution of the present research. Marathon is a genuine competitive sport, which makes these results relevant for other sport settings (e.g., triathlon, cross-country skiing, cycling) (Orr, 2020). However, the results are not exclusively valid for the sport sphere since heterogeneous performance levels can be found in numerous settings where individual-, group-, and firm-variation is regularly observed. For instance, further research is encouraged that investigates the physiological responses of different groups of professional workers – both athletes and non-athletes – based on their skill level. Researchers should be aware of these elements and examine as precisely as possible each specific case prior to performing estimations for future scenarios. Understanding why groups experience heat stress differently under identical circumstances is crucial for relevant scientific and policy recommendations.

DATA AVAILABILITY STATEMENT

All data used in this research are publicly available and open access. Productivity data are available at http://www.marathonguide.com and weather data are available at https://maps.nrel.gov/nsrdb-viewer/.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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REFERENCES

Armstrong, L. E., Casa, D. J., Millard-Stafford, M., Moran, D. S., Pyne, S. W., and Roberts, W. O. (2007). Exertional heat illness during training and competition. *Med. Sci. Sports Exerc.* 39, 556–572.

Barreca, A., Clay, K., Deschenes, O., Greenstone, M., and Shapiro, J. S. (2016). Adapting to climate change: the remarkable decline in the US temperature-mortality relationship over the twentieth century. *J. Polit. Econ.* 124, 105–159. doi: 10.1086/684582

Barroso, O., Mazzoni, I., and Rabin, O. (2008). Hormone abuse in sports: the antidoping perspective. *Asian J. Androl.* 10, 391–402. doi: 10.1111/j.1745-7262.2008.00402.x

Błażejczyk, K., Jendritzky, G., Bröde, P., Fiala, D., Havenith, G., Epstein, Y., et al. (2013). An introduction to the universal thermal climate index (UTCI). *Geogr. Pol.* 86, 5–10. doi: 10.7163/gpol.2013.1

Brocherie, F., and Millet, G. P. (2015). Is the wet-bulb globe temperature (WBGT) index relevant for exercise in the heat? *Sports Med.* 45, 1619–1621. doi: 10.1007/s40279-015-0386-8

Brotherhood, J. R. (2008). Heat stress and strain in exercise and sport. *J. Sci. Med. Sport* 11, 6–19. doi: 10.1016/j.jsams.2007.08.017

Burke, M., Hsiang, S. M., and Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature* 527, 235–239. doi: 10.1038/nature15725

Chavaillaz, Y., Roy, P., Partanen, A. I., Da Silva, L., Bresson, É, Mengis, N., et al. (2019). Exposure to excessive heat and impacts on labour productivity liked to cumulative CO_2 emissions. *Sci. Rep.* 9:13711.

Cheung, S. S., Lee, J. K. W., and Oksa, J. (2016). Thermal stress, human performance, and physical employment standards. *Appl. Physiol. Nutr. Metab.* 41, S148–S164.

Coris, E. E., Ramirez, A. M., and Van Durme, D. J. (2004). Heat illness in athletes: the dangerous combination of heat, humidity and exercise. *Sports Med.* 34, 9–16. doi: 10.2165/00007256-200434010-00002

Day, E., Fankhauser, S., Kingsmill, N., Costa, H., and Mavrogianni, A. (2019). Upholding labour productivity under climate change: an assessment of adaptation options. *Clim. Policy* 19, 367–385. doi: 10.1080/14693062.2018.1517640

Dear, K. (2018). Modelling productivity loss from heat stress. *Atmosphere* 9, 1–9.

Del Coso, J., Fernández, D., Abián-Vicen, J., Salinero, J. J., González-Millán, C., Areces, F., et al. (2013). Running pace decrease during a marathon is positively related to blood markers of muscle damage. *PLoS One* 8:e57602. doi: 10.1371/journal.pone.0057602

Dell, M., Jones, B. F., and Olken, B. A. (2012). Climate change and economic growth: evidence from the last half century. *Am. Econ. J. Macroecon.* 4, 66–95. doi: 10.1257/mac.4.3.66

Doherty, C., Keogh, A., Davenport, J., Lawlor, A., Smyth, B., and Caulfield, B. (2020). An evaluation of the training determinants of marathon performance: a meta-analysis with meta-regression. *J. Sci. Med. Sport* 23, 182–188. doi: 10.1016/j.jsams.2019.09.013

Donahue, E. G., Miquelon, P., Valois, P., Goulet, C., Buist, A., and Vallerand, R. J. (2006). A motivational model of performance-enhancing substance use in elite athletes. *J. Sport Exerc. Psychol.* 28, 511–520. doi: 10.1123/jsep.28.4.511

Dunne, J. P., Stouffer, R. J., and John, J. G. (2013). Reductions in labour capacity from heat stress under climate warming. *Nat. Clim. Change* 3, 563–566. doi: 10.1038/nclimate1827

Dyble, M., Thorley, J., Page, A. E., Smith, D., and Migliano, A. B. (2019). Engagement in agricultural work is associated with reduced leisure time among Agta hunter-gatherers. *Nat. Hum. Behav.* 3, 792–796. doi: 10.1038/s41562-019-0614-6

Epstein, Y., and Moran, D. S. (2006). Thermal comfort and the heal stress indices. *Industrial Health* 44, 388–398. doi: 10.2486/indhealth.44.388

El Helou, N., Tafflet, M., Berthelot, G., Tolaini, J., Marc, A., Guillaume, M., et al. (2012). Impact of environmental parameters on marathon running performance. *PLoS One* 7:e37407. doi: 10.1371/journal.pone.0037407

Ely, M. R., Cheuvront, S. N., Roberts, W. O., and Montain, S. J. (2007). Impact of weather on marathon-running performance. *Med. Sci. Sports Exerc.* 39, 487–493. doi: 10.1249/mss.0b013e31802d3aba

Fishman, R., Carillo, P., and Russ, J. (2019). Long-term impacts of exposure to high temperatures on human capital and economic productivity. *J. Environ. Econ. Manage.* 93, 221–238. doi: 10.1016/j.jeem.2018.10.001

Flouris, A. D., Dinas, P. C., Ioannou, L. G., Nybo, L., Havenith, G., Kenny, G. P., et al. (2018). Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. *Lancet Planet Health* 2, e521–e531. doi: 10.1016/s2542-5196(18)30237-7

Gosling, C. M., Gabbe, B. J., McGivern, J., and Forbes, A. B. (2008). The incidence of heat casualties in sprint triathlon: the tale of two Melbourne race events. *J. Sci. Med. Sport* 11, 52–57. doi: 10.1016/j.jsams.2007.08.010

Hancock, P. A., Ross, J. M., and Szalma, J. L. (2007). A meta-analysis of performance response under thermal stressors. *Human Factors* 49, 851–877. doi: 10.1518/001872007x230226

Hellon, R. F., Lind, A. R., and Weiner, J. S. (1956). The physiological reactions of men of two age groups to a hot environment. *J. Physiol.* 133, 118–131. doi: 10.1113/jphysiol.1956.sp005570

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., et al. (2017). Estimation economic damage from climate change in the United States. *Science* 356, 1362–1369.

ISO (2017). *ISO 7243:2017. Ergonomics of the Thermal Environment – Assessment of Heat Stress using the WBGT (wet bulb globe temperature) Index*. Geneva: ISO.

Kampmann, B., Bröde, P., and Fiala, D. (2012). Physiological responses to temperature and humidity compared to the assessment by UTCI, WGBT and PHS. *Int. J. Biometeorol.* 56, 505–513. doi: 10.1007/s00484-011-0410-0

Kjellstrom, T., Holmer, I., and Lemke, B. (2009). Workplace heat stress, health and productivity – an increasing challenge for low and middle-income countries during climate change. *Global Health Action* 2:10.3402/gha.v2i0.2047. doi: 10.3402/gha.v2i0.2047

Kjellstrom, T., Freyberg, C., Lemke, B., Otto, M., and Briggs, D. (2018). Estimating population heat exposure and impacts on working people in conjunction with climate change. *Int. J. Biometeorol.* 62, 291–306. doi: 10.1007/s00484-017-1407-0

Knechtle, B., Di Gangi, S., Rüst, C. A., Rosemann, T., and Nikolaidis, P. T. (2018). Men's participation and performance in the Boston Marathon from 1897 to 2007. *Int. J. Sports Med.* 39, 1018–1027. doi: 10.1055/a-0660-0061

Knechtle, B., Di Gangi, S., Rüst, C. A., Villiger, E., Rosemann, T., and Nikolaidis, P. T. (2019). The role of weather conditions on running performance in the Boston Marathon from 1972 to 2018. *PLoS One* 14:e0212797. doi: 10.1371/journal.pone.0212797

Kurakake, S., Sugawara, K., Kumae, T., Shimaoka, A., Mathida, K., and Okamura, N. (1988). A study on the effect of physical load of baseball umpire, during a baseball game in the summer. *Japanese J. Hygiene* 42, 1013–1022. doi: 10.1265/jjh.42.1013

Ladell, W. S. S. (1955). The effects of water and salt intake upon the performance of men working in hot and humid environments. *J. Physiol.* 127, 11–46. doi: 10.1113/jphysiol.1955.sp005235

Lara, B., Salinero, J. J., and Del Coso, J. (2014). The relationship between age and running time in elite marathoners is U-shaped. *Age* 36, 1003–1008. doi: 10.1007/s11357-013-9614-z

Lemke, B., and Kjellstrom, T. (2012). Calculating workplace WBGT from meteorological data: a tool for climate change assessment. *Industrial Health* 50, 267–278. doi: 10.2486/indhealth.ms1352

Liu, W., Zhong, W., and Wargocki, P. (2017). Performance, acute health symptoms and physiological responses during exposure to high air temperature and carbon dioxide concentration. *Build. Environ.* 114, 96–105. doi: 10.1016/j.buildenv.2016.12.020

Maffetone, P. B., Malcata, R., Rivera, I., and Laursen, P. B. (2017). The Boston marathon versus the world marathon majors. *PLoS One* 12:e0184024. doi: 10.1371/journal.pone.0184024

Martinich, J., and Crimmins, A. (2019). Climate damages and adaptation potential across diverse sectors of the United States. *Nat. Clim. Change* 9, 397–404. doi: 10.1038/s41558-019-0444-6

Massimino, F. A. (1988). Common triathlon injuries: special considerations for multisport training. *Ann. Sports Med.* 4, 82–86.

Miller-Rushing, A. J., Primack, R. B., Phillips, N., and Kaufmann, R. K. (2012). Effects of warming temperatures on winning times in the Boston Marathon. *PLoS One* 7:e43579. doi: 10.1371/journal.pone.0043579

Mohr, M., Nybo, L., Grantham, J., and Racinais, S. (2012). Physiological responses and physical performance during football in the heat. *PLoS One* 7:e39202. doi: 10.1371/journal.pone.0039202

Montain, S. K., Ely, M. R., and Cheuvront, S. N. (2007). Marathon performance in thermally stressing conditions. *Sports Med.* 37, 320–323. doi: 10.2165/00007256-200737040-00012

Mora, C., Dousset, B., Caldwell, I. R., Powell, F. E., Geronimo, R. C., Bielecki, C. R., et al. (2017). Global risk of deadly heat. *Nat. Clim. Change* 7, 501–506.

Maughan, R. J. (2010). Distance running in hot environments: a thermal challenge to the elite runner. *Scand. J. Med. Sci. Sports* 20, 95–102. doi: 10.1111/j.1600-0838.2010.01214.x

Nikolaidis, P. T., Di Gangi, S., Chtourou, H., Rüst, C. A., Rosemann, T., and Knechtle, B. (2019b). The role of environmental conditions on marathon running performance in men competing in Boston marathon from 1897 to 2018. *Int. J. Environ. Res. Public Health* 16:614. doi: 10.3390/ijerph16040614

Nikolaidis, P. T., Alvero-Cruz, J. R., Villiger, E., Rosemann, T., and Knechtle, B. (2019a). The age-related performance decline in marathon running: the paradigm of the Berlin marathon. *Int. J. Environ. Res. Public Health* 16, 1–12.

Orr, M. (2020). On the potential impacts of climate change on baseball and cross-country skiing. *Managing Sport Leisure* 25, 307–320. doi: 10.1080/23750472.2020.1723436

Périard, J. D., Racinais, S., and Sawka, M. N. (2015). Adaptations and mechanisms of human heat acclimation: applications for competitive athletes and sports. *Scand. J. Med. Sci. Sports* 25, 20–38. doi: 10.1111/sms.12408

Roberts, W. O. (2010). Determining a "Do not start" temperature for a marathon on the basis of adverse outcomes. *Med. Sci. Sports Exerc.* 42, 226–232. doi: 10.1249/mss.0b013e3181b1cdcf

Rokach, L., and Maimon, O. (2005). "Clustering methods," in *Data Mining and Knowledge Discovery Handbook*, eds O. Maimon, and L. Rokach (Berlin: Springer), 321–352.

Sherwood, S. C., and Huber, M. (2010). An adaptability limit to climate change due to heat stress. *Proc. Natl. Acad. Sci. U.S.A.* 107, 9552–9555. doi: 10.1073/pnas.0913352107

Smith, K. R., Woodward, A., Lemke, B., Otto, M., Chang, C. J., Mance, A. A., et al. (2016). The last summer olympics? Climate change, health, and work outdoors. *Lancet* 388, 642–644. doi: 10.1016/s0140-6736(16)31335-6

Spector, J. T., Bonauto, D. K., Sheppard, L., Busch-Isaksen, T., Calkins, M., Adams, D., et al. (2016). A case-crossover study of heat exposure and injury risk in outdoor agricultural workers. *PLoS One* 11:e0164498. doi: 10.1371/journal.pone.0164498

Strauss, R. H., and Curry, T. J. (1983). Social factors in wrestlers' health problems. *Phys. Sportsmed.* 11, 86–99. doi: 10.1080/00913847.1983.11708685

Suping, Z., Guanglin, M., Yanwen, W., and Ji, L. (1992). Study of the relationships between weather conditions and the marathon race, and of meteorotropic effects on distance runners. *Int. J. Biometeorol.* 36, 63–68. doi: 10.1007/BF01208915

Takakura, J. Y., Fujimori, S., Takahashi, K., Hijioka, Y., Hasegawa, T., Honda, Y., et al. (2017). Cost of preventing work place heat-related illness through worker breaks and the benefit of climate-change mitigation. *Environ. Res. Lett.* 12, 1–12.

Tanabe, S., Haneda, M., and Nishihara, N. (2015). Workplace productivity and individual thermal satisfaction. *Build. Environ.* 91, 42–50. doi: 10.1016/j.buildenv.2015.02.032

Tatterson, A. J., Hahn, A. G., Martini, D. T., and Febbraio, M. A. (2000). Effects of heat stress on physiological responses and exercise performance in elite cyclists. *J. Sci. Med. Sport* 3, 186–193. doi: 10.1016/s1440-2440(00)80080-8

Trapasso, L. M., and Cooper, J. D. (1989). Record performances at the Boston marathon: biometeorological factors. *Int. J. Biometeorol.* 33, 233–237. doi: 10.1007/bf01051083

Trezza, B. M., Apolinario, D., de Oliveira, R. S., Busse, A. L., Gonçalves, F. L. T., Saldiva, P. H. N., et al. (2015). Environmental heat exposure and cognitive performance in older adults: a controlled trial. *Age* 37, 1–10.

Tyler, C. J., Reeve, T., Hodges, G. J., and Cheung, S. S. (2016). The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sports Med.* 46, 1699–1724. doi: 10.1007/s40279-016-0538-5

Varghese, B. M., Hansen, A., Bi, P., and Pisaniello, D. (2018). Are workers at risk occupational injuries due to heat exposure? A comprehensive literature review. *Safety Sci.* 110, 380–392. doi: 10.1016/j.ssci.2018.04.027

Vihma, T. (2010). Effects of weather on the performance of marathon runners. *Int. J. Biometeorol.* 54, 297–306. doi: 10.1007/s00484-009-0280-x

Volkwein, K. A. E. (1995). Ethics and top-level sport – a paradox? *Int. Rev. Sociol. Sport* 30, 311–320. doi: 10.1177/101269029503000305

Ward, J. H. (1963). Hiearchical grouping to optimize an objective function. *J. Am. Stat. Assoc.* 58, 236–244. doi: 10.1080/01621459.1963.10500845

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., et al. (2018). The 2018 report of the Lancet countdown on health and climate change: shaping the health of nations for centuries to come. *Lancet* 392, 2479–2514.

Witterseh, T., Wyon, D. P., and Clausen, G. (2004). The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and of the performance of office work. *Indoor Air* 14, 30–40. doi: 10.1111/j.1600-0668.2004.00305.x

Yi, W., and Chan, A. P. C. (2015). Optimal work pattern for construction workers in hot weather: a case study in Hong Kong. *J. Comput. Civil Eng.* 29, 1–11.

Zander, K., Botzen, W., Oppermann, E., Kjellstrom, T., and Garnett, S. T. (2015). Heat stress causes substantial labour productivity loss in Australia. *Nature Clim. Change* 5, 647–651. doi: 10.1038/nclimate2623

Zare, S., Hasheminejad, N., Shirvan, H. E., Hemmatjo, R., Sarebanzadeh, K., and Ahmadi, S. (2015). Heat stress causes substantial labour productivity loss in Australia. *Nat. Clim. Change* 5, 647–651. doi: 10.1038/nclimate2623

Zare, S., Hasheminejad, N., Shirvan, H. E., Hemmatjo, R., Sarebanzade, K., and Ahmadi, S. (2018). Comparing universal thermal climate index (UTCI) with selected thermal indices/environmental parameters during 12 months of the year. *Weather Clim. Extrem.* 19, 49–57. doi: 10.1016/j.wace.2018.01.004

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Positional In-Match Running Demands of University Rugby Players in South Africa

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The implementation of the Varsity Cup rugby competition among South African universities has sparked interest in university rugby cultures around the country. The Varsity Cup has established itself as one of the most important rugby competitions for full-time students. The development of specific conditioning programs for rugby players requires a thorough understanding of the game and the unique demands of playing positions. Therefore, the study aimed to investigate the in-match running demands of South African university rugby players by using GPS during match play for primary and secondary positional groups. Rugby players (n = 40) from two universities were assessed during match play (n = 17) over a competitive season by using GPS. Players were grouped into two primary positional groups, forwards (n = 22) and backs (n = 18), and five secondary positional groups, tight forwards (n = 14), loose forwards (n = 8), half backs (n = 5), inside backs (n = 6), and outside backs (n = 7). The GPS analysis provided the following match-play movements: total distance, high-speed meters, maximum velocity, match intensity, the number of accelerations and decelerations, and velocity zone. Halfbacks recorded the highest total distance (6620.9 ± 784.4 m; p = 0.02) and match intensity (77.7 ± 11.6 m/min; p = 0.01). Outside backs recorded the highest maximum velocity (8.385 ± 1.242 m/s; p = 0.00). Loose forwards registered the highest number of accelerations (385.5 ± 122.1) and decelerations (378.7 ± 108.1). Backs and their specific subgroups play at and within high velocity thresholds, significantly higher (p = 0.01) than that of the forwards. Forwards tend to be involved in a higher amount of accelerations and decelerations during match play, suggesting that forward play is at close quarters to the opposition. During university rugby matches, the backs covered greater distances and speeds than the forwards, whereas the forwards achieved more accelerations and decelerations than backs. Results from the study can assist Varsity Cup strength and conditioning coaches to prepare players for the position-specific demands of the competition.

Keywords: GPS, rugby union, positional groups, student athletes, performance analysis

INTRODUCTION

Rugby union ("rugby"), as an intermittent, high-intensity, collision sport that is popular globally, is characterized by physically intense phases of play and displays of speed, skill, and strength (Lindsay et al., 2015). In South Africa, rugby is enjoyed by players of all ages (Harris and Wise, 2011). Universities in South Africa have become part of an inter-university competition (Varsity Cup) that allows students to compete against one another on a semi-professional level. The Varsity Cup (VC) rugby competition in South Africa has become the most innovative and stimulating competitions in South Africa in terms of ideas (rules and law changes) and match play. The VC has expanded since it commenced in 2008 and has developed into a high-intensity, physically high-demanding competition at a university level. Furthermore, all the players are full-time students and have a full academic program. Nine university teams partake in a round-robin format to determine the top four university teams that would progress to knockout rounds. Teams play an equal number of matches both home and away over the 9-week round-robin format with one bye before the knockout stages of the competition. Limited information on the management of players to perform on all the demands of being a student athlete in South Africa has been published. However, since the onset of professionalism in rugby in 1995, the demands of the game have increased. The game became more intense, with players becoming heavier, and the backs particularly became taller (Quarrie and Hopkins, 2007; Vahed et al., 2014). The number of impacts and impacts at high speed (McLellan et al., 2011; Owen et al., 2015) and increased ball-in-play time (Schoeman and Coetzee, 2014) contributed to the changing demands of the sport. These increases could predominantly be attributed to changes in laws and improved match analysis, equipment technology, and player conditioning (Quarrie and Hopkins, 2007).

Along with increased demands on players, the demands differ per position played (Duthie et al., 2003; Austin et al., 2011; Cahill et al., 2013; Tee and Coopoo, 2015; Tee et al., 2017). Players are generally separated into two primary positional groups, namely, backs and forwards, and further subdivided into secondary positional groups discussed later in the "Materials and Methods" section (Duthie et al., 2003). All players are required to perform core actions/activities, such as tackling and rucking, during a match (Duthie et al., 2003), but the technical and tactical demands on players are different for the playing positions (Owen et al., 2015; Tee et al., 2018). Technically, backs focus on handling, passing, kicking, and running, whereas forwards focus on body position in contact and ball carrying. Tactically backs may aim to beat the defense using skillful moves and speed, where forwards may look to physically beat opponents to gain field advantage. To determine these position-specific characteristics, it is often difficult due to the dynamic movement of opposition players; accurate methods to quantify in-match running demands are required. Rugby as a sport takes place in a complex dynamic setting (Rothwell et al., 2017). In such a system, recorded player data for specific metrics become dependent on the actions of the opposition, known as the ecological and dynamic systems approach (Vilar et al., 2012). Although not a focus of this specific study, the understanding of the dynamic systems approach can assist in the understanding of recorded metrics as well as specific skill acquisition (Vilar et al., 2012; Rothwell et al., 2017). To develop specific conditioning programs and recovery strategies for rugby players, a thorough understanding of the game and the unique demands of different playing positions is essential (Venter et al., 2011).

A modern method used to quantify these positional demands is through global positioning systems (GPS). Research on players' primary positional demands (Cunniffe et al., 2009) revealed that the total distances covered by elite rugby players per game by forwards were 6,680 m, and by backs, 7,227 m. Other studies confirmed that forwards accumulated 5,850 m (Cahill et al., 2013), 6680 m (Cunniffe et al., 2009), and 5,370 m (Cunningham et al., 2016) of total running distance. The backs accumulated total running distances of 6,545 m (Cahill et al., 2013), 7,227 m (Cunniffe et al., 2009), and 6,230 m (Cunningham et al., 2016). Austin et al. (2011) reported that the total distances covered by secondary positional groups during the Super Rugby tournament were as follows: front row (4,662 ± 659 m); back row (5,262 ± 131 m); inside backs (6,095 ± 213 m); and outside backs (4,774 ± 1,017 m). Yamamoto et al. (2017) found in a study on Japanese professional rugby players that the distance covered for the front row was 5604.0 m, second and third row forwards 5690.2 m, scrumhalf's 7001.0 m, and backs 6072.3 m. However, little research has been carried out that quantified the running demands of university rugby players per positional group. Particular attention should be paid to the specific physical requirements of players in different positions to ensure that they receive adequate training (Tee et al., 2017) and individualized recovery.

GPS uses wearable microtechnology to record geographic positions over time and create a movement profile for players (Owen et al., 2015). Using this form of player movement analysis, individual external player loads can indicate specific positional demands of these players. The purpose of any rugby-specific physical training program should be to optimally prepare players for the demands of match play (Owen et al., 2015; Tee et al., 2018). This can be achieved by maximizing training specificity through the manipulation of training activities to simulate or exceed the skill and physical demands of the match (Tee et al., 2018). Tee et al. (2018) noted that physical preparation should not be done in isolation but with all the subsequent components for performance. Training sessions should be based around a combination of physical and mental aspects of the game that emulate match specificity, such as moving at high velocities and making decisions based on stimuli, such as defenders (Tee et al., 2018). The purpose of the current study was to give strength and conditioning coaches an indication of the match-specific positional running demands of South African university rugby players to develop and execute specific training sessions to maximize performance. Performance profiling of players participating in university rugby is necessary to establish normative values; the performance profiles can assist strength and conditioning coaches in monitoring players' readiness for competition. Additionally, teams with the means to monitor training sessions can maximize performance and minimize injury risk through analyzing player load. Repeated exposure to high-speed running, accelerations, and decelerations will increase both injury risk and player load. Therefore, the current study aimed to investigate the in-match running demands of South African university rugby players by using GPS during match play for primary and secondary positional groups.

MATERIALS AND METHODS

Participants

A total of 40 male rugby players from two South African universities competing in the 2018 VC rugby competition volunteered to participate in the study (**Table 1**). A total of 17 matches were played by the two teams against different teams and each other, both home and away for the competition duration. All players were informed about the purpose of the study and gave informed consent before participating in the study. The participants' demographic information is shown in **Table 1**. Data were excluded from the study if a participant played less than 60 min or the GPS device lost signal. A total of 271 observations were included based on the inclusion and exclusion criteria.

Players were categorized according to their playing positions and divided into primary positional groups described by Cahill et al. (2013) and Owen et al. (2015), namely, forwards (loose-head prop, hooker, tight-head prop, locks, blind-side flanker, open-side flanker, and eighth man) and backs (scrum-half, fly half, left winger, inside center, outside center, right winger, and fullback). The grouping was assumed to accurately reflect similar match demands for the playing positions and allow comparison with previous research. The secondary positional grouping subdivided the team into five groups, similar to the study by Owen et al. (2015). The five secondary positional groups for the current study consist of the tight forwards (loose head prop, hooker, tight-head prop, and locks), loose forwards (blind-side flanker, open-side flanker, and eighth-man), half backs (scrumhalf and fly half), inside backs (inside and outside centers), and outside backs (right- and left-wingers and fullbacks). The current study grouped the scrum and fly halves into one group called the half backs. The two positions were combined because the studies by Quarrie et al. (2013) and Tee and Coopoo (2015) reported no significant differences between the two playing positions. **Table 2** presents the in-match running demands variables used in the current study. Only three velocity zones were measured as these zones were seen to best describe the running demands of rugby players, where velocity zones 1 and 2 represented low-velocity movements such as walking. The Health Sciences Research Ethics Committee (HSREC) (UFS-HSD2017/0062) at the University of the Free State approved the study.

Data Collection Procedure

Players from the two universities were fitted with Catapult Minimax X4 10 Hz GPS units for the matches (Catapult;

TABLE 2 | In-match running demands variables used in the study.

Variables	Description
Total distance (m)	Total distance describes the total number of meters covered by a player during the match. The metric is measured by the displacement of the GPS unit over time.
High-speed meters (m)	High-speed meters refer to distance covered at high speed. For the purpose of the current study, all meters ran above 5.56 m/s were registered as high-speed meters. Similar to total distance, the time between displacements of different samples when recording data indicates the type of meterage registered.
Maximum velocity (m/s)	Represents the maximum velocity achieved by a player during the match. Maximum velocity is registered at the peak of the player's running performance.
Match intensity (m/min)	Measured as meters covered per minute, this metric represents an internal calculation of the GPS software that determines the meters ran over the duration of the match and equates it as match intensity. Cummins et al. (2013) similarly referred to relative distance (with reference to match intensity) as a calculated workload based on the overall distance covered per minute.
Number of accelerations (n) and decelerations (n)	Accelerations and decelerations indicate a change in speed over the established velocity zones. Accelerations are registered because of increases in speed through the velocity zones and decelerations are recorded because of decreases in speed through the velocity zones.
Velocity zones	Velocity zones 3 (4.44–5.56 m/s), 4 (5.57–6.94 m/s), and 5 (>6.95 m/s) were indicative of the total distance covered within the velocity zones.

TABLE 1 | Demographic information of participants per positional group.

Positional group	n	Age (years) M ± SD	Height (cm) M ± SD	Weight (kg) M ± SD	Observations n
Combined	40	20.77 ± 0.44	179.55 ± 1.21	91.52 ± 0.83	271
Forwards	22	20.75 ± 0.61	183.34 ± 1.04ˆ	101.24 ± 1.13ˆ	147
Backs	18	20.78 ± 0.06	177.02 ± 0.75	85.05 ± 0.52	124
Tight forwards	14	20.84 ± 1.36	183.10 ± 7.7[cde]	107.05 ± 8.83[cde]	94
Loose forwards	8	20.65 ± 2.58	183.58 ± 5.63[cde]	95.43 ± 6.57[cde]	53
Half-backs	5	20.72 ± 1.48	175.22 ± 5.87	81.10 ± 7.68	36
Inside backs	6	20.67 ± 1.62	178.33 ± 4.05	88.43 ± 7.43	36
Outside backs	7	20.95 ± 1.57	177.50 ± 5.01	85.60 ± 8.64	52

ˆ denotes significant differences in weight between primary positional groups. [a] denotes significant differences when comparing tight forwards to other secondary positional groups. [b] denotes significant differences when comparing loose forwards to other secondary positional groups. [c] denotes significant differences when comparing half backs to other secondary positional groups. [d] denotes significant differences when comparing inside backs to other secondary positional groups. [e] denotes significant differences when comparing outside backs to other secondary positional groups ($p \leq 0.05$).

Melbourne, Australia). These two universities made use of the Catapult Minimax X4 10 Hz GPS units with the same velocity zones allowing for comparisons to be made on players' performance. It should also be noted that the use of GPS units during matches is not common within the VC setting. The GPS units fitted into specialized neoprene vests designed specifically for positioning and securing of the unit on the player's upper back. The GPS unit was switched on before the start of the warm-up and switched off after the match. The warm-up and half-time data were excluded and discarded. The data were analyzed to identify information regarding player demands as presented in **Table 3** during match play in primary and secondary positional groups. Data were extracted and divided into the relative periods from the GPS units, using the Catapult Open Field (version 1.21.1) software (Catapult; Melbourne, Australia). Data were extracted as a csv file for further clean-up in a Microsoft Excel spreadsheet before being analyzed by the Statistica 13 data processing package (version 13.0.159.8) (Dell Inc., Round Rock, TX, United States).

Data Analysis

The Statistica 13 software package was used to process the data. Participant information was described by using descriptive statistics (mean [M] ± standard deviation [SD]). Mixed model ANOVA was used with "player" and "player*period" as random effects, and "position," "period," and "position*period" as fixed effects. Fisher least significant difference (LSD) testing was used for *post-hoc* testing. Normality assumptions were evaluated by inspecting normal probability plots and were mostly found to be acceptable. Participants were grouped according to primary and secondary positional groups. The position*period effect was found to be not significant in all cases, so the results for the position effect are reported.

RESULTS

Results for all recorded metrics and per positional group are presented in **Table 3**. When comparing the primary positional groups, backs recorded significantly higher totals for high speed meters (p = 0.01), maximum velocity (p = 0.01), and velocity zones 3 (p = 0.01), 4 (p = 0.01), and 5 (p = 0.01). No significant differences were observed for the total distance covered and the number of accelerations and decelerations.

When comparing secondary positional groups, significant differences were observed for all metrics except for the number of accelerations and decelerations between the different subgroups. Half backs covered the highest total distance, significantly more (p = 0.02) than tight forwards. The outside backs covered the most high-speed meters (556.450 m), significantly more than all secondary positional groups (p = 0.01). The outside backs recorded the highest maximum velocity (8.385 ± 1.242 m/s), significantly different (p = 0.01) from the tight forward, loose forward, and half back positions. Tight forwards recorded the lowest maximum velocity (6,066 ± 1,079 m/s) and were significantly lower (p = 0.01) than all secondary positional groups. Half backs recorded the highest match intensity (77.7 ± 11.6

TABLE 3 | Positional demands for different variables per match during the 2018 Varsity Cup tournament (mean ± standard deviation).

Positional groups	Total distance (m)	High-speed meters (m)	Maximum velocity (m/s)	Match intensity (m/min)	Accelerations (n)	Decelerations (n)	VZ^3 (4.45–5.56 m/s)	VZ^4 (5.57–6.94 m/s)	VZ^5 (>6.95 m/s)
Forwards	5734.4 ± 693.7	158.1 ± 30.8	6.598 ± 0.944	68.6 ± 9.5	363.8 ± 132.2	358.5 ± 117.7	197.4 ± 48.0	65.15 ± 24.5	27.9 ± 12.7
Backs	6261.6 ± 745.2	459.2 ± 58.7$^\wedge$	7.865 ± 1.001$^\wedge$	72.9 ± 11.4	367.9 ± 114.3	361.7 ± 96.4	305.3 ± 65.4$^\wedge$	158.3 ± 40.6$^\wedge$	71.5 ± 30.8$^\wedge$
Tight Forwards	5352.9 ± 798.6	69.7 ± 22.2	6.066 ± 1.079	66.8 ± 10.4	342.2 ± 142.3	338.4 ± 127.3	259.9 ± 43.7	61.2 ± 18.2	8.5 ± 7.8
Loose Forwards	6115.9 ± 588.8	246.4 ± 39.4	7.129 ± 0.809^a	70.4 ± 8.5	385.5 ± 122.1	378.7 ± 108.1	529.5 ± 52.2^a	199.2 ± 30.6^a	47.2 ± 17.5^a
Half Backs	6620.9 ± 784.4^a	349.3 ± 54.5^a	7.279 ± 0.866^a	77.7 ± 11.6^{ab}	366.0 ± 115.5	362.8 ± 98.8	760.6 ± 88.7^{abcd}	291.3 ± 46.4^a	58.0 ± 18.6^a
Inside Backs	6084.6 ± 779.4	471.9 ± 55.8^{abc}	7.930 ± 0.895^{abc}	71.2 ± 11.3	363.3 ± 116.2	356.5 ± 98.6	573.9 ± 57.5^a	321.1 ± 37.6^a	150.9 ± 31.9^{ab}
Outside Backs	6079.5 ± 671.7	556.5 ± 65.8^{abc}	8.385 ± 1.242^{abc}	69.7 ± 11.4	374.5 ± 111.2	365.9 ± 91.8	497.0 ± 49.8^a	336.6 ± 37.8^{ab}	219.9 ± 41.9^{abc}

^{a,b,c,d,e} *indicates significant differences.* $^\wedge$ *indicates differences for primary positional groups.* ^{a,b,c,d,e} *indicates differences for secondary positional groups.*

m/min), significantly higher than tight forwards and outside backs ($p = 0.01$).

Half backs recorded the highest distance within velocity zone 3 (760.6 ± 88.7 m), significantly higher than all secondary positional groups ($p = 0.00$). Outside backs recorded the highest distance within velocity zones 4 (336.6 ± 37.8 m), significantly different ($p = 0.01$) from tight and loose forwards, and 5 (219.9 ± 41.9 m), significantly different from tight forwards, loose forwards, and half backs ($p = 0.01$).

DISCUSSION

The current study aimed to investigate the in-match running demands of South African university rugby players by using GPS during match play for primary and secondary positional groups. To the authors' knowledge, no studies that assessed the in-match running demands of South African university rugby players have been conducted to date, which makes it difficult to draw comparisons.

The findings of the current study were similar to studies by McLellan et al. (2011) and Austin and Kelly (2014) (both elite-level rugby leagues), and Reardon et al. (2015) (elite rugby). All these studies reported that backline players achieved a greater total distance covered than the forwards during matches. Results differed only in the number of meters ran where younger players were participants. Venter et al. (2011) analyzed under-19 players, but their findings differed from the trend where front row forwards covered the most distance followed by the outside backs. Austin and Kelly (2014), however, found that players from both positional groups recorded higher total distance averages than those seen in similar studies. This could be attributed to the fact that their study involved elite rugby league players, who played with only 13 players on a regulation-sized field. The current study supported earlier findings by Austin et al. (2011) on Super 14 rugby players where backline players covered greater distances than forwards.

In the current study, the half backs recorded the highest total distance covered, with the tight forwards recording the least total distance in meters. This result was contrary to the findings of Quarrie et al. (2013), where outside backs achieved the greatest total distance (5,950 ± 755 m), followed by half backs (5,756 ± 915 m). This finding could be attributed to differences in sampling and grouping of players or the increased ball in playtime of the modern game. Austin et al. (2011) reported similar results to the findings of the current study. The study found that the inside backs achieved the greatest total distances; however, the study made use of four positional groups and combined the half backs and inside backs (Austin et al., 2011). The results for total distances covered vary to some degree between studies published in the literature. Discrepancies, such as sampling, competition level, age, and period of playing time in the case of Venter et al. (2011) could have influenced the results. Uncontrollable elements, such as the tactical planning of coaches and player fitness, would also affect the accuracy of results during match play. Teams could have further been influenced by tournament laws, such as the VC where players must overcompensate while other players in the team must sit out during the power play. Because of a lack of studies conducted on the student athlete population and the VC competition itself, strong inferences cannot be made that the law changes influenced the total distances covered. The results of the players also do not differ greatly from what has already been reported in the literature.

Limited literature is available on high-speed meters covered for primary positional groups. Players in the study by Reardon et al. (2015) covered more high-speed meters than the current study. These higher totals were possible because the participants were elite rugby players. Possible reasons for the large differences could be the inability of the tight forwards to reach the minimum speed to register high-speed meters and the number of contact events involving the tight forwards. Our findings were similar to those reported by Reardon et al. (2015) for secondary positional groups where outside backs recorded the highest and tight forwards the lowest high-speed meters. Jones et al. (2015), however, noted that the inside backs covered the most and the tight forwards covered the least distance for meters at high speed. Both studies indicate that they made use of professional players for their data collection, where player level, competition laws, and coaching tactics may affect the results of recorded data. Players exposed to high-speed meters during training may be able to cope with match loads better when experiencing constant exposure to high-speed meters. In the study by Reardon et al. (2015), the teams might have played a more running-oriented game that allowed the forwards to register more meters covered but still have the outside backs covering more meters at high speeds. Jones et al. (2015) possibly recorded teams where the tactic was to use the inside backs group to control the attacks through the middle of the field. Line breaks and higher numbers of phases could have contributed to the high number of meters by inside backs.

The maximum velocity of the primary positional groups was significantly different for the full match, whereas literature reported that the backs attained the highest scores. Our results conform to current literature (Duthie et al., 2006; Reardon et al., 2015; Tee and Coopoo, 2015) at different competition levels. The results of the current study followed a trend indicating some consistency in recorded results. Differences in results could be determined by playing level and game plans where teams play to their strengths. The maximum velocity of different playing positions of the current followed similar trends within published literature. Reardon et al. (2015) reported individual positions maximum velocities, where outside backs' positions (wingers and fullbacks) registered maximum velocities of 8.34 and 7.99 m s^{-1}, respectively. Inside backs registered 8.05 m s^{-1} (Reardon et al., 2015), which were lower than that of the outside backs, and it corresponds with the results of the current study. Owen et al. (2015) noted that forwards, because of their size and weight, were not physically able to move at high speeds, unlike the lighter smaller backline players. Forwards are also tactically used for their physicality and not necessarily speed. Another possible reason is the forwards' involvement in set pieces and phase play, which is generally slow, while backs are often already moving when they receive the ball. Another notable point is the space within which both positional groups operate in. Backs are in more open playing field, while forwards are used physically in slower phase play.

The backs recorded a higher match intensity average for the duration of the match when compared to the forwards, similar to Cunniffe et al. (2009) and Reardon et al. (2015). These high averages may be attributed to the player level because the participants were professional players. Tee and Coopoo (2015), however, reported results that differed from other studies; their study revealed that there was no statistical difference between the forwards and backs. The difference between the two groups, population fitness and game plan, may have resulted in such close scores. The inside backs and loose forwards recorded the second and third highest averages in the current study. This might be a result of the physical demands of each position, where the loose forwards are involved in rucking, tackling, and defensive work regularly compared to the inside backs and outside backs who cover more distance in single bouts and at greater speeds, but less frequently. Limited research has been conducted on match intensity, especially regarding the secondary positional groups. A possible explanation might be the practicality of the information, where coaches and researchers might not see the use of the data because they could analyze the total distance recorded. Match intensity combined with match analysis statistics might be able to distinguish player work rate during matches. Coaches could analyze a player's effectiveness on the field after seeing a high match intensity recording from a GPS unit. Similarly, match intensity may offer an indication of player intensity during training providing an indication of intensity rather than only volume as in the case with total distance.

Limited information on the number of accelerations and decelerations in rugby has been published. The current study recorded higher acceleration and deceleration counts compared to previous research by Owen et al. (2015). However, only one-half of match play was recorded in the Owen et al. study to increase the sample size. This large difference in the number of accelerations and decelerations from the current study could be attributed to the inclusion and exclusion criteria used. Delaney et al. (2018) noted that the average velocity of most team sports was between 1.3 and 2.3 m/s (low intensity), which could question the ability of the players to accelerate and decelerate. Rugby as a stop-start, high-impact sport requiring players to accelerate and decelerate numerous times within matches was highlighted by the study on Super Rugby players by Owen et al. (2015).

The constant effort to move contributes to fatigue during play, affecting the ability to perform (Hewit et al., 2011). Dalen et al. (2016) focused on accelerations and decelerations among

TABLE 4 | Practical applications and recommendations based on recorded match demands.

Position	Results	Practical application
Forwards	Covered less total distance, lower maximum velocity, lower match intensity, and completed less accelerations and decelerations.	Focus on increasing overall fitness to improve total distance and match intensity scores. Expose the groups to a series of high-intensity running protocols and construct games and drills that expose the forwards to extensive or prolonged running at a higher match intensity. Contact at higher match intensities could also be integrated into training to add more positional specificity of game demands to the conditioning of the position.
Backs	Covered more total distance, attained a higher maximum velocity, had a higher match intensity, and completed more accelerations and decelerations.	Focus on increasing overall fitness. Focus on ability to accelerate and decelerate safely and effectively from high velocity. Repeat exposure to high-intensity and high-speed running to avoid detraining effects. The implementation of repeat speed, maximal aerobic speed running, and high-intensity gameplay to further expose players that could result in overreaching on running demands.
Tight forwards	Covered the least total distance, attained the lowest maximum velocity, lowest match intensity, and lowest accelerations and decelerations.	Focus on increasing overall fitness. Focus on improving ability to perform repeated outs of high intensity to assist with increasing match intensity. Maximal aerobic speed running and drills ensuring players are overloaded adequately to meet running demands during training. Variations in work-to-rest ratios and metabolic training such as tempo or lactate running could be used.
Loose forwards	Highest number of accelerations and decelerations. High total distance, maximum velocity, and match intensity.	Focus on overall fitness. Implement acceleration and deceleration strategies to expose players to high braking and acceleration loads. Repeat speed training to further expose players to forces of acceleration and deceleration to stimulate adaptations assisting the management of braking and accelerating forces on the body.
Half backs	Highest total distance Highest match intensity	Focus on overall running fitness. Implement work-to-rest ratios within training to maximize running efficiency. Expose players to high training intensities to simulate match conditions through repeat speed, maximal aerobic speed, and overspeed running.
Inside backs	High match intensity, maximum velocity, and total distance	Focus on overall fitness. Focus on maintaining high running velocity over longer distances. Repeated bouts of high intensity running or repeat speed, while adjusting the work to rest ratios stimulating adaptations for consistent high-speed running.
Outside backs	Highest maximum velocity	Focus on overall fitness. Focus on high speed running to expose players to longer periods of high-intensity running. Maximal speed running and repeat speed ability through varied rest periods during training can be implemented. The focus may be aimed at the quality of the speed meters covered rather than the distance.

soccer players and highlighted the physical strain of accelerating and decelerating on players. Metrics such as acceleration, deceleration, mass, and velocity provide player load (Dalen et al., 2016). It is unclear whether there are trends within published literature in the number of accelerations and decelerations. It is difficult to compare literature because researchers analyze different aspects of accelerating and decelerating, such as Hewit et al. (2011); Owen et al. (2015), and Delaney et al. (2018) who reported on the forcefulness of accelerating and decelerating. Assessing the number of accelerations and decelerations may indicate match demands on players for soft tissue injury management strategies or adapted training to cope with the demands of matches.

The backs and back secondary groups outperformed both the forwards and forward secondary groups in terms of distance covered in all three zones for the duration of the match; this agrees with researched literature. Reardon et al. (2015) reported that scrumhalves and fly halves covered less distance when compared to half backs of the current study. The experimental law changes in VC should be considered, where teams may play within these velocity zones to outpace opponents and benefit from the extra points on offer for scoring. Reardon et al. (2015) did, however, report on all meters covered >5.0 m/s, lower velocities than the current study. Cahill et al. (2013) reported that scrumhalves registered higher than the reported meters in the current study, which can be attributed to the groupings of positions because scrumhalves were identified as individual positions. Quarrie et al. (2013), however, reported values of non-significant or higher recorded metrics for fly half players when viewing individual position results; this could justify the selected positional groups of the current study. As mentioned by Cahill et al. (2013); Owen et al. (2015), and Tee et al. (2017), scrumhalf and fly half positions are constantly involved in set and phase play, often as the link between the forwards and backs providing context to the roles of the position.

The limitations of this study were GPS units that malfunctioned, reducing the number of valid data points, small sample size, and recording only 17 matches. The study has highlighted the following limitations: (1) small sample size due to GPS malfunction, players and teams not meeting the GPS or minimum time requirements, and only recording two teams over one competitive season; (2) lack of normative values for velocity thresholds; (3) lack of normative values for velocity thresholds for both primary and secondary positional groups, as well as the use of absolute thresholds over individualized thresholds; (4) tactical substitutions of players further reducing sample size; (5) no consistent data on valid inclusion times for player data; and (6) no contact data recorded, which may have impacted the results seen for some metrics.

Practical Implications

The coaching staff in a university rugby environment can identify player demands during match play and focus efforts on these areas during training. **Table 4** represents the positional recommendations for primary and secondary positional groups based on match-recorded data. Season and session planning may be taken into consideration, or for priority matches and examination periods. Recorded data on player running demands may also provide an indication of player ability during match play, which could be paired with training data. Similarly, the coaching staff may plan or cancel sessions based on player load data, where specific session running demands could increase player injury risk. Coaching sessions that may have yielded superior or inferior results than expected could lead to changes in the planning of player training sessions. This form of player monitoring would ideally enhance the management of player loads. The possibility of individualized player profiles or primary and secondary positional profiles can assist teams with regard to accuracy in which they prepare and execute training. Adjustments to velocity zones for the different positional groups can be done to accurately represent player ability during training. The recorded data reported here, paired with video analysis, could provide an even better indication of player movement and tactical impacts on playing positions for the future of rugby at a university level in South Africa.

CONCLUSION

The major findings of the study note that backs covered higher speed meters and achieved higher maximum velocities than forwards for primary positional groups. The halfbacks covered the highest total distance and the most distance within velocity zone 3, and the outside back covered the highest high-speed meters among all secondary positional groups. Although the VC competition had a variety of law changes, many of the results remained significantly unchanged as seen in previous research listed in the "Discussion" section. As mentioned before, the involvement of the half back positions during a match may indicate the importance of conditioning in those specific positions for players to be able to handle the specific match loads. It is also important to note that no impact data have been recorded, where such data might better describe the lower totals of the tight forwards group involved in the set phases of play. Recorded data of the current study might serve as a stepping stone to in-match running demands in the South African university rugby context and stimulate further research on other aspects of this unique population and a changing game. It must be noted that only two universities were part of the study, and the results do not represent the whole university rugby population. Further research should be aimed at developing training programs catering to the demands of match play during training. These programs should be tailored to a specific metric, such as total distance or high-speed meters, and the implications thereof. Further research on player wellness during training demands spikes or increased loads to simulate match conditions, which leads to another avenue to explore, namely, player management.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethics Committee (HSREC) (UFS-HSD2017/0062) at the University of the Free State approved the study. The patients/participants provided their written informed consent to participate in this study.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

CD collected the data and drafted the manuscript. All authors contributed to the article and approved the submitted version.

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REFERENCES

Austin, D., Gabbett, T., and Jenkins, D. (2011). The physical demands of Super 14 rugby union. *J. Sci. Med. Sport* 14, 259–263. doi: 10.1016/j.jsams.2011.01.003

Austin, D. J., and Kelly, S. J. (2014). Professional rugby league positional match-play analysis through the use of global positioning system. *J. Strength Cond. Res.* 28, 187–193. doi: 10.1519/jsc.0b013e318295d324

Cahill, N., Lamb, K., Worsfold, P., Headey, R., and Murray, S. (2013). The movement characteristics of English Premiership rugby union players. *J. Sports Sci.* 31, 229–237. doi: 10.1080/02640414.2012.727456

Cummins, C., Orr, R., O'Connor, H., and West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Med.* 43, 1025–1042. doi: 10.1007/s40279-013-0069-2

Cunniffe, B., Proctor, W., Baker, J. S., and Davies, B. (2009). An evaluation of the physiological demands of elite rugby union using global positioning system tracking software. *J. Strength Cond. Res.* 23, 1195–1203. doi: 10.1519/jsc.0b013e3181a3928b

Cunningham, D., Shearer, D. A., Drawer, S., Eager, R., Taylor, N., Cook, C., et al. (2016). Movement demands of elite U20 international rugby union players. *PLoS One* 11:e0153275. doi: 10.1371/journal.pone.0153275

Dalen, T., Ingebrigtsen, J., Ettema, G., Hjelde, G. H., and Wisløff, U. (2016). Player load, acceleration, and deceleration during forty-five competitive matches of elite soccer. *J. Strength Cond. Res.* 30, 351–359. doi: 10.1519/jsc.0000000000001063

Delaney, J. A., Cummins, C. J., Thornton, H. R., and Duthie, G. M. (2018). Importance, reliability, and usefulness of acceleration measures in team sports. *J. Strength Cond. Res.* 32, 3485–3493. doi: 10.1519/jsc.0000000000001849

Duthie, G., Pyne, D., and Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Med.* 33, 973–991. doi: 10.2165/00007256-200333130-00003

Duthie, G. M., Pyne, D. B., Marsh, D. J., and Hooper, S. L. (2006). Sprint patterns in rugby union players during competition. *J. Strength Cond. Res.* 20, 208–214. doi: 10.1519/00124278-200602000-00034

Harris, J., and Wise, N. (2011). Geographies of scale in international rugby union. *Geograph. Res.* 49, 375–383. doi: 10.1111/j.1745-5871.2011.00714.x

Hewit, J., Cronin, J., Button, C., and Hume, P. (2011). Understanding deceleration in sport. *Strength Condition. J.* 33, 47–52. doi: 10.1519/ssc.0b013e3181fbd62c

Jones, M. R., West, D. J., Crewther, B. T., Cook, C. J., and Kilduff, L. P. (2015). Quantifying positional and temporal movement patterns in professional rugby union using global positioning system. *Eur. J. Sport Sci.* 15, 488–496. doi: 10.1080/17461391.2015.1010106

Lindsay, A., Draper, N., Lewis, J., Gieseg, S. P., and Gill, N. (2015). Positional demands of professional rugby. *Eur. J. Sport Sci.* 15, 480–487. doi: 10.1080/17461391.2015.1025858

McLellan, C. P., Lovell, D. I., and Gass, G. C. (2011). Performance analysis of elite rugby league match play using global positioning systems. *J. Strength Cond. Res.* 25, 1703–1710. doi: 10.1519/jsc.0b013e3181ddf678

Owen, S. M., Venter, R. E., Du Toit, S., and Kraak, W. J. (2015). Acceleratory match play demands of a Super Rugby team over a competitive season. *J. Sports Sci.* 33, 2061–2069. doi: 10.1080/02640414.2015.1028086

Quarrie, K. L., and Hopkins, W. G. (2007). Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004. *J. Sports Sci.* 25, 895–903. doi: 10.1080/02640410600944659

Quarrie, K. L., Hopkins, W. G., Anthony, M. J., and Gill, N. D. (2013). Positional demands of international rugby union: evaluation of player actions and movements. *J. Sci. Med. Sport* 16, 353–359. doi: 10.1016/j.jsams.2012.08.005

Reardon, C., Tobin, D. P., and Delahunt, E. (2015). Application of individualized speed thresholds to interpret position specific running demands in elite professional rugby union: a GPS study. *PLoS One* 10:e0133410. doi: 10.1371/journal.pone.0133410

Rothwell, M., Stone, J. A., Davids, K., and Wright, C. (2017). Development of expertise in elite and sub-elite British rugby league players: a comparison of practice experiences. *Eur. J. Sport Sci.* 17, 1252–1260. doi: 10.1080/17461391.2017.1380708

Schoeman, R., and Coetzee, D. F. (2014). Time-motion analysis: discriminating between winning and losing teams in professional rugby. *South Afr. J. Res. Sport Phys. Educ. Recreat.* 36, 167–178.

Tee, J. C., Ashford, M., and Piggott, D. (2018). A tactical periodization approach for rugby union. *Strength Condition. J.* 40, 1–13. doi: 10.1519/ssc.0000000000000390

Tee, J. C., and Coopoo, Y. (2015). Movement and impact characteristics of South African professional rugby union players. *South Afr. J. Sports Med.* 27, 33–39.

Tee, J. C., Lambert, M. I., and Coopoo, Y. (2017). Impact of fatigue on positional movements during professional rugby union match play. *Int. J. Sports Physiol. Perform.* 12, 554–561. doi: 10.1123/ijspp.2015-0695

Vahed, Y., Kraak, W., and Venter, R. (2014). The effect of the law changes on time variables of the South African Currie Cup Tournament during 2007 and 2013. *Int. J. Perform. Anal. Sport* 14, 866–883. doi: 10.1080/24748668.2014.11868764

Venter, R. E., Opperman, E., and Opperman, S. (2011). The use of global positioning system (GPS) tracking devices to assess movement demands and impacts in under-19 rugby union match play: sports technology. *Afr. J. Phys. Health Educ. Recreat. Dance* 17, 1–8. doi: 10.1016/j.humov.2016.05.007

Vilar, L., Araújo, D., Davids, K., and Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Med.* 42, 1–10. doi: 10.2165/11596520-000000000-00000

Yamamoto, H., Takemura, M., Kaya, M., and Tsujita, J. (2017). Physical demands of elite rugby union match-play using global positioning system. *Football Sci.* 14, 15–23.

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Performance Advantages of Left-Handed Cricket Batting Talent

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The purpose of this study was to examine performance advantages associated with batting stance, in the form of left- vs. right-handed dominant stance, and orthodox vs. reverse stance, of talented junior cricket batters within age-restricted competitions. Data were sourced from the national male younger age competition (YAC; Under-17; $n = 237$) and older age competition (OAC; Under-19; $n = 302$), as well as female YAC (Under-15; $n = 234$) and OAC (Under-18; $n = 260$) over a 4-year period. Left-hand dominant (LHD) batters were consistently overrepresented in the male YAC (Right: 69.2%; Left: 30.8%) and OAC (Right: 68.2%; Left: 31.8%) compared with the expected general population distribution. Male LHD batters exhibited a significantly ($p < 0.05$) higher batting aggregate (YAC: 116.82 ± 84.75 vs. 137.84 ± 89.74; OAC: 117.07 ± 89.00 vs. 146.28 ± 95.99), scored more runs (YAC: 19.65 ± 12.32 vs. 23.96 ± 14.71; OAC: 19.27 ± 12.61 vs. 23.98 ± 14.15), spent more time batting (YAC: 45.33 ± 25.89 min vs. 54.59 ± 28.62 min; OAC: 39.80 ± 21.79 min vs. 49.33 ± 27.41 min), and scored more boundary-4s per game (YAC: 1.83 ± 1.40 vs. 2.44 ± 1.87; OAC: 1.76 ± 1.32 vs. 2.19 ± 1.83), across both YAC and OAC groups with small effect sizes. No overrepresentation was present for either female group (YAC, Right: 88.5%/Left: 11.5%; OAC, Right: 90.0%/Left: 10.0%). Female LHD batters exhibited significantly higher batting aggregate (68.97 ± 53.17 vs. 102.96 ± 73.48), batting average (13.24 ± 10.88 vs. 17.75 ± 12.28), and spent more time batting per game (25.52 ± 15.08 vs. 37.75 ± 26.76 min), but only at the OAC level with small-moderate effects sizes. Finally, there were few performance advantages identified to batting with a reverse stance, with further work needed to clarify any potential biomechanical benefits. Team selection practices may exploit the left-handed advantage by over-selecting talented left-handed junior cricketers. Practical implications for coaches include creating practice environments that negate the negative frequency-dependent selection, such as providing more practice opportunities for their players against left-handed opponents.

Keywords: handedness, laterality, frequency dependence, talent identification and development, talent selection

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INTRODUCTION

The overrepresentation of left-handers, compared with the expected distribution seen in the general population, has been well established within interactive time-restrictive skills (Hagemann, 2009; Harris, 2010; Loffing, 2017). The most prominent explanation for the left-hander's advantage has been the *negative frequency-dependent hypothesis* (Raymond et al., 1996; Grouios, 2004). This hypothesis presumes that athletes in interactive sports are much more likely to play and practice against right-handed opponents. As a result, these athletes develop both greater familiarity and highly specific skills to anticipate the action outcomes of their right-handed opponents via attunement to crucial perceptual information (Loffing and Hagemann, 2014). While a greater proportion of left-handers are commonly observed in high-level sports (∼30%) compared to the general population incidence (∼10–15%), a specific left-handed performance advantage during competition has not been clearly reported (Grouios et al., 2000; Loffing, 2017).

Evidence of a relative advantage for anticipating the actions of a right-handed (or footed) opponent has been reported across a number of interactive tasks including predicting left- and right-handed serves in volleyball (Loffing et al., 2012b), predicting kicking direction from left- and right-footed opponents in soccer (McMorris and Colenso, 1996) and predicting left- and right-handed serves in tennis (Loffing et al., 2009). Loffing et al. (2012a) concluded that the performance advantage for left-handers may be attributed to more highly skilled visual perception, stemming from more frequent encounters with right-handers (Loffing et al., 2012b). Unsurprisingly, handedness has also been reported as a potentially influential factor in team selection, with Brooks et al. (2004) finding that the most successful teams at the 2003 Cricket World Cup had nearly 50% representation of left-handed cricket batsmen.

Additional explanations for the prominence of left-handers within elite sporting teams have also included potential advantages afforded by sport-specific rule constraints and innate technical advantages (Grondin et al., 1999). For instance, Raymond et al. (1996) suggested that a greater frequency of left-handers may result from the constraints (e.g., rules) within the performance environment. For example, baseball batters who bat left-handed may have tactical or strategic advantages in that (i) their stance places them closer to first base toward which they must run and (ii) their momentum at the end of the swing is already directed toward first base (as opposed to toward third base for batters with a right-handed stance). Similarly, the leg-before-wicket rule in cricket may advantage cricket batters who bat left-handed. In the familiar situation of facing a right-handed bowler, it is much more challenging for a left-handed batter to be dismissed leg-before-wicket due to particularities in where the ball must bounce to be adjudicated as "out." However, potential advantages of handedness within interactive sporting tasks remain in development (Mann et al., 2017). Mann et al. (2016) examined the prevalence of left-handedness in elite cricket batters and found not only an increased frequency of left-hand dominant (LHD) stance cricket batters, but also a tendency for batters (particularly left-handers) to adopt a "back-to-front" batting stance. The reverse stance hypothesis was therefore proposed as a potential technical advantage when holding a cricket bat with the dominant hand positioned further away from the hitting end of the bat (Mann et al., 2016). Interestingly, this stance was more common in LHD stance batters and it is unknown as to what degree either factor influences performance.

While there is evidence that left-handedness—and perhaps a "reversed stance"—may be advantageous at the elite level of competition (Mann et al., 2016), much less is known about the age, gender, or performance level at which these advantages might emerge, particularly as other talent selection bias has been previously highlighted in cricket (Connor et al., 2019). If the *negative frequency-dependent hypothesis* were apparent, then it might be reasonable to expect the advantage of the left-handed cricket batters to increase over time due to a progressive accrual of experience competing against right vs. left-handed opponents. Loffing et al. (2012a) reported a moderate positive impact of left-handedness on tennis performance, which decreased over a time span of years for males, and was almost entirely absent in professional female tennis players. These results suggest that a left-hander's advantage may primarily happen within lower performance levels and be a rarity at the elite level. Alternately, others have shown that the magnitude of some performance advantages increases and can become increasingly more important, along the developmental pathway (Weissensteiner et al., 2008). Therefore, development of a handedness advantage at the junior level may be important for future performance, yet remains to be confirmed.

The aim of this study was to examine the magnitude of performance advantages associated with batting stance, in the form of left- vs. right-handed dominant stance, and orthodox vs. reverse stance, in junior cricket players within age-restricted competitions. Both male and female players were examined to account for any potential sex differences in performance due to handedness (Loffing, 2017). We hypothesized that the magnitude of the performance advantage, associated with batting handedness (left vs. right) and batting stance (orthodox vs. reverse), would be larger for both male and female cricket batters participating in the older age competition (OAC).

MATERIALS AND METHODS

Participants and Procedures

Playing data for all male younger-age cricketers who competed at the Annual National Junior championships in Australia between 2012 and 2015 were obtained from an open source online database[1] (excluding male Under-17, which included data from 2013 to 2015) and confirmed via the National Sporting body's database. Players were then separated into whether they competed in the younger age competition (YAC; male Under-17 and female Under-15) or the OAC (male Under-19 and female Under-18). Batting handedness was determined by the players throwing hand, in line with previous work (Cairney et al., 2018). Players were included and categorized as batters if they (1) were

[1] www.nationalchamps.com.au

listed by the coach as a batter in the top seven positions and (2) batted in these positions during at least three innings of the tournament. In total, 237 YAC and 302 OAC-19 males, and 234 YAC and 260 OAC female players met the criteria. This research received institutional approval from James Cook University (H6267) and was conducted in accordance with the National Statement on Ethical Conduct in Human Research (2007).

Data Analysis

Measures of batting performance were collated from the tournament database. Two measures of absolute performance were recorded: (i) *batting aggregate*, representing the total number of runs scored at the tournament, and (ii) *number of innings batted*. Relative measures included (i) *batting average* (i.e., number of runs scored divided by number of dismissals), (ii) *runs per innings* (i.e., number of runs scored divided by number of innings), (iii) *strike rate* (i.e., runs scored per 100 balls), (iv) *boundary-4s per game* (i.e., average number of "fours" scored per innings), (v) *boundary-6s per game* (i.e., average number of "sixes" scored per innings), and (vi) *time per innings* (i.e., average time spent batting per innings). Finally, the percentage of innings was recorded where the batter was (i) *not dismissed* (i.e., not outs), and where the batter had scored (ii) *ducks* (i.e., scores of 0 runs per player) and (iii) *centuries* (i.e., scores of 100 runs or more per player). Participant's batting handedness was recorded as either right-hand dominant (RHD) or LHD. Batting stance was also recorded as being *orthodox* (dominant hand placed on the bottom of the bat) if the dominant hand matched the batting handedness (e.g., left-handed batter, LHD) or *reversed* (dominant hand placed on top off the bat) if the dominant hand did not match the batting handedness (e.g., right-handed batter, LHD).

Statistical Analysis

All data were analyzed using the Statistical Package of Social Sciences (SPSS, version 25, IBM Corp., Armonk, NY, United States) with the alpha level set at ≤ 0.05 and descriptive information expressed as mean $\pm$ standard deviation. First, any over- or underrepresentation of left-handedness, when compared with the proportions expected from the general population (RH = 85%; LH = 15%; Raymond et al., 1996; Johnston et al., 2009; Medland et al., 2009), was determined using chi-squared goodness-of-fit tests. Measures of batting performance measures were compared between groups (e.g., left- and right-handed stances; orthodox and reverse stances) using separate one-way MANOVAs for each group. Effect sizes (95% confidence interval) were calculated using Cohen's *d*, and reported as 0.2, 0.5, and 0.8 as small, moderate, and large, respectively (Cohen, 1988).

RESULTS

Representation

There was a significant overrepresentation of LHD cricket batters compared with the general population at both the YAC and OAC male level (**Table 1**). For females, there was no significant overrepresentation of LHD cricket batters at either the YAC or OAC level when compared to the left-handedness expected of the general population (**Table 2**).

Batting Performance—Males

Irrespective of their age group, when compared to RHD cricket batters, LHD male batters had significantly higher batting aggregates, runs per innings, time spent batting, and boundary-4s (small ES, **Table 2**). LHD in the YAC group had a significantly higher batting average ($p < 0.05$), whereas the advantage in the OAC group for LHD batters was marginal ($p = 0.07$). LHD batters also exhibited significantly less ducks in the YAC group only, and significantly more centuries scored in the OAC group ($p < 0.05$). All other variables across both YAC and OAC groups were similar, including the number of matches, innings, boundary-6s, and strike rate, with all exhibiting a small ES (**Table 2**).

Batting Performance—Females

There was no significant difference between LHD and RHD batters for each performance measure at the YAC level (all small ES, **Table 3**). At the OAC level, LHD exhibited significantly greater batting aggregate, batting average, average runs per game, and batting time ($p < 0.05$; small-moderate ES, **Table 3**). No other differences were observed between LHD and RHD batters at the OAC level for number of matches or innings, boundary-4s and -6s scored, strike rate, non-dismissals, and ducks or centuries scored (small ES, **Table 3**).

Batting Stance

Younger age competition reverse stance male cricket batters had significantly greater batting time (small-moderate ES) compared with orthodox stance batters ($p < 0.05$) while no other significant differences between batting variables were evident between the different stances (trivial to small-moderate ES, **Table 4**). The OAC reverse stance batters also had significantly greater batting time as well as greater boundary-4s (small-moderate ES, **Table 4**) compared with orthodox stance batters ($p < 0.05$). There were no other significant differences evident between the different stances for OAC level (trivial to small-moderate ES, **Table 4**).

Female cricket batters with a reverse batting stance in the YAC group exhibited significantly greater batting aggregate and batting time ($p < 0.05$; small ES, **Table 5**). Batting average was also greater for reverse stance female batters ($p < 0.05$). No other differences were evident between reverse and orthodox stance for the YAC group. There were also no significant differences between stances for any performance measure at the OAC level (trivial to small-moderate ES, **Table 5**).

DISCUSSION

The purpose of this study was to examine the magnitude of performance advantages associated with various batting stances, within an interactive striking task. We found that LHD cricket batters were overrepresented in competition for junior males, but not for females. Furthermore, male LHD batters in both groups scored more runs and batted for longer periods of time when compared with their right-handed counterparts. For

TABLE 1 | Number (and percentage) of left- and right-hand dominant male and female batters.

	Competition level	Right-handed batting stance	Left-handed batting stance	χ^2	*p*-Value
Male	YAC	164 (69.2%)	73 (30.8%)	19.58	<0.001
	OAC	206 (68.2%)	96 (31.8%)	22.14	<0.001
Female	YAC	207 (88.5%)	27 (11.5%)	0.96	0.33
	OAC	234 (90.0%)	26 (10.0%)	1.96	0.16

General population left-handedness = 15%.

TABLE 2 | Mean (±standard deviation) batting performances measures for left- and right-handed male batters during the YAC and OAC and effect size calculations between batters with associated 95% confidence interval (CI).

		Right-handed batting stance	Left-handed batting stance	Effect size (95% CI)	*p*-Value
Matches	YAC	6.26 ± 1.56	5.99 ± 1.58	0.17 (– 0.11, 0.45)	0.22
	OAC	5.80 ± 1.43	5.83 ± 1.63	0.02 (– 0.26, 0.22)	0.86
Innings	YAC	5.65 ± 1.63	5.85 ± 1.51	0.12 (– 0.40, 0.16)	0.39
	OAC	5.77 ± 1.53	5.71 ± 1.46	0.04 (– 0.20, 0.28)	0.74
Batting aggregate	YAC	116.82 ± 84.75	137.84 ± 89.74	0.24 (– 0.49, 0.00)	<0.05
	OAC	117.07 ± 89.00	146.28 ± 95.99	0.32 (– 0.60, –0.04)	<0.05
Batting average	YAC	22.78 ± 14.41	27.63 ± 17.09	0.32 (– 0.56, –0.07)	<0.05
	OAC	23.76 ± 17.02	28.19 ± 17.62	0.26 (– 0.54, 0.02)	0.07
Runs per innings	YAC	19.65 ± 12.32	23.96 ± 14.71	0.33 (– 0.57, –0.08)	<0.01
	OAC	19.27 ± 12.61	23.98 ± 14.15	0.36 (– 0.64, –0.08)	<0.05
Batting time (per game)	YAC	45.33 ± 25.89	54.59 ± 28.62	0.35 (– 0.59, –0.10)	<0.01
	OAC	39.80 ± 21.79	49.33 ± 27.41	0.40 (– 0.68, –0.12)	<0.01
Boundary-4s (per game)	YAC	1.83 ± 1.40	2.44 ± 1.87	0.39 (– 0.64, –0.15)	<0.01
	OAC	1.76 ± 1.32	2.19 ± 1.83	0.29 (– 0.56, 0.00)	<0.05
Boundary-6s (per game)	YAC	0.24 ± 0.38	0.26 ± 0.38	0.05 (– 0.29, 0.19)	0.69
	OAC	0.21 ± 0.35	0.26 ± 0.35	0.17 (– 0.44, 0.11)	0.25
Strike rate	YAC	57.11 ± 21.84	58.86 ± 18.25	0.08 (– 0.33, 0.16)	0.50
	OAC	59.43 ± 22.68	60.75 ± 20.67	0.06 (– 0.34, 0.22)	0.67
Non-dismissal (%)	YAC	12.07 ± 15.54	8.87 ± 12.99	0.09 (– 0.15, 0.33)	0.47
	OAC	15.45 ± 18.59	13.72 ± 15.35	0.10 (– 0.18, 0.38)	0.29
Ducks scored	YAC	11.58 ± 11.37	7.25 ± 13.21	0.34 (0.06, 0.62)	<0.05
	OAC	10.31 ± 14.21	7.521 ± 1.41	0.21 (– 0.04, 0.45)	0.09
Centuries scored	YAC	1.88 ± 8.07	3.18 ± 5.90	0.20 (– 0.47, 0.08)	0.17
	OAC	1.29 ± 4.71	3.29 ± 7.57	0.35 (– 0.59, –0.10)	<0.05

female LHD cricket batters, only the OAC group scored more runs and spent more time batting compared with their right-handed counterparts. Reverse stance batters exhibited some performance advantages over orthodox stance batters, including greater batting time (YAC and OAC) and boundary-4s (OAC) for males, and greater runs scored and batting time for female cricket batters (YAC). These findings demonstrate evidence of a small left-handed advantage in cricket batting, with limited performance advantage for either orthodox or reverse batting stance at the youth representative level.

Left-handed male cricket batters were found to be more prevalent in junior elite competition when compared to the proportion expected from the general population (**Table 1**). Similar findings have been reported at the elite level for males, whereby batting records from the 2003 cricket World Cup showed that the most successful teams in the competition had close to 50% representation of left-handed batsmen (Brooks et al., 2004). Mann et al. (2016) investigated left- and right-handedness among the greatest elite male cricket batters to have played the game, and reported comparable proportions to this study (left-handers = 33%; right-handers = 67%). Additionally, Mann et al. recorded the handedness of inexperienced cricket batters, finding levels comparable to the general population (left-handers = 15.2%; right-handers = 84.8%). Collectively, the current and prior findings confirm an overrepresentation of left-handed cricket batters at the elite junior and senior levels (Mann et al., 2016; Loffing, 2017).

Hagemann (2009), in his review of advantages according to handedness, reported that overrepresentations commonly occur in sporting tasks that involve the anticipation of an opponent's action. There has also been further suggestion that left-handedness is particularly evident during more temporally demanding sporting tasks such as tennis, cricket batting, or baseball batting (Loffing et al., 2010, 2012b; Loffing, 2017), although the exact temporal demand threshold at which a handedness advantage becomes apparent is unclear. It is thought

TABLE 3 | Mean (±standard deviation) batting performances measures for left- and right-handed female batters during the YAC and OAC and effect size calculations between batters with associated 95% confidence interval (CI).

		Right-handed batting stance	Left-handed batting stance	Effect size (95% CI)	*p*-Value
Matches	YAC	7.54 ± 0.51	7.40 ± 0.50	0.28 (– 0.13, 0.69)	0.18
	OAC	7.50 ± 0.65	7.56 ± 0.58	0.08 (– 0.48, 0.32)	0.69
Innings	YAC	6.46 ± 1.65	6.60 ± 1.32	0.09 (– 0.50, 0.32)	0.67
	OAC	6.22 ± 1.32	6.67 ± 1.41	0.34 (– 0.74, 0.07)	0.10
Batting aggregate	YAC	76.96 ± 63.48	92.24 ± 63.02	0.24 (– 0.65, 0.17)	0.25
	OAC	68.97 ± 53.17	102.96 ± 73.48	0.61(– 1.01, –0.20)	<0.01
Batting average	YAC	15.01 ± 13.03	17.00 ± 12.15	0.15 (– 0.57, 0.26)	0.47
	OAC	13.24 ± 10.88	17.75 ± 12.28	0.41(– 0.81, 0.00)	<0.05
Runs per innings	YAC	11.25 ± 8.23	13.57 ± 8.09	0.28 (– 0.69, 0.13)	0.18
	OAC	10.66 ± 7.84	14.54 ± 8.89	0.49 (– 0.89, –0.08)	<0.05
Batting time	YAC	21.64 ± 12.50	24.76 ± 12.90	0.25 (– 0.66, 0.17)	0.24
	OAC	25.52 ± 15.08	37.75 ± 26.76	0.73 (– 1.13, –0.32)	<0.01
Boundary-4s	YAC	1.22 ± 1.08	1.43 ± 1.08	0.20 (– 0.61, 0.22)	0.35
	OAC	0.74 ± 0.75	1.00 ± 1.02	0.34 (– 0.74, 0.07)	0.10
Boundary-6s	YAC	0.03 ± 0.11	0.02 ± 0.07	0.03 (– 0.39, 0.44)	0.90
	OAC	0.02 ± 0.06	0.00 ± 0.03	0.21 (– 0.20, 0.61)	0.31
Strike rate	YAC	56.61 ± 23.60	63.33 ± 22.34	0.29 (– 0.70, 0.13)	0.18
	OAC	50.19 ± 20.33	50.75 ± 12.91	0.03 (– 0.43, 0.37)	0.89
Non-dismissals (%)	YAC	19.28 ± 17.80	17.44 ± 16.72	0.10 (– 0.31, 0.52)	0.62
	OAC	16.43 ± 15.82	15.22 ± 12.54	0.08 (– 0.32, 0.48)	0.70
Ducks scored	YAC	0.15 ± 0.17	0.16 ± 0.14	0.06 (– 0.46, 0.34)	0.68
	OAC	0.14 ± 0.14	0.14 ± 0.16	0.00 (– 0.41, 0.41)	0.98
Centuries scored	YAC	0.00 ± 0.02	0.00 ± 0.00	0.00 (– 0.40, 0.40)	0.47
	OAC	0.00 ± 0.03	0.00 ± 0.00	0.00 (– 0.41, 0.41)	0.63

TABLE 4 | Mean (±standard deviation) batting performances measures for orthodox and reverse stance during the male YAC and OAC and effect size calculations between batters with associated 95% confidence interval (CI).

		Orthodox batting stance	Reverse batting stance	Effect size (95% CI)	*p*-Value
Matches	YAC	6.21 ± 1.55	6.04 ± 1.62	0.11 (– 0.21, 0.42)	0.50
	OAC	5.83 ± 1.44	5.75 ± 1.64	0.05 (– 0.21, 0.31)	0.71
Innings	YAC	5.69 ± 1.59	5.73 ± 1.62	0.03 (– 0.34, 0.29)	0.85
	OAC	5.82 ± 1.52	5.53 ± 1.43	0.19 (– 0.59, –0.06)	0.16
Batting aggregate	YAC	121.44 ± 90.45	142.90 ± 96.54	–0.23 (– 0.55, 0.08)	0.15
	OAC	120.99 ± 86.07	131.45 ± 89.08	–0.12 (– 0.38, 0.14)	0.37
Batting average	YAC	24.71 ± 17.50	26.59 ± 16.51	–0.11 (– 0.42, 0.21)	0.50
	OAC	23.83 ± 15.03	25.89 ± 16.71	–0.13 (– 0.40, 0.13)	0.32
Runs per innings	YAC	19.97 ± 13.13	23.45 ± 13.43	–0.26 (– 0.58, 0.05)	0.10
	OAC	20.29 ± 12.42	23.31 ± 15.46	–0.23 (– 0.49, 0.04)	0.09
Batting time (per game)	YAC	41.14 ± 23.53	48.58 ± 25.00	–0.31 (– 0.63, 0.00)	<0.05
	OAC	46.45 ± 25.73	54.02 ± 30.43	–0.28 (– 0.54, –0.02)	<0.05
Boundary-4s (per game)	YAC	1.84 ± 1.53	2.07 ± 1.39	–0.15 (– 0.47, 0.16)	0.35
	OAC	1.90 ± 1.42	2.41 ± 1.99	–0.32 (– 0.59, –0.06)	<0.05
Boundary-6s (per game)	YAC	0.21 ± 0.34	0.29 ± 0.38	–0.23 (– 0.54, 0.09)	0.16
	OAC	0.24 ± 0.38	0.26 ± 0.41	–0.04 (– 0.30, 0.23)	0.78
Strike rate	YAC	59.48 ± 22.46	61.13 ± 20.61	–0.07 (– 0.39, 0.24)	0.64
	OAC	57.73 ± 21.06	57.48 ± 19.89	0.01 (– 0.25, 0.28)	0.93
Non-dismissal (%)	YAC	16.02 ± 18.34	10.78 ± 14.21	0.30 (– 0.02, 0.61)	0.06
	OAC	12.71 ± 15.54	8.90 ± 13.17	0.25 (– 0.01, 0.52)	0.06
Ducks scored	YAC	0.11 ± 0.13	0.08 ± 0.10	0.21 (– 0.11, 0.52)	0.20
	OAC	0.10 ± 0.14	0.07 ± 0.11	0.24 (– 0.02, 0.51)	0.07
Centuries scored	YAC	0.02 ± 0.06	0.03 ± 0.08	0.15 (– 0.46, 0.17)	0.36
	OAC	0.02 ± 0.05	0.03 ± 0.07	0.22 (– 0.49, 0.04)	0.10

TABLE 5 | Mean (±standard deviation) batting performance measures for orthodox and reverse stance during the female YAC and OAC tournaments and effect size calculations between batters with associated 95% confidence interval (CI).

		Orthodox batting stance	Reverse batting stance	Effect size (95% CI)	*p*-Value
Matches	YAC	7.55 ± 0.51	7.36 ± 0.49	0.37 (– 0.04, 0.78)	0.08
	OAC	7.49 ± 0.66	7.60 ± 0.55	−0.17 (– 0.53, 0.19)	0.36
Innings	YAC	6.44 ± 1.64	6.80 ± 1.29	−0.23 (– 0.64, 0.19)	0.28
	OAC	6.25 ± 1.31	6.37 ± 1.50	−0.09 (– 0.45, 0.27)	0.62
Batting aggregate	YAC	75.79 ± 62.60	103.08 ± 67.59	−0.43 (– 0.85, −0.02)	<0.05
	OAC	72.24 ± 57.47	76.60 ± 53.07	−0.08 (– 0.44, 0.28)	0.68
Batting average	YAC	14.82 ± 13.00	18.78 ± 12.02	−0.45 (– 0.72, 0.11)	<0.05
	OAC	13.83 ± 11.58	13.38 ± 8.10	0.04 (– 0.32, 0.40)	0.83
Runs per innings	YAC	11.11 ± 8.18	14.82 ± 8.09	−0.31 (– 0.87, −0.04)	0.15
	OAC	11.09 ± 8.29	11.17 ± 6.58	−0.01 (– 0.37, 0.35)	0.96
Batting time (per game)	YAC	21.38 ± 12.48	27.15 ± 12.22	−0.46 (– 0.88, −0.05)	<0.05
	OAC	26.99 ± 16.93	26.58 ± 19.02	0.02 (– 0.34, 0.38)	0.90
Boundary-4s (per game)	YAC	1.21 ± 1.07	1.55 ± 1.12	−0.31 (– 0.72, 0.10)	0.14
	OAC	0.77 ± 0.81	0.78 ± 0.68	−0.02 (– 0.37, 0.34)	0.93
Boundary-6s (per game)	YAC	0.03 ± 0.11	0.02 ± 0.07	0.08 (– 0.33, 0.49)	0.70
	OAC	0.02 ± 0.06	0.01 ± 0.03	−0.02 (– 0.20, 0.52)	0.39
Strike rate	YAC	56.66 ± 24.10	62.91 ± 16.60	−0.27 (– 0.68, 0.15)	0.21
	OAC	49.42 ± 18.65	54.99 ± 24.10	−0.28 (– 0.64, 0.08)	0.12
Non-dismissal (%)	YAC	19.27 ± 17.98	17.52 ± 14.73	0.10 (– 0.31, 0.51)	0.64
	OAC	16.45 ± 15.78	15.34 ± 13.72	0.07 (– 0.29, 0.43)	0.70
Ducks scored	YAC	0.15 ± 0.17	0.13 ± 0.12	0.12 (– 0.29, 0.54)	0.20
	OAC	0.14 ± 0.14	0.17 ± 0.16	0.22 (– 0.58, 0.14)	0.07
Centuries scored	YAC	0.00 ± 0.02	0.00 ± 0.00	0.15 (– 0.26, 0.57)	0.36
	OAC	0.00 ± 0.03	0.00 ± 0.00	0.10 (– 0.26, 0.46)	0.10

that the *negative frequency* effect may influence the acquisition of perceptual or strategic skills required to outperform a left-handed opponent (Schorer et al., 2012). Specifically, a greater proportion of practice time would likely be spent against right-handed opponents, which may afford better attunement to the perceptual information available from right-handers. This may result in increased difficulty when responding to or anticipating the actions of left-handers (Schorer et al., 2012), given the fewer experiences practicing against skillful left-handers (compared with right-handers).

This study also highlighted a number of performance advantages for left-handed male cricket batters, irrespective of their elite age level competition (**Tables 2**, **3**). LHD batters had greater run scoring metrics (e.g., batting aggregate, batting average, runs per innings), batted for a longer period of time, and struck more boundary-4s. It should be noted that while there was a significant difference between these measures, there were also small effect sizes between LHD and RHD batters. No differences between strike rate, boundary-6s, and non-dismissals suggest that LHD batters do not score at a faster rate, nor are they dismissed by the opposition any less often than RHD (e.g., see **Table 2**). Some studies have also reported performance metric advantages for left-handers in other interceptive striking sports such as tennis and baseball (Grondin et al., 1999; Loffing et al., 2010), though there has been far less reported evidence for interactive sports which do not involve a striking implement (Baker and Schorer, 2013; Tirp et al., 2014; Cingoz et al., 2018). Rather than being explained by innate factors, the superiority of left-handers during sporting tasks can be explained due to a combination of tactical or strategic factors (Grouios et al., 2000; Loffing et al., 2012a). One of these crucial factors is the negative frequency effect of left-handers, which highlights the advantage left-handers possess due to their unfamiliarity of their competitors. Schorer et al. (2012) intervention study further supported the importance of familiarity and practice against left-handers, which reported that correctly anticipating the actions of left- or right-handers was dependent on whether participants had been practicing against a left- or right-handed opponent. The findings of these studies have important practical implications for coaches and athletes. In order to minimize the negative frequency effect of left-handers, training environments should be designed in an effort to provide greater opportunities for athletes to practice against left-handed competitors.

Interestingly, the prevalence of left-handedness in female cricket batters at the YAC and OAC level corresponded with levels expected within the general population (**Table 3**) with differences in performance metrics between LHD and RHD batters at the OAC level only. These findings support Loffing (2017) examination of left-handed overrepresentation in sports that have significant temporal demands, which are reportedly greater in the men's game due to faster bowling speeds (Felton et al., 2019). The performance advantage observed for OAC LHD batters may therefore be explained due to increased temporal demands within the older age group competition compared with the younger age group competition (Pyne et al., 2006; Connor et al., 2018). One other possible explanation for the contrasting differences in left-handedness prevalence and performance advantages is the degree to which there is competition for selection. Selection pressures within the "talent system" increase as selection between athletes becomes more competitive. In their review of other selection biases (i.e., relative age effects), Musch and Grondin (2001) described how selection biases increased, as the size of the playing pool from which players were selected from also increased. The 2018/19 cricket participation census released by Cricket Australia highlighted the vast difference between the percentage of male (∼70%) and female players (∼30%) participating in cricket. Therefore, a smaller population pool from which to select players may attenuate certain biases, such as handedness, and the performance advantage they afford male cricketers. Loffing (2017) highlighted similar findings in racket sports, which reported an overrepresentation of left-handers compared to the general population in elite male competition, but not the female competition. It is currently unclear whether the reduced handedness bias is due to potentially less selection pressures or the temporal demands of the sport. Further research is required to investigate laterality in female competitions.

Finally, to better understand any potential left-handed advantage, moderating factors such as the adoption of a "reversed" stance (Mann et al., 2016) were also analyzed in the current study. The reversed-stance advantage hypothesis (Mann et al., 2016) proposed an explanation for certain performance advantages above and beyond the negative frequency-dependent effects available to all left-handers. Their findings highlighted that professional cricket batsmen were seven times more likely to adopt a reversed stance than inexperienced batsmen. The current study provided some preliminary evidence for reverse stance batters having limited performance advantage at the talent pathway level. One explanation for these small performance advantages may be due to a potential technical advantage imposed by having a dominant hand on the top of the bat handle, rather than the bottom. The role of the top hand is thought to be primarily responsible for guiding the path of the bat in order to intercept the ball (Stretch et al., 1995, 1998). Therefore, it may be more advantageous for the dominant hand to be placed on top of the bat handle (reverse stance) rather than the bottom when attempting to forcefully contact the ball. However, more empirical work is required on the reverse-stance before any practical recommendations can or should be made to coaches, practitioners, and learners.

There are some limitations to consider within this study. First, handedness was compared to the expected distribution within the general sporting population, which may not accurately reflect the exact percentage of amateur level cricketers who are left-handed. Future studies would benefit from analyzing a sample of amateur or recreational level players within the population being investigated (Mann et al., 2016). Analysis was also specific to cricket batters and may not generalize to cricket bowlers. The use of frequencies and counts for those variables in the current study should be analyzed as independent measures for predictive (e.g., counts used via linear regression) and association (e.g., frequencies used via Crosstabs Commands) models in future work. Second, cricketers in this study were categorized based on whether they competed in a younger age or older age national competition, which relies on chronological age cutoffs. Previous research has highlighted that selection in these competitions can heavily bias the sample population toward relative older players (Connor et al., 2019). Finally, the nature of this study does not allow for the analysis of explanatory factors of various batting stances. Rather, it is an examination of batting stance and its impact on real-world sporting performance. Further investigations seeking to explore the mechanisms underpinning batting stance could focus on potential biomechanical differences across various skill levels (Stretch et al., 1995; Sarpeshkar and Mann, 2011).

CONCLUSION

The current study has demonstrated a small left-handed performance advantage for cricket batters at the junior national representative level. This advantage was evident for both male and female batters despite overrepresentation of left-handers being evident in the male pathway system only. Highly competitive and large talent selection pools, coupled with temporally demanding sporting tasks, are proposed to explain the increased representation of left-handers in elite junior cricket. The lower frequency of female left-handers (in this case, compared with right-handers) would mean that there are also less practice opportunities against left-handers, which may partially explain the left-hander's performance advantage for female cricket. Further, this study provided evidence for the reverse stance hypothesis contributing a limited performance advantage to cricket batting. Together, these findings highlight the emergence of selection and performance biases occurring at the male and female youth representative level. Practical implications for coaches include creating practice environments that minimize the negative frequency effect, such as providing more practice opportunities against left-handed opponents. Future performance analysis research is encouraged to examine whether selecting a greater number of left-handers increases the likelihood of winning matches.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

The study was conducted according to the ethical guidelines of the authors' affiliated institution. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study as analyzed data were archival data available in the public domain.

AUTHOR CONTRIBUTIONS

JC contributed to the conception and design of the work, writing of the manuscript, and analysis and interpretation of data. DM, AL, and KD contributed to the writing and critiquing of the manuscript and interpretation of data. M-AG contributed to the critiquing of the manuscript, data analysis, and interpretation of the data. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.01654/full#supplementary-material

REFERENCES

Baker, J., and Schorer, J. (2013). The Southpaw advantage?-lateral preference in mixed martial arts. *PLoS One* 8:e79793. doi: 10.1371/journal.pone.0079793

Brooks, R., Bussiere, L. F., Jennions, M. D., and Hunt, J. (2004). Sinister strategies succeed at the cricket World Cup. *Proc. R. Soc. Lond. Ser. B Biol. Sci.* 271(Suppl._3), S64–S66.

Cairney, J., Chirico, D., Li, Y. C., Bremer, E., and Graham, J. D. (2018). Are Canadian-born major league baseball players more likely to bat left-handed? A partial test of the hockey-influence on batting hypothesis. *PLoS One* 13:e0195252. doi: 10.1371/journal.pone.00195252

Cingoz, Y. E., Gursoy, R., Ozan, M., Hazar, K., and Dalli, M. (2018). Research on the relation between hand preference and success in karate and taekwondo sports with regards to gender. *Adv. Phys. Educ.* 8:308. doi: 10.4236/ape.2018.83027

Cohen, J. (1988). "The effect size index," in *Statistical Power Analysis For The Behavioral Sciences*, ed. J. Cohen (New York, NY: Lawrence Erlbaum Associated Publishers), 20–26.

Connor, J. D., Farrow, D., and Renshaw, I. (2018). Emergence of skilled behaviors in professional, Amateur and junior cricket batsmen during a representative training scenario. *Front. Psychol.* 9:2012. doi: 10.3389/fpsyg.2018.02012

Connor, J. D., Renshaw, I., and Doma, K. (2019). Moderating factors influence the relative age effect in Australian cricket. *PeerJ* 7:e6867. doi: 10.7717/peerj.6867

Felton, P., Lister, S., Worthington, P. J., and King, M. A. (2019). Comparison of biomechanical characteristics between male and female elite fast bowlers. *J. Sports Sci.* 37, 665–670. doi: 10.1080/02640414.2018.1522700

Grondin, S., Guiard, Y., Ivry, R. B., and Koren, S. (1999). Manual laterality and hitting performance in major league baseball. *J. Exper. Psychol. Hum. Percept. Perform.* 25:747. doi: 10.1037/0096-1523.25.3.747

Grouios, G. (2004). Motoric dominance and sporting excellence: training versus heredity. *Percept. Mot. Skills* 98, 53–66. doi: 10.2466/pms.98.1.53-66

Grouios, G., Tsorbatzoudis, H., Alexandris, K., and Barkoukis, V. (2000). Do left-handed competitors have an innate superiority in sports? *Percept. Mot. Skills* 90, 1273–1282. doi: 10.2466/pms.2000.90.3c.1273

Hagemann, N. (2009). The advantage of being left-handed in interactive sports. *Attent. Percept. Psychophys.* 71, 1641–1648. doi: 10.3758/app.71.7.1641

Harris, L. J. (2010). In fencing, what gives left-handers the edge? Views from the present and the distant past. *Laterality* 15, 15–55.

Johnston, D. W., Nicholls, M. E., Shah, M., and Shields, M. A. (2009). Nature's experiment? Handedness and early childhood development. *Demography* 46, 281–301. doi: 10.1353/dem.0.0053

Loffing, F. (2017). Left-handedness and time pressure in elite interactive ball games. *Biol. Lett.* 13:20170446. doi: 10.1098/rsbl.2017.0446

Loffing, F., and Hagemann, N. (2014). Skill differences in visual anticipation of type of throw in team-handball penalties. *Psychol. Sport Exerc.* 15, 260–267. doi: 10.1016/j.psychsport.2014.01.006

Loffing, F., Hagemann, N., and Strauss, B. (2009). The serve in professional men's tennis: effects of players' handedness. *Intern. J. Perform. Analys. Sport* 9, 255–274. doi: 10.1080/24748668.2009.11868482

Loffing, F., Hagemann, N., and Strauss, B. (2010). Automated processes in tennis: do left-handed players benefit from the tactical preferences of their opponents? *J. Sports Sci.* 28, 435–443. doi: 10.1080/02640410903536459

Loffing, F., Hagemann, N., and Strauss, B. (2012a). Left-handedness in professional and amateur tennis. *PLoS One* 7:e49325. doi: 10.1371/journal.pone.0049325

Loffing, F., Schorer, J., Hagemann, N., and Baker, J. (2012b). On the advantage of being left-handed in volleyball: further evidence of the specificity of skilled visual perception. *Attent. Percept. Psychophys.* 74, 446–453. doi: 10.3758/s13414-011-0252-1

Mann, D. L., Loffing, F., and Allen, P. M. (2017). The success of sinister right-handers in baseball. *N. Engl. J. Med.* 377, 1688–1690. doi: 10.1056/nejmc1711659

Mann, D. L., Runswick, O. R., and Allen, P. M. (2016). Hand and eye dominance in sport: are cricket batters taught to bat back-to-front? *Sports Med.* 46, 1355–1363. doi: 10.1007/s40279-016-0516-y

McMorris, T., and Colenso, S. (1996). Anticipation of professional soccer goalkeepers when facing right-and left-footed penalty kicks. *Percept. Mot. Skills* 82, 931–934. doi: 10.2466/pms.1996.82.3.931

Medland, S. E., Duffy, D. L., Wright, M. J., Geffen, G. M., Hay, D. A., Levy, F., et al. (2009). Genetic influences on handedness: data from 25,732 Australian and Dutch twin families. *Neuropsychologia* 47, 330–337. doi: 10.1016/j.neuropsychologia.2008.09.005

Musch, J., and Grondin, S. (2001). Unequal competition as an impediment to personal development: a review of the relative age effect in sport. *Dev. Rev.* 21, 147–167. doi: 10.1006/drev.2000.0516

Pyne, D. B., Duthie, G. M., Saunders, P. U., Petersen, C. A., and Portus, M. R. (2006). Anthropometric and strength correlates of fast bowling speed in junior and senior cricketers. *J. Strength Condition. Res.* 20:620. doi: 10.1519/00124278-200608000-00025

Raymond, M., Pontier, D., Dufour, A.-B., and Møller, A. P. (1996). Frequency-dependent maintenance of left handedness in humans. *Proc. R. Soc. Lond. Ser. B Biol. Sci.* 263, 1627–1633. doi: 10.1098/rspb.1996.0238

Sarpeshkar, V., and Mann, D. L. (2011). Biomechanics and visual-motor control: how it has, is, and will be used to reveal the secrets of hitting a cricket ball. *Sports Biomech.* 10, 306–323. doi: 10.1080/14763141.2011.629207

Schorer, J., Loffing, F., Hagemann, N., and Baker, J. (2012). Human handedness in interactive situations: negative perceptual frequency effects can be reversed! *J. Sports Sci.* 30, 507–513. doi: 10.1080/02640414.2012.654811

Stretch, R. A., Buys, F. J., Toit, E. D., and Viljoen, G. (1998). Kinematics and kinetics of the drive off the front foot in cricket batting. *J. Sports Sci.* 16, 711–720. doi: 10.1080/026404198366344

Stretch, R. A., Buys, F. J., and Viljoen, G. (1995). The kinetics of the drive off the front foot in cricket batting: hand grip force. *South Afri. J. Res. Sport Phys. Educ. Recreat.* 18, 83–93.

Tirp, J., Baker, J., Weigelt, M., and Schorer, J. (2014). Combat stance in judo-laterality differences between and within competition levels. *Intern. J. Performa. Analys. Sport* 14, 217–224. doi: 10.1080/24748668.2014.11868716

Weissensteiner, J., Abernethy, B., Farrow, D., and Müller, S. (2008). The development of anticipation: a cross-sectional examination of the practice experiences contributing to skill in cricket batting. *J. Sport Exerc. Psychol.* 30, 663–684. doi: 10.1123/jsep.30.6.663

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