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Coaching female athletes

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Coaching female athletes

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Editorial: Coaching female athletes

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health and physiology, performance optimization and monitoring, coaching, leadership and support systems, athlete well-being and long-term development

Editorial on the Research Topic
Coaching female athletes

The number of female athletes participating at high-performance levels is increasing. This has created more opportunities for competition in professional leagues and raised the standards of national team competitions in numerous sporting codes (1). However, a disproportionate volume of sports research tends to focus overtly on men, and these results are applied (often incorrectly) to female athletes (2). Biological, psychological, emotional, and social differences exist, and when combined with the environmental, infrastructural, and resource differences within female sports, there is a need to create female-specific knowledge for coaches.

Contemporary research suggests that many studies within the domain of female athletes were conducted with a gendered bias and used research to reinforce existing gender norms. There are emerging critiques of existing sports science literature that tend to reinforce traditional social constructs, with female athletes seen as fragile, in need of care, and nurturing. The concept of women being unable to accept criticism or being too emotional or fragile, physically not being aggressive enough, and not being able to handle coaching methodologies that are usually associated with men's teams has resulted in the conclusion that sometimes coaches in women's sports "hold back". Female athletes are also often referred to as different, and coaching them is considered challenging (3). These negative stereotypes, in fact, are likely to hinder the progress of female athletes (4).

As women's sports grow, structural and cultural shifts occur, which may result in changing expectations (5). Many previous studies were conducted in an environment in which, regardless of participation level, pathways to professionalism for female athletes were minimal. Even within elite female sports, athletes often lack access to the same resources and developmental background as their elite male counterparts (6). Currently, this is changing in some countries and sports. Despite higher competition levels and more women pursuing high-level sports opportunities, a persistent societal misconception remains that women in sports are primarily driven by social engagement rather than competition and performance (5). It remains to be seen how the expectations and requirements for the now increasing number of professional female players will impact coaching methodologies (7).

In this Research topic, we focused on "*Coaching female athletes*", with 12 published research articles that fit within the broader themes of i) Health and Physiology,

ii) Performance Optimization and Monitoring, iii) Coaching, Leadership, and Support Systems, and iv) Athlete Well-being and Long-Term Development. Within the health and physiology theme, Jones et al. highlighted the complexities associated with female reproductive health and performance in a longitudinal study of elite British track and field athletes. These athletes perceived an inferior performance when estrogen and progesterone levels were low. The authors advocated for more support for athletes and individual strategies to be utilized to optimize athlete health and performance. Roffler et al. noted that menstrual cycle symptoms vary widely within the same team, and that tracking symptoms can inform an individualized healthcare and management approach that can be used to help coaches adjust training load. Meanwhile, Vardardottir et al. demonstrated that repeated patterns of low energy availability and low carbohydrate intake increase the risk of relative energy deficiency (REDs) for female athletes.

Regarding the performance optimization and monitoring theme, which aims to help coaches and sports scientists predict performance development in young female athletes, Romann et al. focused on the development of a new analysis method to improve reliability and provide a predictive model for future performance. This model can help coaches individualize training programs. Stojiljković et al. created a valid and reliable tool to assess drop jump performance interlimb asymmetry in young female basketball players. The My Jump 2 app is low-cost and easy for coaches to use to improve and monitor jumping performance. Sammoud et al. hypothesized that backward running as a training method would provide greater physical fitness benefits than forward running for young female handball players. Their findings suggest that improved performance may come from a combination of both. Adding important information to help profile the physical performance attributes of elite female handball players, an area that has been largely overlooked in the literature, the results by Radovic et al. related to eccentric performance characteristics can be used by coaches to guide structured training programs focused on lower-body strength and power.

Focusing on coaching, leadership, and support systems, Mashilo and Kubayi investigated the coach-athlete dyadic relationship for South African school athletes and the importance of trust within the partnership. They concluded that coaches need to promote fairness in all aspects of their coaching and individualize encouragement and support. In our own contribution (Carson et al.), we explored the intense tournament environment and how a coach navigates the additional pressures and time constraints to build a team. Individual feedback sessions and empowering the female athletes were important for the coach and instrumental in building a trusting relationship. In their study, Alruwaili focused on how to increase Saudi Arabian female participation in sports and identified that a transformational leadership style, with an emphasis on inspirational motivation, is an effective means to engage more women in physical activity and break down sociocultural barriers.

The final two studies focused on athlete well-being and long-term development. Zach et al. addressed the difficult topic of sexual harassment among athletes and highlighted the differences in perceptions and interpretations of sexual harassment. The authors reinforce the need for improved education and awareness to promote a safer culture in sports and encourage sports organizations to create better-defined policies and adopt a zero-tolerance approach. Ehnold et al. investigated engagement with off-field educational programs for female soccer players in Germany. Despite the growing professional opportunities for female soccer players, over 90% of the players were actively engaged in academic or vocational education. It is known that commitment to other activities outside the sporting environment can help athletes develop different identities, which is important for long-term development.

The 12 manuscripts in this research topic provide valuable insights into the developing literature on coaching female athletes. Interestingly, there appear to be few differences in the barriers that are faced by women who wish to participate in sports worldwide. Despite increased attention to women's sports, access to facilities, resources, and quality support remains limited. From a coaching perspective, female athletes differ from male athletes, and we are only just beginning to build the research base to show how women can be coached most effectively. An athlete-centered approach to coaching is crucial, with a positive coach-athlete relationship appearing more important for female athletes than male athletes. As such, coaches are encouraged to develop their relational skills and ensure individualization for each athlete they engage with. This individualization is important for all areas of female athlete performance, including training load, athletic development, support, health, and well-being.

Author contributions

KB: Conceptualization, Data curation, Formal analysis, Project administration, Visualization, Writing – original draft, Writing – review & editing. TN: Conceptualization, Data curation, Project administration, Visualization, Writing – review & editing. FC: Conceptualization, Visualization, Writing – original draft, Writing – review & editing, Project administration.

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The effects of backward vs. forward running training on measures of physical fitness in young female handball players

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Introduction: This study examined the effects of an 8-week backward running (BR) vs. forward running (FR) training programmes on measures of physical fitness in young female handball players.
Methods: Twenty-nine players participated in this study. Participants were randomly assigned to a FR training group, BR training group, and a control group.
Results and discussion: Within-group analysis indicated significant, small-to-large improvements in all performance tests (effect size [*g*] = 0.36 to 1.80), except 5-m forward sprint-time in the BR group and 5- and 10-m forward sprint-time in the FR group. However, the CG significantly decreased forward sprint performance over 10-m and 20-m ($g = 0.28$ to 0.50) with no changes in the other fitness parameters. No significant differences in the amount of change scores between the BR and FR groups were noted. Both training interventions have led to similar improvements in measures of muscle power, change of direction (CoD) speed, sprint speed either forward or backward, and repeated sprint ability (RSA) in young female handball players, though BR training may have a small advantage over FR training for 10-m forward sprint time and CoD speed, while FR training may provide small improvements over BR training for RSA_{best}. Practitioners are advised to consider either FR or BR training to improve various measures of physical fitness in young female handball players.

KEYWORDS
team sports, athletic performance, motor activity, youth sports, sports medicine

Introduction

Competitive handball match play is characterized by high-intensity activity patterns (1). In female handball, key physical fitness components such as linear sprint, change of direction (CoD) speed, jumping ability, and repeated sprint ability (RSA) are crucial for competitive success (2). These physical attributes are crucial for handball players to excel in the dynamic nature of the game. Jumping allows for powerful shots, effective defensive blocks, and successful aerial duels (2, 3). CoD speed enables quick and agile movements to evade opponents and swiftly change attacking or defensive strategies (2). Linear sprint facilitates fast counterattacks and the pursuit of opponents (2). Finally, repeated sprint ability ensures sustained high-intensity performance throughout the game, allowing players to execute multiple high-intensity actions consecutively (3). Mastering these skills is essential for female handball players aiming to dominate the court. There is evidence that compared to lower-level competitive female handball players, higher-level ones displayed better performance in sprint over short distances, RSA, CoD speed, and horizontal jumping (4). Accordingly, the development of female handball players' key components of physical fitness should be prioritized and optimized through well-designed conditioning programmes.

The principle of training specificity dictates that the greatest improvements will occur in the athletic task that presents similar features from biomechanical and physiological standpoints with the trained exercise (5–7). However, there are indications that changes could also occur in movements that were not specifically trained (7, 8). For example, Negra et al. (8) revealed moderate improvement in RSA parameters (i.e., $RSA_{total\ time}$, and $RSA_{best\ time}$) following either nine weeks of specific (i.e., RSA with CoD) or unspecific (i.e., RSA without CoD) training interventions in youth male soccer players aged 15 years. As per specific training methods, recent evidence indicated that non-specific training such as reverse-movement training [i.e., backward running (BR)] may also have the potential to stimulate positive adaptations with marked transfer to athletic tasks (9). Indeed, several studies (8–10) supported the utility of BR training to improve a range of physical fitness components related to both maximal neuromuscular performance (e.g., sprint, CoD, and jumping ability) and cardiorespiratory functioning (e.g., running economy). For instance, Terbalanche et al. (10) suggested that netball-specific exercises performed backwards, can be included in the conditioning and skills training programmes to improve speed, CoD (i.e., 505 CoD, Ladder, and *T*-test), and power measures. Likewise, Ordway et al. (11) noted improvement in forward running (FR) economy (2.54%) without altering maximal oxygen consumption (VO_{2max}) or body composition after ten-week of BR training in trained young male runners aged 26 years. Further, Uthoff et al. (9) showed greater positive effects on 10 m forward sprint speed [effect size (ES) = −0.47], 20-m forward sprint speed (ES = −0.26), and countermovement jump (CMJ) height (ES = 0.51) after eight-week of biweekly BR training compared to FR training in adolescent male athletes aged 15 years.

Overall, based on the existing literature, it seems that BR training leads to positive effects on various measures of physical fitness (10, 12) which could even exceed those achieved following FR training (12). However, to the best of our knowledge, there is no study available that directly contrasted the effects of FR vs. BR training on key measures of physical fitness in young female handball players, pointing to a gap in the literature. Therefore, this study aimed to examine the effects of an eight-week in-season BR training vs. FR training, in combination with regular handball training, on key measures of physical fitness in young female handball players. We hypothesized, that BR training would result in greater enhancements in measures of physical fitness compared to FR training (12).

Methods

Experimental design

A three-group randomized-controlled trial design was applied to examine the effects of FR training vs. BR training on measures of physical fitness in young female handball players. For two sessions per week, the first part of the regular handball training of the participants was replaced with either FR training or BR training. The control group (CG) continued to undertake its regular handball training. The pre-and post-intervention assessments included tests of forward and backward sprint speed (i.e., 20 m with 5- and 10 m split intervals), forward CoD speed (i.e., 505 CoD test), jumping ability [i.e., standing long jump (SLJ)], and forward RSA. All tests were conducted 48 h after the players' most recent training session or match, at the same time of day (7:30–9:30 a.m.) and under the same environmental conditions (29–33°C, no wind). Players who failed to attend 85% of the scheduled training sessions were excluded from the study. Physical fitness tests were performed in a fixed order over two days. On the first day, anthropometric measurements were conducted, followed by the sprint speed and the CoD speed tests. The second day was devoted to the jumping and RSA tests. Two experienced conditioning trainers, who were blinded to group allocation, conducted all measurements.

Participants

We conducted an *a priori* sample size calculation for the 10 m sprint test. We set α at 0.05 and the statistical power at 0.80. The estimated effect size of Cohen's $d = 1.20$ is based on a similar study (9). Therefore, the required number of participants per group was determined to be six. To account for potential participant attrition twenty-nine female handball players, from the same regional handball team, were recruited to take part in the study. Of note, all the groups followed the same handball training program under the supervision of the same coaches. Participants were randomly assigned to a FR training group (n = 9), a BR training group (n = 9), or an active CG (n = 11). The anthropometric characteristics of the three groups are detailed in **Table 1**. All participants were classified as experienced handball players with 9.0 ± 1.3 years of systematic handball training experience involving four-to-five training sessions per week. All players met the following inclusion criteria: (i) they had undertaken continuous handball training over the past three

TABLE 1 Participants' characteristics (mean ± standard deviation).

Parameters	Overall (n = 29)	BR group (n = 9)	FR group (n = 9)	Control group (n = 11)
Age (y)	20.1 ± 2.17	20.1 ± 2.15	19.9 ± 2.62	20.2 ± 1.99
Body height (cm)	1.67 ± 0.07	1.66 ± 0.05	1.70 ± 0.66	1.64 ± 0.09
Body mass (kg)	64.2 ± 9.93	61.3 ± 7.57	70.0 ± 10.3	61.9 ± 10.1

BR, backward running; FR, forward running.

months with no musculoskeletal injuries sustained, (ii) absence of potential medical problems that could compromise participation in the study, and (iii) none were engaged in any other sport or played with any other handball club.

The study was conducted as per the latest Declaration of Helsinki, and the protocol was approved by the local Ethics Committee of the «blind for review purposes». Signed written informed consent (parents/legal guardians) and assent (participants) were obtained before the commencement of the study. All participants were told that they were free to withdraw from the study without any penalty at any time, with no obligation to explain.

Training programmes

The programmes were conducted during the second half of the in-season period. All groups participated in the same regular handball-specific training program over the eight-week intervention period. Handball training sessions for all groups included fast footwork drills, technical skills and moves, position games, and tactical games. The FR and BR training sessions were integrated into the regular handball training routine of the intervention groups after their standard warm-up, replacing 20–25 min of low-intensity handball drills, on Tuesdays and Thursdays (**Table 2**). After either the FR or BR training sessions, the players completed the remainder (60–70 min) of their regular handball training. The running training program involved players performing linear running either forward or backward. The players performed slow, moderate, and fast sprints, corresponding to ∼20–45, ∼50–75, and >95% of maximal sprint effort, respectively. These speeds were chosen to reflect common running intensities that young female players are capable of self-selecting using autoregulation. Similar to a previous study (9), coaching cues were used to reinforce the BR technique (i.e., "slight lean of the chest forward", "use similar arm action to FR", and "high heel recovery of the swing leg"). Likewise, specific technical instructions, such as; (a) "knee-up and toe-up," (b) "drive your arms from cheek to hip," (c) "strike the ground with the ball of your foot," and (d) "strike the ground under your hips and push back" were used to reinforce FR techniques. The repetitions by intensity over the prescribed distances for each training session were detailed in **Table 2**. Equal volume and intensity were prescribed for both the FR and BR training groups.

Forward and backward linear sprint speed time

Twenty-meter forward and backward linear sprint speed time was assessed across 20 m distance with split intervals at 5- and 10 m using a single beam electronic timing system (Microgate SRL, Bolzano, Italy). Participants started in a standing split stance position with their lead foot 0.3 m behind the first infrared photoelectric gate, which was placed 0.75 m above the ground to ensure that it captured trunk movement and avoided false signals through limb motion. In total, four single-beam photoelectric gates were used. No rocking or false steps were permitted before starting. The between-trial recovery time was 3 min. The best performance out of three trials was used for further analysis. The intra-class correlation coefficients (ICCs) for test-retest reliability were 0.91, 0.93, and 0.90 for 5-, 10- and 20 m forward sprint performance, respectively, and 0.87, 0.82, and 0.85 for 5-, 10- and 20 m backward sprint performance, respectively.

505 change of direction speed test

The 505 CoD speed test was administered as previously outlined by Negra et al. (8) using an electronic timing system (Microgate, Bolzano, Italy) placed 5 m from the turning line. Players assumed a standing split stance position 10 m from the start line, ran as quickly as possible through the start/finish line, pivoted 180° on their preferred leg at the 15 m turning line indicated by a cone marker, and returned as fast as possible through the start/finish line. To ensure proper execution of the test, a researcher was positioned at the turning line and if the participant changed direction before reaching the turning point, or turned off the incorrect foot, the trial was disregarded and reattempted after 3 min recovery period. A between-trial rest period of 3 min was provided. The best performance out of three trials was used for further analysis. The ICC for test-retest reliability was 0.91.

Standing-long-jump distance

During the bilateral SLJ test, participants stood with their feet shoulder-width apart and their toes behind a starting line. Participants performed a fast flexion of the legs and downward movement of the arms, before jumping forward as far as possible. Participants had to land with both feet at the same time and were not allowed to fall forward or backward. The horizontal distance between the starting line and the heel of the rear foot was recorded using a tape measure to the nearest 1-cm. A between-trial rest period of 1 min was allowed. The best out of three trials was recorded for further analysis. The ICC for test-retest reliability was 0.87.

Repeated sprint ability

The RSA test was assessed via the same photocell system used for the linear speed and 505 CoD tests (Microgate, Bolzano, Italy). Immediately after the standardized warm-up, participants completed a preliminary single shuttle-sprint test (20 + 20 m with 180° CoD). The first trial provided the criterion score for the actual shuttle-sprint test (13). Participants then rested for 5 min before starting the RSA test. During the first sprint, participants had to achieve at least 97.5% of their criterion score, otherwise, they rested for 5 min and then restarted the test (13). We used

TABLE 2 Forward and backward running intervention programs.

		Intensity	Sets (n)	Distance (m)	Distance per intensity (m)	Total distance (m)
Week 1	Session 1	Slow	3	15	45	225
		Moderate	4	15	60	
		Fast	8	15	120	
	Session 2	Slow	3	15	45	225
		Moderate	3	15	45	
		Fast	9	15	135	
Week 2	Session 1	Slow	2	15	30	225
		Moderate	4	15	60	
		Fast	9	15	135	
	Session 2	Slow	2	15	30	225
		Moderate	3	15	45	
		Fast	10	15	150	
Week 3	Session 1	Slow	1	15	15	225
		Moderate	4	15	60	
		Fast	10	15	150	
	Session 2	Slow	2	15	30	225
		Moderate	2	15	30	
		Fast	11	15	165	
Week 4	Session 1	Slow	1	15	15	225
		Moderate	3	15	45	
		Fast	11	15	165	
	Session 2	Slow	1	15	15	225
		Moderate	2	15	30	
		Fast	12	15	180	
Week 5	Session 1	Slow	3	20	60	300
		Moderate	4	20	80	
		Fast	6	20	160	
	Session 2	Slow	3	20	60	300
		Moderate	3	20	60	
		Fast	9	20	180	
Week 6	Session 1	Slow	2	20	40	300
		Moderate	4	20	80	
		Fast	9	20	180	
	Session 2	Slow	2	20	40	300
		Moderate	3	20	60	
		Fast	10	20	200	
Week 7	Session 1	Slow	1	20	20	300
		Moderate	4	20	80	
		Fast	10	20	200	
	Session 2	Slow	2	20	40	300
		Moderate	2	20	40	
		Fast	11	20	220	
Week 8	Session 1	Slow	1	20	20	300
		Moderate	3	20	60	
		Fast	11	20	220	
	Session 2	Slow	1	20	20	300
		Moderate	2	20	40	
		Fast	12	20	240	

such an approach to determine if participants adopted a coping strategy for performance. Of note, all participants attained their criterion score during the first sprint. All participants performed six 20 m shuttle sprints with 180° turns, separated by 25 s of passive recovery (13). Three seconds prior to the commencement of each sprint, players were asked to adopt the ready position using a split stance with their lead foot 0.3 m behind the starting line until the next start signal. From the starting line, they sprinted for 20 m, touched the second line with one foot, performed a 180° CoD, and returned to the starting line as quickly as possible. Participants were instructed to complete all sprints as fast as possible. The RSA best time (RSA_{best}), and the RSA total time (RSA_{tot}) were recorded. Due to the fatigue induced by the test, only one maximal attempt was made i.e., no ICC was calculated. The reliability of this test was examined elsewhere (14).

Statistical analyses

The statistical analyses were conducted using Microsoft Excel (version 16.0; Microsoft Corporation, Seattle, WA, USA) and SPSS 28.0 for Windows (SPSS, IBM Corporation, Chicago, IL, USA). The data were explored using histogram plots and distribution estimation, and the normality of the distribution for all variables was tested and confirmed using the Shapiro-Wilk test. Levene's test was used to assess the homogeneity of variance. Taking a frequentist approach, a repeated measured ANOVA was used to compare within-group pre- post-training performance, helping minimize false positives which can arise during multiple comparisons. Between-group training-related effects were assessed using a one-way analysis of variance (ANOVA) on the change scores (mean differences from pre-training to post-training) (9). Sidak posthoc corrections were applied to locate pairwise differences between groups. Alpha was set at $p < 0.05\%$ and 95% confidence intervals (CI) were used for all analyses. To quantify the magnitude of the performance change both within- and between-group, percentage change and Hedges *g* effect size statistics were calculated (15), with ES magnitudes of <0.2, ≥0.2–0.49, ≥0.5–0.79, and >0.8 classified as trivial, small, moderate, and large, respectively (16, 17). To determine the practical relevance of performance changes, the smallest worthwhile individual change (SWC) was calculated on the pooled standard deviation (SD) of pre-training session scores for all groups and converted to a percentage for each performance variable, where changes were deemed small (SWC = 0.2 × SD), moderate (MWC = 0.6 × SD), or large (LWC = 1.2 × SD) (9, 15).

Results

No injuries were reported as part of the training programmes. Within-group changes from pre- to post-training and between-group comparisons are presented in **Table 3**. The within-group analysis revealed that the BR training induced significant improvements in most performance tests, except forward and backward sprinting over 5 m, forward sprinting over 20 m, and RSA_{best} ($p < 0.05$; Δ4.37%–11.0%; $g = 0.46–1.80$). The FR training induced significant within-group improvements for 10 m and 20 m backwards sprints, 505 CoD, and SLJ ($p < 0.05$; 5.57%–8.65%; $g = 0.36–1.29$). Meanwhile, no significant changes were observed in any of the fitness parameters for the CG.

The one-way ANOVA on the change scores showed a significant group effect for the 505 CoD ($F = 13.204$; $p < 0.001$) and SLJ ($F = 8.654$; $p = 0.001$). The posthoc analysis indicated that, compared with the CG, the change scores for the BR and FR groups were significantly better for 505 CoD time and SLJ ($g = 0.55–1.74$). There were no significant differences in the amount of change scores from pre- to post-test between the BR and FR groups.

Figure 1 provides a graphical reference illustrating the individual percentage changes relative to the magnitudes of worthwhile change detected for the BR, FR, and CG groups for the different performance tests. The BR and FR groups achieved similar individual response rates across all performance tests, with an average of 6, 3, and 2 participants improving above the SWC, MWC, and LWC in the BR group and 5, 4, and 2 participants improving beyond these thresholds in the FR group, respectively. Meanwhile, only 3, 1, and 0 participants from the CG improved beyond the SWC, MWC and LWC, respectively, across the different performance tests. All participants in the BR group improved 505 CoD performance above the MWC, while 8 out of the 9 participants met the threshold for a LWC. The FR and BR groups had each 8 of 9 athletes above the SWC and LWC for the 505 CoD test. Regarding the CG, two or fewer subjects improved performance above the SWC in the performance tests, and while no significant changes were found, 9 out of the 11 participants improved backward 20 m sprint times above the SWC threshold.

Discussion

This study aimed to examine and compare the effects of eight weeks of BR training vs. FR training on measures of physical fitness in female handball players. The main findings indicated that the vast majority of measures of physical fitness improved after both training interventions. More specifically, significant small to large improvements in all performance tests, except 5- and 20 m forward sprint-time, were observed in the BR group. Meanwhile, significant small to large enhancements in 10 m and 20 m backwards sprints, 505 CoD, and SLJ were noted for the FR group. Additionally, the between-group analysis indicated no significant differences in the amount of change scores between the two training interventions.

To the authors' knowledge, this is the first study to directly contrast the effects of BR vs. FR training on measures of physical fitness in young female handball players. Additionally, this study seems to be unique to integrate backward running performance in its testing battery. Although only significant over 10 m and 20 m, BR training improved backward running performance to a moderate effect ($g = 0.58–0.71$) and FR training led to moderate to large improvements in backward running performance ($g = 0.78–0.94$), with both groups showing small to moderate effectiveness, though not statistically significant compared to the CG ($g = 0.29–0.62$). In terms of individual response rates, over half of the participants of both BR and FR groups improved their performances beyond the SWC and nearly reached the threshold for MWC. Interestingly, just over half of the participants of the CG also improved average backward running performance above the SWC threshold. While neither intervention group statistically improved performance relative to the CG, average change score improvements for the BR group were 0.16–0.39 s faster than the CG and average change scores for the FR group were 0.06–0.12 s better than the CG across all distances. These findings suggest that BR and FR training are better than handball training alone and that while either locomotive direction of training could be used to improve

TABLE 3 Descriptive performance testing results with for BRT, FRT, and CG groups including within-group changes from pre- to post-training and between-group differences of the mean changes.

Performance Test	Group	Pre (mean ± SD)	Post (mean ± SD)	Performance change (%) (95% CI)	Post-pre training effect (ES)	Diff BRT-CG (mean ± SE)	Effect size	Diff FRT-CG (mean ± SE)	Effect size	Diff BRT-FRT (mean ± SE)	Effect size
Backward 5 m sprint (s)	BR	1.57 ± 0.29	1.41 ± 0.09	−8.30 (−16.4 to −0.21)	−0.58	−0.13 ± 0.09	−0.55^B	−0.11 ± 0.06	−0.62^F	−0.02 ± 0.10	−0.08^B
	FR	1.64 ± 0.19	1.50 ± 0.04	−7.46 (−13.3 to −1.64)	−0.78						
	CG	1.65 ± 0.12	1.61 ± 0.11	−1.77 (−3.30 to −0.25)	−0.21						
Backward 10 m sprint (s)	BR	2.84 ± 0.51	2.50 ± 0.15*	−10.3 (−17.7 to −2.92)	−0.71	−0.18 ± 0.15	−0.43^B	−0.12 ± 0.09	−0.40^F	−0.06 ± 0.27	−0.13^B
	FR	2.99 ± 0.33	2.71 ± 0.12*	−8.65 (−13.2 to −4.09)	−0.88						
	CG	3.05 ± 0.21	2.89 ± 0.19	−5.18 (−7.20 to −3.16)	−0.67						
Backward 20 m sprint (s)	BR	5.17 ± 0.94	4.53 ± 0.32✧	−10.9 (−17.6 to −4.15)	−0.71	−0.26 ± 0.25	−0.33^B	−0.15 ± 0.14	−0.29^F	−0.10 ± 0.27	−0.12^B
	FR	5.44 ± 0.55	4.90 ± 0.31*	−8.48 (−13.0 to −6.00)	−0.94						
	CG	5.96 ± 0.42	5.48 ± 0.37	−6.40 (−8.75 to −4.05)	−0.80						
Forward 5 m sprint (s)	BR	1.09 ± 0.06	1.07 ± 0.06	−1.35 (−3.80 to 1.11)	−0.22	−0.05 ± 0.02	−0.78^B	−0.05 ± 0.04	−0.63^F	−0.01 ± 0.03	−0.10^B
	FR	1.16 ± 0.07	1.15 ± 0.11	−0.71 (−5.88 to 4.45)	−0.07						
	CG	1.13 ± 0.07	1.17 ± 0.06	3.45 (0.83 to 6.24)	0.50						
Forward 10 m sprint (s)	BR	1.92 ± 0.07	1.87 ± 0.11*	−2.70 (−4.28 to −1.12)	−0.45	−0.11 ± 0.03	−0.73^B	−0.06 ± 0.05	−0.37^F	−0.04 ± 0.05	−0.38^B
	FR	2.05 ± 0.13	2.05 ± 0.17	−0.20 (−4.89 to 4.48)	−0.03						
	CG	2.10 ± 0.17	2.15 ± 0.16	2.69 (0.59 to 4.79)	0.28						
Forward 20 m sprint (s)	BR	3.41 ± 0.18	3.35 ± 0.15	−1.71 (−3.54 to 0.11)	−0.29	−0.06 ± 0.05	−0.29^B	−0.10 ± 0.06	−0.41^F	0.04 ± 0.06	0.16^F
	FR	3.75 ± 0.24	3.66 ± 0.21	−2.51 (−6.11 to 0.08)	−0.35						
	CG	3.83 ± 0.20	3.84 ± 0.21	0.09 (01.79 to 1.96)	0.01						
505 COD (s)	BR	2.93 ± 0.12	2.61 ± 0.16†	−11.0 (−14.2 to −7.88)	−1.80	−0.31 ± 0.06†	−1.74^B	−0.24 ± 0.07✧	−1.11^F	−0.06 ± 0.08	−0.41^B
	FR	3.05 ± 0.14	2.79 ± 0.18†	−8.58 (−12.2 to −4.95)	−1.29						
	CG	3.19 ± 0.08	3.17 ± 0.15	−0.62 (−2.60 to 1.36)	−0.13						
Standing long jump (m)	BR	1.81 ± 0.14	1.89 ± 0.13*	4.37 (2.33 to 6.42)	0.46	0.10 ± 0.02✧	0.55^B	0.11 ± 0.03✧	0.55^F	−0.01 ± 0.03	−0.05^F
	FR	1.55 ± 0.17	1.64 ± 0.21✧	5.57 (1.72 to 9.42)	0.36						
	CG	1.42 ± 0.18	1.40 ± 0.18	−1.29 (−3.51 to 0.94)	−0.08						
RSA_{best} (s)	BR	8.19 ± 0.35	8.00 ± 0.38	−2.27 (−4.22 to −0.31)	−0.40	−0.18 ± 0.14	−0.44^B	−0.33 ± 0.19	−0.70^F	0.15 ± 0.17	0.32^F
	FR	8.92 ± 0.48	8.58 ± 0.53	−3.72 (−6.98 to −0.46)	−0.53						
	CG	9.44 ± 0.38	9.43 ± 0.38	−0.04 (−2.33 to 2.25)	−0.02						
RSA_{total} (s)	BR	52.0 ± 2.53	49.5 ± 2.08*	−4.82 (−7.04 to −2.61)	−0.86	−2.42 ± 0.96	−0.83^B	−1.87 ± 1.24	−0.64^F	−0.55 ± 1.16	−0.19^B
	FR	55.5 ± 2.59	53.5 ± 3.61	−3.57 (−7.04 to −0.11)	−0.50						
	CG	58.6 ± 2.71	58.4 ± 2.20	−0.12 (−2.59 to 2.35)	−0.05						

BR, backward running training; FR, forward running training; CG, control group; COD, Change of direction; RSA, repeat sprint ability; M, mean; SD, standard deviation; ES, effect size; SE, standard error; CI, confidence interval. *,✧,†, significant for within-group and between-group comparisons ($p < 0.050$, 0.010, and 0.001, respectively); B, training effect favouring BRT; F, training effect favouring FRT.

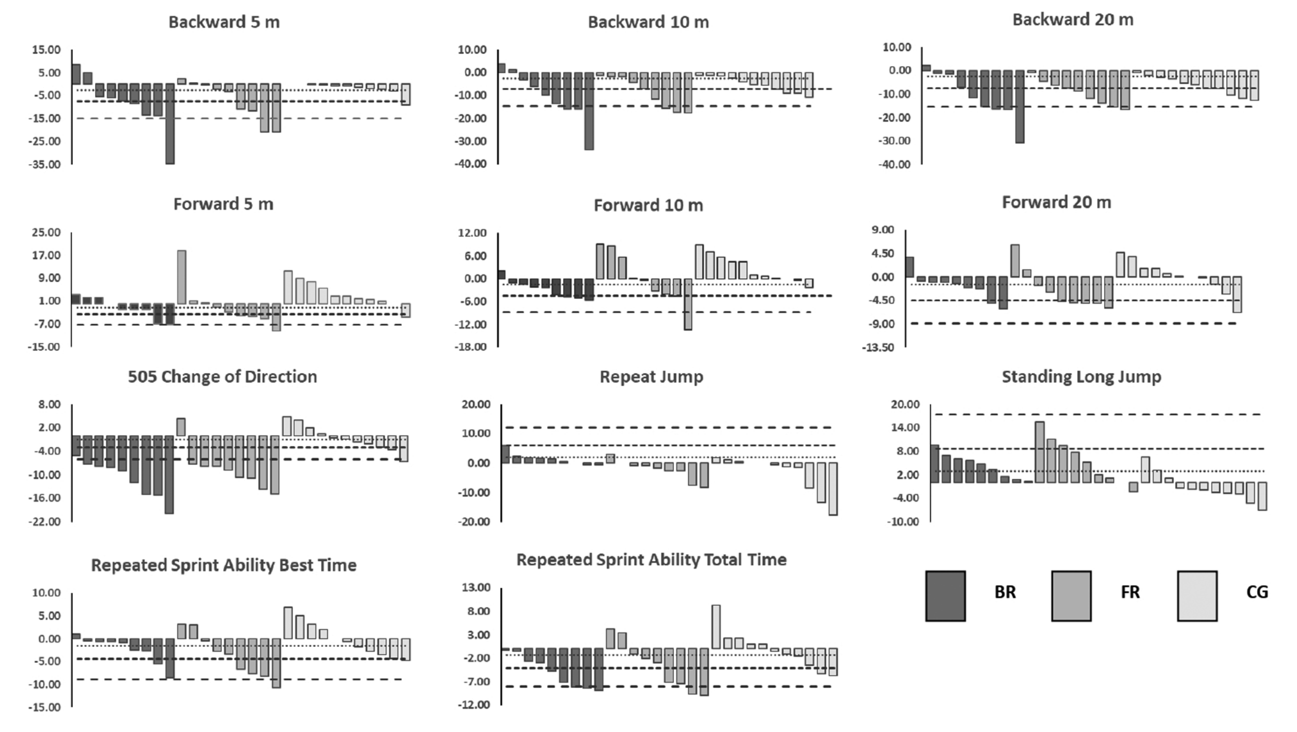

FIGURE 1
Individual percentage change from pre-training to post-training for performance tests relative to small, moderate, and large worthwhile change in performance. ………… Small response (SWC = 0.2); ……….. Moderate response (MWC = 0.6); _ _ _ _ _ _ . Large response (LWC = 1.2); FRT, forward running training group; BRT Backward running training group; CON, control group.

backward running performance, BR appears to induce the most favorable responses. Since handball players have been found to spend an average of 1.4%–2.92% of total playing time running backwards (3, 18), with wings showing the greatest total distance covered using this locomotive technique (3), enhancing this physical trait may transfer to better on-court performance. However, since this is the first study to include BR in an empirically scrutinized testing battery, more research is required to understand the trainability of this direction of running and its actual transference to on-court capabilities.

High levels of linear speed over short and medium (<30 m) distances are important physical fitness attributes in female handball players (2). BR training has been previously found to improve forward sprint performance in youth athletes (9) and maintain this athletic quality relatively better than FR training in well-trained female netball athletes (10). A similar trend was oberserved in the current study, where only BR training was found to significantly enhance forward 10 m sprint performance. BR training led to small improvements across all sprinting distances (Δ1.35%–2.70%; $g = 0.22–0.45$), the FR training induced trivial changes to 10 m and 20 m distances (*Δ*0.71%–2.51%; $g = 0.03–0.35$), and both groups led to small to moderate enhancements compared to the CG across all distances ($g = 0.29–0.78$). The relative response rates were similar for both BR training and FR training, with over half of the participants in each group improving performance beyond the SWC. These relative response rates are lower than previously reported for BR training (∼96%) but similar to responses following FR training (9). While the within-group changes following BR training are in line with the 2.54% increase in performance over 5 m–20 m forward sprints in ∼20 year-old netball athletes (10), they are much lower than the 6.37% average performance increase over 10 m and 20 m distances observed in 14.6 year-old male athletes (9). Given that youth and adult athletes respond differently to exercise (19), the novel stimuli associated with BR could explain the discrepancies observed between those of Uthoff et al. (9) and the current study. Nonetheless, both FR and BR can be used to enhance forward linear sprint ability up to 20 m, though, the findings in this study substantiate previous observations that BR appears to preferentially enhance shorter sprint performance (i.e., ≤10 m) whereas FR leads to more pronounced improvements over longer sprint distances (i.e., ≥20 m) (9).

The ability to change directions effectively is a distinctive feature of success in female handball players (), spending ∼6.92% of their time during matches performing this athletic task (3). Therefore, developing CoD ability of a handball player is likely to be advantageous in on-court competition (2). Our findings showed large pre-to-post improvements in both experimental groups ($g \geq 1.29$) and large positive effects compared to the CG group ($g \geq 1.11$). A higher relative number of participants in the BR and FR groups experienced adaptations to CoD performance greater than the SWC compared with the CG, with all participants in the BR group and all but one participant in the FR group experienced improvements beyond the MWC. Albeit not significant, the BR training induced a small improvement relative to the FR training. The 11.0% and 8.58% increases in 505

CoD performance associated with BR training and FR training, respectively, are greater than the relative 3.18% and 0.75% changes observed by Terblanche and Venter (10) in netball athletes following 6-weeks of netball-specific BR or FR training, respectively. The growing empirical support suggests that BR training and FR training can both be used to improve 505 CoD performance, though BR training appears to have a small advantage compared to FR training. Importantly, however, since the 505 CoD test comprises multiple phases (20, 21), it is unclear whether BR training or FR training leads to phase-specific adaptations (i.e., deceleration, directional change, or reacceleration). Research in this area may help elucidate the effects of running direction on phase-specific adaptations during CoD tasks.

Regarding SLJ, the current study revealed that both BR training and FR training resulted in small, yet significant improvements in SLJ (Δ4.37%–5.57%). Additionally, both interventions were found to be moderately more effective than the CG ($g = 0.55$). Individual analysis indicated that six out of nine in the BR group, and five out of nine in the FR group displayed improvements above the SWC, while only two out of eleven achieved this level of improvement in the CG. These outcomes contradict our expectations that vector-specific training to the SLJ (i.e., FR training) would lead to better improvemtents compared to a non-vector-specific program (i.e., BR training). Indeed, BR training was found to be similarly effective for enhancing horizontal slow-stretch shortening cycle jumping ability. Furthermore, given the dominance of the contractile tissue during BR training (12, 22), squat jump performance may be more sensitive to the stimulus associated with BR because the pause at the end of the eccentric phase will result in less contribution from the elastic tissues on the subsequent concentric phase of the jump (23). Future research should examine the influence of BR training vs. FR training on jump types using differing degrees of elastic utilization.

The ability to repeatedly produce maximal sprint efforts with minimal recovery time is a key physical component for highly-trained female handball players due to the intermittent activity nature that characterize match play and training (3). It has been shown that RSA performance can effectively differentiate between professional- and amateur-level female handball players (18). The current results found that FR training induced moderate within-group improvements for both RSA_{best} (3.72%) and RSA_{total} (3.57%) performance, while BR training led to a small improvement in RSA_{best} (2.27%) and large improvement for RSA_{total} (4.82%) performance, with only the changes to RSA_{total} in the BR group achieving statistical significance. These small to large improvements are greater than the 1.68% and 1.62% improvements for best and average RSA, respectively, following ten weeks of complex strength training in ∼17-year-old female handball players (5), and greater than the 0.83% RSA_{best} and 2.30% RSA_{total} improvements observed in 15–16-year-old female handball players after 8-week of plyometric training (24). Though direct comparisons with previous studies are not conclusive, based on the results of the current study, BR and FR training appear to be effective methods for healthy, trained female handball players to improve the RSA better than previously used methods such as complex strength training or plyometric training. A high inverse correlation has been found between RSA ability and maximum oxygen consumption in handball players (25). Meaning that players with greater aerobic capacity will demonstrate better RSA. However, while BR training has been previously shown to improve FR economy, it has not been found to alter maximum oxygen consumption (11). Given that BR training has been found to improve both RSA and FR economy without associated increases in maximum oxygen consumption, an alternative metabolic (e.g., PCr recovery and H^+ buffering) or neuromuscular changes (e.g., neural drive and motor-unit recruitment) may be stimulating these adaptations.

In conclusion, the findings of the current study suggest that both BR and FR training can be used to improve backward and forward linear sprinting, CoD, horizontal jumping, and RSA performance in well-trained female handball players, though BR training may have a small advantage over FR training for 10 m sprint 505 CoD, and RSA_{total}.

Though the effectiveness of BR training on measures of athletic performance has been explored since the mid-to-late 2000's (10, 26), empirical evidence in this area is still limited, with only a handful of studies looking at the performance adaptations associated with this direction of running (9–11, 26, 27). Therefore, more research on this topic should be conducted to gain a better understanding of direction-specific adaptations associated with BR and FR on phase-specific CoD performance, jump types utilizing varying degrees of elastic contribution, and the physiological and neuromuscular responses underpinning aerobic adaptations. It is important to note that the present results should be further confirmed through future studies, particularly those involving longer training periods exceeding 8 weeks. Extending the duration of the training program may provide additional insights into the long-term effects and sustainability of the observed improvements.

Conclusion

Both forward and BR training can be used, in combination with the handball training routine, to improve backward and forward sprinting, CoD, horizontal jumping, and RSA in young highly-trained female handball players. Practitioners working with youth female handball players are advised to consider implementing either FR or BR training into the training schedule. It should be mentioned though that BR training may have a small advantage over FR training for forward 10 m sprint, 505 CoD speed, while FR training may provide small improvements over BR training for RSA_{best}.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics Committee of the Research Laboratory (LR23JS01) «Sport Performance, Health & Society». The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Approval was obtained by the Ethical Committee of the Portugal Football School (PFS 16/2022).

Author contributions

SS, RB, AU, and YN contributed to the conception and design of the study. YN conducted the training intervention. SS, RB, and YN performed the testing. SS, RB, RRC, JM, and HC wrote the first draft of the manuscript. YN and HY wrote sections of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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.

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A leadership-based framework for improving Saudi Arabian female participation in sports

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Study purpose: To analyze the relationship between the leadership styles and sports engagement among female sport persons in Saudi Arabia and proposes a framework model for improving Saudi Arabian female participation in sports.
Methods: This study adopted an online cross-sectional survey design for achieving the research aim. Survey instruments included multi-factor leadership questionnaire (MLQ) and Utrecht Work Engagement Scale (UWES). The study participants included adult female sports persons from various sports clubs in Saudi Arabia. A total of 329 responses were received, out of which 35 were incomplete; therefore, a total of 294 responses were considered for the data analysis.
Results: Transformational leadership style was identified to be the most preferred style compared to transactional and laissez-fare leadership styles. Older participants (>25 years) perceived transformational leadership scales including inspirational motivation, intellectual stimulation, and individual consideration to be more effective ($p < 0.05$) compared to younger participants. Transformational leadership has strong positive correlation with all engagement scales (as correlation coefficient "r" was greater than 0.7, $p < 0.01$).
Conclusion: Inspirational motivation could be an effective approach in increasing the female participation in Saudi Arabia, as they are mentally unprepared due to the experience of socio-cultural restrictions for decades.

KEYWORDS
Saudi Arabia, participation, engagement, females, sports, barriers, leadership styles, transformational leadership

Introduction

As part of the Vision 2030 program, Saudi Arabia is transitioning away from an economy that is dependent on oil and toward one that is focused on information (1). During this procedure, numerous issues were taken into consideration, one of which was the promotion of women's empowerment, particularly through the encouragement of female participation in sports. Participation in sports enhances physical activity among the individuals. The concept of "physical activity" encompasses all forms of body motions generated by skeletal muscles that necessitate energy expenditure surpassing the baseline level (2). There is a growing body of literature that suggests a strong correlation between frequent participation in physical activity and its positive impact on an individual's overall health and well-being (3, 4). Moreover, it is worth noting that several governmental investigations and consensus statements have underscored the fundamental significance of physical activity in both individual and communal contexts (5–7). Physical inactivity and sedentary behavior have been recognized as significant contributors to various chronic non-communicable diseases, including diabetes mellitus, obesity, cardiovascular disorders, some types of cancer, osteoporosis, and mental impairments

(8, 9). Moreover, it has been established that insufficient engagement in physical exercise is associated with untimely death (10). As a result, the monitoring of physical activity or sports engagement among the individuals has progressively emerged as a matter of public health significance. It has been observed that the focus on women environment was mainly on their involvement, improvement, and achieving their rights, which needs a change in socio-cultural, political, legal, economic, and environmental systems (11). However, there are a variety of barriers that prevent Saudi women from participating in sports. These obstacles include socio-cultural, family, and institutional aspects (12, 13).

One of the most significant characteristics of cultures that has been the topic of debate for millennia everywhere in the world is the way in which women are treated unfairly in those communities. Even though gender inequality has been somewhat addressed in many countries because of policy and regulations, prejudice remains deeply ingrained in the society and culture of a select number of nations. It is a factor of societal and cultural norms reflecting the subservient roles of women in the society (14). For example, in a few countries such as Pakistan, Afghanistan, and Saudi Arabia, the practice of patriarchal conjugal relationships reflects the incorrect perception of linking women's discrimination to religion. In these countries, the practice of patriarchal conjugal relationships reflects the ill perception of linking women discrimination to religion. According to OECD (15), Saudi Arabia is one of the nations in which several problems have been highlighted about women. These problems include discrimination in the family, threats to physical integrity, a lack of productive and financial resources, restrictions on civil freedoms, and more. In addition, discrimination in fundamental rights such as work, healthcare, and personal development were just a few parts of the concerns that were harming the empowerment of women in Saudi Arabia (16, 17). In most cases, the influence of these variables prevents women from accessing a variety of possibilities that can help them achieve their goals and slows down the process of their growth. One of these areas in the country that women are not allowed to participate in, which has been the case for quite some time now, is sports.

According to a recent study conducted by Al-Dubayan (17), inequalities in organizations are still prevalent in Saudi Arabia. These inequalities are particularly prevalent in the adoption of customs such as wasta and asabiyyah, in which advantages were given to family members or those belonging to the same status. In Saudi Arabia, sports organizations are the same as any other kind of organization, just like any other kind of organization, they involve a variety of tasks such as training, management of sports activities, and so on. On the other hand, as part of its Vision 2030 program, the Saudi government has undertaken several measures at the national level to improve the quality of life and health of women and girls, and at the international level, it has increased the visibility of Saudi female athletes (18). Because of this, the number of women who manage sports clubs and teams as well as the number of women who participate in sports has increased by 56%, which is a promising indicator for the expansion of options available to women who are interested in participating in sports (19). On the other hand, there are still obstacles that make it difficult for women to participate in sports. To allow women to participate in a variety of sports, for instance, it was necessary to consider numerous socio-cultural elements, such as gender segregation and Islam (20, 21). In addition, the attitudes of family members, the location of the home (whether it be urban or rural), and the degree of education were shown to be the primary obstacles for female engagement in sports (21). In a similar vein, in educational settings, physical fitness, social experience, and formal competition all have a beneficial effect on physiological experience, which in turn has a positive effect on the attitude of female students towards sports (22). Therefore, there may be a variety of areas in which the obstacles that prevent women from participating in sports can be recognized based on the research that is done, and these areas need to have competent leadership handled.

Although, there is issues with gender equality in sports participation globally, its impact was mainly observed in the Middle East till the past decade (23). Furthermore, it was observed that when compared to other Arab or Muslim women, Saudi women are subject to a greater number of limitations since they are prohibited (legally or culturally) from doing many things by themselves and are required to have a male guardian present to participate in some activities (24). Young Arabic Muslim women who participate in sports are perceived as taking on a challenge to the limits of their ethnic identities when compared to their peers who do not (24). Young Arabic Muslim women who firmly position themselves within the context of their ethnic identities are not interested in sports since participating in athletics is not viewed as respectable femininity among Arabic Muslim culture (25). Even though the Kingdom of Saudi Arabia places a strong emphasis on the importance of protecting the female population, the lack of physical education for girls in schools, which only stopped very recently, the limited number of fitness centers and gyms for women, a particular body image, and the prevalence of women staying at home and leading rather passive or static lives have all contributed to a somewhat unhealthy lifestyle among women (26). In the past, Saudi women have not had access to physical education or sports, which is evidenced by the poor health status they currently suffer from (44% obesity rate), which is significantly higher than the national average (35.4%) and nearly three times as high as the worldwide average (13%) (13). Although, significant changes have been introduced in the past few years in kingdom for promoting female physical activity and health, there is a change being observed in women participation in sports and physical activity, but they still face issues in different contexts (27, 28). A recent study (29) suggested an ambitious policy that was well-founded, as well as the achievement of several goals in Saudi Arabia. It was discovered that the most obvious results have thus far been the rapid, albeit modest cultural change in terms of physical activity, allowing women to participate in sports and raising the level of physical activity among Saudis. This transformation was one of the most evident achievements. Despite this, there are still some objectives that have not been met, most notably those associated with the participation of women in sports. In conclusion, there has been some movement toward the actualization of the policy regarding the promotion of physical activity; however, there are several factors that exist that have hampered achievement in particular domains, revealing a lack of effective leadership practices in motivating female participation in sports (29).

With the change being observed, it is essential that there is a need to increase research in this area to better analyze the policies, and the impact of various factors on women participation in sports in Saudi Arabia. Such research studies can have various benefits, as it can aid in promoting gender equality, promoting women's empowerment, improving health outcomes, and reaping economic and social benefits. It enables policymakers, sports organizations, and leaders to identify strategies that encourage female participation and create a more inclusive and equitable sports landscape. However, the number of studies focusing on the women and sports participation is very low as observed in a recent systematic review (30). Therefore, to address such gaps, this study aims to analyze the relationship between the leadership styles and sports engagement among female sport persons in Saudi Arabia and proposes a framework model for improving Saudi Arabian female participation in sports.

Hypothesis development

The relationship between transformational leadership style (a leadership style that focuses on inspiring and motivating followers to achieve their full potential and exceed their own expectations) and engagement was studied in various contexts such as manager and employee relations. Studies (31–33) have identified that transformational leadership contributed to various aspects such as needs satisfaction, less job strain, increased autonomy, and support, leading to a positive correlation between transformational leadership and employee engagement. In the context of sports, transformational leadership was related with athletes well-being and satisfaction (34), leading to a positive correlation with sports/physical activity engagement (35, 36). In this context, this study considers following hypothesis.

H1: Transformational leadership exhibits strong positive correlation with engagement in sports.

Similarly, studies (37–42) have identified that transactional leadership (a leadership style that emphasizes the exchange of rewards and punishments between the leader and their followers based on the completion of tasks and meeting performance expectations) reflect moderate positive correlations with engagement in physical activity as it promotes non-autonomous motivation; but laissez-faire leadership (characterized by leaders who give their team members a high degree of autonomy and decision-making authority) reflected negative correlations with engagement in physical activities. In this context, the following hypotheses are formulated.

H2: Transactional leadership exhibits moderate positive correlation with engagement in sports.

H3: Laissez-faire leadership exhibits negative correlation with engagement in sports.

Methods

This study adopted an online cross-sectional survey design for achieving the research aim.

Questionnaire design

The first part of the questionnaire focuses on collecting the demographic information of the participants, which includes age, education, and sports experience. The second and third parts of questionnaires includes two pre-validated and academically recognized survey questionnaires respectively, which include: multi-factor leadership questionnaire (MLQ) (43) and Utrecht Work Engagement Scale (UWES) (44). MLQ is one of the prominent questionnaires that is used for identifying leadership styles in different settings (45); and UWES, although developed for assessing work engagement in organization, it is adopted in sports environment for assessing sports engagement (44). Using these questionnaires, individual leadership scales and sports engagement scales can be correlated to test the hypothesis. The MLQ consists of 21 questions, each of which must be scored on a Likert scale ranging from 0 (never) to 4 (very often), with 1 denoting never and 5 denoting never more than once in a while. The focus of items 1–12 is on several forms of transformational leadership, which can be further subdivided into idealized influence (items 1–3), inspiring motivation (items 4–6), intellectual simulation (items 7–9), and individual attention (items 10–12). Items 13–18 are associated with transactional leadership styles, which can be subdivided into management by exception (items 16–18) and contingent reward (items 13–15). Items 19–21 are associated with a leadership style known as laissez-faire. UWES-9 has 15 items which are grouped under vigor, dedication, and absorption categories. The participants' degrees of agreement or disagreement with each question on the UWES-9 are reflected by their placement on a scale with five points, ranging from 1 (Never) to 5 (Always). The UWES-9 consists of 15 items, five of which are categorized as belonging to the vigor category, five to the dedication category, and five to the absorption category, respectively.

Two Arabic translators were employed to translate the questionnaire from English to Arabic. The individual translated versions are compared and a final version is developed by the authors. The final version is reviewed by the academic professors from Language and cultural studies department and minor changes related to grammar were suggested, which were implemented. After having the questionnaire translated into Arabic, a pilot study was carried out with 21 participants. The results, which showed a Cronbach's alpha of better than 0.70 for all items, suggested good internal reliability and consistency (38).

Using Google Survey, an online version of the survey questionnaire was created, and a link to that online version is being established for the purpose of data collection.

Participants, recruitment, and sampling

As the study is focused on female sportspersons, the participants in this study included female sportspersons in Saudi Arabia aged more than 18 years. The participants from the study were recruited from the five sports clubs in Saudi Arabia. Five sports clubs were contacted for participation in this study, to whom an invitation email with survey link was sent. The email was then forwarded to the members of respective female sports clubs. In addition, snow-ball sampling (45) was used, where a request was placed in the email to forward the link to their colleagues who are female sports persons.

Considering the 14 million Saudi female population (46), estimated sample was calculated using Cochran's formula (47), at 95% CI and 5% of Margin of error, giving an estimated sample of 384 participants.

Data collection and analysis

The data was collected online using an online-administered survey questionnaire. The invitation email was sent to 594 female sports persons, from five sports clubs. A total of 329 responses were received, out of which 35 were incomplete; therefore, a total of 294 responses were considered for the data analysis.

The data was analyzed with SPSS version 20.0, and a variety of statistical methods, such as *t*-tests and Pearson's correlation, were utilized. To remove any potential sources of bias from the analysis of the results, missing data were eliminated. The key finding of the investigation is a correlation between leadership style and the level of participation displayed by sportspeople.

Results

As the study is focused on analyzing female sports persons perceptions of leadership styles and sports engagement, only 294 female sports persons are included (See **Table 1**). Considering the education attributes of the participants, majority of them were diploma holders (44.9%), followed by bachelor's degree holders (40.1%), master's degree holders (10.2%, and 4.8% participants with primary/secondary school education. Considering the age factor, most of the participants were distributed across three age groups including 22–25 years (31.3%), 18–21 years (29.3%), and 26–29 years (22.8%). About 9.5% were aged between 30 and 33 years, and 7.1% were aged more than 33 years. In relation to experience in sports, 43.2% participants had three to five years of experience, followed by 40.5% having six to ten years of experience, and 16.3% having more than ten years of experience.

TABLE 1 Participants demographics.

Variable	Demographic characteristics	Frequency counts	Percentage
Education	Primary/Secondary education	14	4.8%
	Diploma	132	44.9%
	Bachelor's degree	118	40.1%
	Master's degree	30	10.2%
Age	18–21	86	29.3%
	22–25	92	31.3%
	26–29	67	22.8%
	30–33	28	9.5%
	>33	21	7.1%
Experience in sports (participating in sports related activities for how many years?)	3–5 years	127	43.2%
	6–10 years	119	40.5%
	>10 years	48	16.3%

Considering the perceptions on different leadership styles, transformational leadership was most preferred by the participants, as it can be observed from mean rating or average scores for sub-scales including idealized influence (3.11 out of 5), inspirational motivation (3.16), intellectual stimulation (3.04), individual consideration (3.11). Transactional leadership styles are less preferred as the mean ratings of sub-scales reflected low to medium preferences: contingent rewards (2.66) and management by exception (2.65). Laissez-faire leadership was least preferred by the participants as it achieved lower ratings (2.47) compared to other leadership styles. All engagement sub-scales vigor (2.71), dedication (2.72), and absorption (2.72) indicated low to medium levels of engagement in sports activities.

To further analyze the results by participants groups (see **Table 2**), *t*-tests were conducted. Statistically significant differences ($p < 0.05$) were observed between younger and older participants in relation to transformational leadership scales including inspirational motivation ($p = 0.03$, p, 0.05), intellectual stimulation ($p = 0.02$, $p < 0.05$), and individual consideration ($p = 0.03$, $p < 0.05$). Older participants preferred transactional leadership styles more than the younger participants. However, no statistically significant differences were observed among the participants with different levels of sports experience in relation to transformational and laissez-faire leadership styles. Statistically significant difference ($p < 0.05$) was observed with respect to transactional leadership sub-scale: management by exception ($p = 0.03$, $p < 0.05$) among the participants with different experience levels. Participants with experience over five years preferred management by exception factor more than the participants with lower experience levels.

Interestingly, no statistically significant differences were observed between the participants groups with respect to sports engagement (see **Table 3**).

Table 4 presents correlations between the leadership styles and sports engagement sub-scales. It is evident that transformational leadership has strong positive correlation with all engagement scales (as correlation coefficient "r" was greater than 0.7, $p < 0.01$). Furthermore, correlations between transactional leadership and laissez-faire leadership styles were identified to be

TABLE 2 Perceptions about leadership styles grouped by age and sports experience variables.

			N	Mean	SD	*t*-value	*p*-value
Idealized influence	Age	≤25 years	178	3.02	1.0	1.6265	.0525
		>25 years	116	3.23	1.18		
	Experience	3–5 years	127	3.04	1.34	0.8271	0.2044
		> 5 years	167	3.15	.97		
Inspirational motivation	Age	≤25 years	178	3.08	.8	1.8795	0.0306*
		>25 years	116	3.29	.87		
	Experience	3–5 years	127	3.12	.95	0.7618	0.2234
		>5 years	167	3.2	.74		
Intellectual stimulation	Age	≤25 years	178	2.91	1.03	2.8574	0.0023*
		>25 years	116	3.25	1.01		
	Experience	3–5 years	127	3.07	1.13	0.3468	0.3645
		>5 years	167	3.03	.99		
Individual consideration	Age	≤25 years	178	3.02	.97	1.8088	0.0358*
		>25 years	116	3.23	1.05		
	Experience	3–5 years	127	3.13	1	0.4059	0.3421
		>5 years	167	3.08	1.02		
Contingent reward	Age	≤25 years	178	2.62	1.16	.7924	0.2944
		>25 years	116	2.72	1.18		
	Experience	3–5 years	127	2.59	1.21	1.0629	0.1443
		>5 years	167	2.73	1.14		
Management by exception	Age	≤25 years	178	2.59	1.12	1.2532	0.1056
		>25 years	116	2.75	1.03		
	Experience	3–5 years	127	2.52	1.13	1.881	0.0305*
		>5 years	167	2.76	1.04		
Laissez-faire	Age	≤25 years	178	2.45	1.21	0.4424	0.3292
		>25 years	116	2.51	1.17		
	Experience	3–5 years	127	2.44	1.22	0.5635	0.2867
		>5 years	167	2.51	1.16		

*Statistically significant difference.

TABLE 3 Perceptions about sports engagement grouped by age and sports experience variables.

Engagement factor	Variable	Group	*N*	Mean	SD	*t*-value	*p*-value
Vigor	Age	≤25 years	178	2.68	1.32	0.6697	0.2518
		>25 years	116	2.78	1.16		
	Experience	3–5 years	127	2.74	1.41	0.4103	0.3409
		>5 years	167	2.68	1.15		
Dedication	Age	≤25 years	178	2.64	1.24	1.4977	0.0677
		>25 years	116	2.84	1.31		
	Experience	3–5 years	127	2.71	1.31	0.0924	0.4632
		>5 years	167	2.73	1.25		
Absorption	Age	≤25 years	178	2.63	1.21	1.6223	0.0531
		>25 years	116	2.85	1.28		
	Experience	3–5 years	127	2.7	1.26	0.2541	0.3997
		>5 years	167	2.74	1.22		

TABLE 4 Correlations between MLQ and UWES sub-scales.

	Vigor	Dedication	Absorption
Idealized influence	.736**	.744**	.731**
Inspirational motivation	.764**	.798**	.793**
Intellectual stimulation	.734**	.768**	.772**
Individual consideration	.727**	.764**	.769**
Contingent reward	.557**	.544**	.535**
Management by exception	.553**	.547**	.541**
Laissez-faire	.518**	.507**	.511**

**Correlation is significant at the 0.01 level (2-tailed).

having moderate relationship (as correlations ranged between 0.5 and 0.6) with all sub-scales of engagement levels including vigor, dedication, and absorption.

Discussion

The findings in this study indicated that sports managers exhibited transformational leadership styles far better than transactional and laissez-faire leadership styles. Furthermore, transactional leadership styles and laissez-faire leadership styles were also adopted, but to a lower extent. Although, all the three leadership styles were exhibited, sports managers were more inclined towards transformational leadership styles. It may be possible that managers exhibit different leadership styles according to the working conditions (48–51), because of which different styles can be observed by the sports persons. However, previous studies (52, 53) observed that Saudi women unknowingly act in accordance with male ideals, as they are culturally nourished with the thinking of male superiority over females; and as such, they tend to prefer masculine leadership, which is characterized by assertiveness and competitiveness. However, the sports managers for female sports persons include female managers (54, 55), who may adopt transformational leadership styles which are characterized by support, motivation, and cooperation rather than masculine leadership styles, which is evident from the high mean scores for transformational leadership sub-scales in this study.

Among the transformational leadership sub-scales, inspirational motivation was observed to be the most frequently displayed sub-scale. Given the various socio-cultural barriers for females in Saudi Arabia (23–28) from entering sports, motivational approach could be an effective strategy to boost the morale and engagement of the female sports persons in Saudi Arabia. Accordingly, inspirational motivation exhibited strong correlation with sports engagement sub-scales including vigor, dedication, and absorption; compared to other transactional leadership sub-scales. Intrinsic motivation is one of the benefits of adopting transformational leadership. Studies (56–59) have observed that motivation related intervention such as gamification can enhance positive attitudes and emotions of the individuals to engage in physical activities. These findings suggest that transformational leadership style could be more favorable in increasing sports engagement compared to other styles as it fosters motivation among the sportspersons through enhanced support from the leaders. In addition, skills and sports literacy/awareness were also identified to be significant factors influencing the sports engagement (60, 61), which require transformative approach which focuses on support, change management, continuous improvement, and skills development through an inspirational motivation. Supporting these outcomes, the hypotheses H1 was proved to be true. Similarly, hypotheses H2, indicating moderate positive correlation of transactional leadership on engagement in sports was observed to be true supporting the findings from (37–40). However, in contrast to the findings in (37–42), laissez-faire leadership exhibited moderate positive correlation with engagement in sports, resulting in hypotheses H3 to be determined as false. These contrasting results may be due to the prevalence of laissez-faire and paternalistic leadership styles in Saudi Arabia since early childhood in different contexts (62, 63).

However, several barriers including lack of time, safety, parental support, policies, access to sport and PA facilities, and transportation, as well as climate were observed for participation in physical activities among females in Saudi Arabia (64). Furthermore, the weekly physical activity levels of Saudi citizens aged above 15 years was identified to be 13% in 2015, 19% in 2019, which is very low compared to the target of 40% set by the country, indicating poor physical activity levels among citizens (65). Therefore, there is a need for strong support, effective and efficient policies from the government to foster the change in attitudes of the people in society towards the participation of females in physical activities and sports. The initiatives led by Vision 2030 has contributed to the increase in female participation in physical activities and sports in Saudi Arabi. For instance, establishment of female sports clubs, easing regulations for female participation in sports, deploying an operational process for sustainable and inclusive sports ecosystems launched by HRH Princess Reema bint Bandar Al Saud, have greatly contributed to the female participation in sports in the last few years (66). The changes being introduced recently could be the factor affecting the differences in the younger groups perceptions about transformational leadership styles as observed from the findings. Studies (30, 67) have also highlighted the importance and the need for workshops, training and support, motivation in educational institutions such as schools and universities to foster the change in attitudes of the people ad increase the participation in sports and physical activities. As a result, younger students may increase their participation, and the need for motivation may be slightly replaced with the need for stimulation, influence, and consideration.

In Saudi Arabia, only 17.4% of the population are practicing sports or physical activity for more than 150 min a week (67), which is less compared to 32% in European Union (68) and 22% in the USA (69). Few individuals participate in sports such as football (20.5%), swimming (5.3%), running (3.7%), and Swedish exercises (a system of active and passive exercises that use different muscles and joints of the body) (8.5%) in Saudi Arabia (70), indicating low engagement levels. Therefore, there is an urgent need to improve sports engagement in the Kingdom.

Based on the discussion, a framework model is presented in **Figure 1** to promote the participation and engagement of females in sports in Saudi Arabia.

The framework has seven main components, which are explained below:

1. Inspirational Vision:

   The first step in the transformational leadership model is to establish an inspiring vision that emphasizes the value and benefits of female participation in sports. This vision should be communicated effectively to various stakeholders, including government officials, sports organizations, community leaders, and families. By illustrating the positive impact of women's involvement in sports on individual well-being, health, personal growth, and national development, the model aims to generate enthusiasm and support.

2. Leadership Development:

   To drive the transformation, it is crucial to develop a strong cohort of transformational leaders who are passionate about promoting female participation in sports. These leaders should be selected from diverse backgrounds, including sports, academia, government, and community organizations. Specialized leadership development programs can be designed

FIGURE 1
Framework model for promoting participation and engagement of Saudi females in sports.

to enhance their knowledge, skills, and understanding of gender issues in sports. The training should focus on empowering leaders to challenge societal norms, advocate for change, and create opportunities for female athletes.

3. Inclusive Infrastructure:

   Creating a supportive and inclusive infrastructure is essential for increasing female participation in sports. This includes building sports facilities that cater to the specific needs of women, such as women-only gyms, swimming pools, and sports clubs. Additionally, promoting accessible and safe transportation options for female athletes will help overcome logistical barriers. Collaboration with sports organizations and private sector entities can be encouraged to invest in infrastructure development, ensuring it aligns with the specific requirements of female athletes.

4. Skill Development and Education:

   To encourage women to engage in sports, it is vital to provide comprehensive skill development and educational opportunities. Establishing sports academies and training programs exclusively for women, facilitated by experienced coaches and mentors, will foster talent, and empower aspiring athletes. Furthermore, incorporating physical education programs in schools and universities that prioritize gender equality in sports can help shape positive attitudes towards female participation from a young age.

5. Cultural Change and Awareness:

   Addressing deep-rooted cultural barriers is crucial for long-term success. The transformational leadership model aims to initiate a cultural shift by promoting awareness campaigns and engaging influential figures, such as religious leaders, celebrities, and media personalities. These campaigns should highlight the accomplishments and success stories of female athletes, challenge gender stereotypes, and emphasize the importance of equal opportunities in sports. Collaborations with media outlets can be established to ensure widespread coverage of women's sports events and achievements.

6. Supportive Policies and Regulations:

   To ensure sustainability, supportive policies and regulations need to be implemented. Government entities and sports organizations should work together to formulate policies that eliminate gender-based discrimination, provide equal funding and resources for female sports programs, and enforce strict measures against gender-based harassment and violence in sports settings. These policies should also mandate gender diversity on decision-making bodies to ensure female voices are heard.

7. Evaluation and Continuous Improvement:

   Regular evaluation and feedback mechanisms are essential to assess the effectiveness of the transformational leadership model. By collecting data on female participation rates, athlete satisfaction, infrastructure utilization, and public perception, areas of improvement can be identified and adjustments made accordingly. This ongoing assessment will ensure the model remains adaptable and responsive to evolving needs and challenges.

Implications and limitations

There are few limitations which can be identified in this study. Firstly, the study population only focuses on the female sports persons, and does not include female students from school or universities, as a result, the findings in this study should be generalized with care. Secondly, it is important that the results of this study be viewed and generalized with care as there may be inevitable and unaccountable self-selection bias in the data.

There are various implications of the findings derived from this study. The findings in this study can be used by the decision-makers in developing strategies for attracting the female population in engaging physical activity by deploying leaders with transformational leadership, especially those who can motivate effectively. Secondly, these findings can be used to improve the quality of life of Saudi residents by increasing sports engagement, as studies have observed various health benefits such as improved physical and mental health (71, 72) and reduced risk of chronic illnesses (73, 74). Thirdly, this study contributes to the lack of female sports research study in Saudi Arabia by providing significance of the relationship between leadership styles and sports engagement among females in Saudi Arabia.

Conclusion

Understanding the relationship between leadership styles and sports engagement among females in Saudi Arabia is important because of the achievement of Vision 2030 goals to increase female participation in all activities and to achieve sustainable sports system. However, the existence of various barriers for female participation highlighted the need for adopting inspirational motivation approach reflecting the transformational leadership practice by the sports managers. Thus, the findings indicated that transformational leadership is an effective approach to increase female participation and engagement in sports in Saudi Arabia.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the author, without undue reservation.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Soccer above all? Analysis of academic and vocational education among female soccer players in the German women's Bundesliga and 2nd women's Bundesliga

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Introduction: Career-related (financial) reasons as well as advantages in terms of expanding social support systems, promoting a balanced lifestyle and personal development suggest that female soccer players should pursue academic or vocational education in parallel to elite sport. However, dual careers are fraught with challenges, mainly due to simultaneity in time and the associated conflicting goals. The aim of this article is to analyze the vocational or academic educational careers of professional female soccer players.
Methods: To generate the data, an online survey was conducted among soccer players in the German Women's Bundesliga and 2nd Women's Bundesliga. A total of n = 200 questionnaires (German: $n = 191$; English: $n = 9$) were included in the analysis, which corresponds to approx. 29.6% of the population addressed.
Results: 90.6% of the players are pursuing or have already completed academic or vocational education. The majority (71.2%) of female soccer players choose to study. 81.8% of players report no impact or even a positive impact of soccer on their performance in academic or vocational education. Willingness to pursue and complete academic or vocational education is influenced by membership of the A-National Team, time spent playing soccer, form of school-leaving qualification, nationality and age.
Discussion: This study increases the visibility of professional women's soccer as an object of analysis in sports science research, follows up on demands for a more athlete-centered approach and generates further insights for research and practice with regard to the success of dual careers in elite sport.

KEYWORDS
women's soccer, elite sport, women's Bundesliga and 2nd women's Bundesliga, vocational and academic education, influencing factors, logistic regression

1 Introduction

Elite women's soccer is one of the most dynamically growing sports in the world (1). However, women's soccer has much lower income returns compared to men's soccer (2). Exceedingly few players will therefore succeed in securing their post-sport career financially in the long term through income earned during their soccer career (3). Thus, for most female soccer players, a career start or change will be necessary after the end of their top-level sporting career. It should be noted that the skills acquired in soccer are only conditionally transferable to the requirements in most occupational fields. This means that, at the end of a sports career, the (sports-related) human capital is devalued and can only be transferred to non-sports occupational fields to a limited extent (4). A successful transition from a sports career to a professional career after sport is therefore likely to depend to a large extent on whether female soccer players are able to adapt to the demands of the labor market in good time through appropriate further education. Adequate qualifications are indispensable for successfully making the transition to the regular labor market. By taking advantage of vocational or academic qualification offers, breaks in career and life trajectories can be prevented or at least reduced (5). In this respect, female soccer players should already think about their professional career after sport during their sports career in order to avoid the danger of falling into “professional nothingness” after the end of their soccer career (4).

However, vocational or academic certificates and experience can only be acquired if sufficient time resources are available. The choice of (further) vocational or academic education is made more difficult by the simultaneity of careers in sport and education and the associated conflicts of objectives regarding limited time resources (6). The challenges of a dual career that combines elite sport and vocational or academic education increase in comparison to dual careers of elite sport and school (7).

The aim of this article is to analyze vocational or academic education among professional women soccer players in the German Women’s Bundesliga and 2nd Women’s Bundesliga. The focus is on the following research questions: (*1*) *To what extent do elite female soccer players have started or already completed vocational or academic education during their sporting career? (2) To what extent does a sporting career influence vocational or academic education? (3) What factors influence the willingness for starting and completing vocational or academic education?*.

2 State of research

Studies on educational and professional careers in soccer mainly refer to the male sector. The focus is on the analysis of post-sport career paths in particular. Barth et al. (8) show in a systematic review that previous studies focus on health-related aspects and psychological problems after the end of a career (9–14). The aspect of occupational mobility (promotion and relegation) is also addressed in previous studies (15, 16). Furthermore, studies are available that address financial competencies (17, 18), the financial transition after the end of a career (19) and consumer and savings behavior (20, 21), as well as professional soccer as risks for the post-sporting career (22). In addition, statistics show that only around half of male soccer players in the third and fourth leagues in Germany pursue vocational education or already have a vocational or academic qualification (23).

For professional women’s soccer, a Danish study shows that female soccer players have strong difficulties in balancing top-level sport with education, work and family commitments. As a consequence, these problems lead to an increased risk of early exit from soccer (24). A study of Canadian and Norwegian female soccer players shows that it is also difficult for female soccer players to find a career within soccer (for example, as a coach or in management) after their sporting career ends (25). Using the example of English female soccer players, it could be clarified that they prefer dual careers to a large extent, whereby the focus is placed on studying. The players cite the factor of “security” for their post-sport career as the main reason for pursuing a dual career (7).

Outside of soccer, there are many studies that deal with the topic of dual careers. As Vidal-Vilaplana et al. (26) present in a review, more than 100 articles on the topic of dual careers among elite athletes have been published in the period since 2017. A brief narrative overview of research on dual careers in elite sport and vocational or academic education outside soccer shows the following: existing studies address the compatibility of sporting demands and further education-related concerns of athletes (27–32). Aquilina (27), for example, shows in a cross-national comparative study that a university education and sporting success are quite compatible or can complement each other synergistically. Mutual benefits of pursuing a dual career are seen by the athletes, for example, in the fact that pressure and frustration in sport can be reduced through educational success and, vice versa, pressure and frustration in university education can be reduced through sporting success. Furthermore, athletes report that physical challenges can be better overcome through intellectual stimulation and that skills learned in one area can be transferred to the other. In addition, dual careers can lead to athletes showing a stronger sense of “balance” and therefore make them more motivated to continue their elite sporting career in the long term (27). On the other hand, the time-consuming aspect of pursuing an educational qualification alongside a sporting career should not be neglected. If these areas of life are not well coordinated, and if the athlete is not able to combine both areas in such a way that the burdens are well-balanced and acceptable for them, this can lead to increased stress, impaired mental health, burnout or cause them to drop out (33, 34).

Further studies examine the influence of mechanisms and factors on the process of dual careers of athletes. In addition to the handling of time compatibility (6, 35), factors that both enable and prevent top athletes from realizing dual careers are analyzed (32, 35–37). The flexibility of educational institutions and the stretching of vocational or academic education over time are also examined (38, 39).

Complementary studies address experiences in the context of dual careers and their prioritization (40–45). In terms of typologies of dual careers, a basic distinction is made between athletes who (a) focus equal attention on their sporting career and educational/vocational career, (b) prioritize their sporting career or (c) focus exclusively on sport (46). This distinction was extended by including career identity, athletic identity and self-efficacy in the analysis, whereby athletes who prioritize education or vocation could also be typologized (42). In addition, the holistic objective life situation of elite athletes is analyzed in further studies by using assessments of the socioeconomic system (athletic, educational, vocational, and financial) for typification (45).

Reflecting on the state of research, it becomes clear that although many studies are available in the context of dual careers, there is comparatively little focus on soccer, the most prominent sport in many European countries. This is especially true for professional women's soccer. An analysis of vocational and academic education that is taken up during the top-level sporting career is particularly relevant for women's soccer that, on the one hand, receives more media attention than most Olympic sports but, on the other hand, offers far lower earning opportunities than male soccer. Accordingly, it is important to empirically analyze the value that female players attach to educational investments and which behaviors go hand in hand with this.

3 Theoretical framework

3.1 Educational decisions in the context of human capital theory

The fundamental decision as to whether female soccer players pursue parallel vocational or academic education during their top-level sporting career can be modelled in the context of human capital theory (47). This theory assumes that investments in human capital (e.g., through academic or vocational education) lead to an increase in productivity, which in turn leads to a higher attainable income (48). Education, qualification and learning activities in this sense represent individual investment in the performance potential (human capital) that can be utilized on the labor market (47). Individuals invest in education (vocational or academic) in order to earn higher incomes in the future after discounting the education (see critical discussion from 49, among others). Such investment decisions in human capital are linked to expected (opportunity) costs and expected income or career opportunities. Accordingly, those job-related education options are chosen that promise the greatest career opportunities and associated income returns for the costs incurred (time, money) (47).

Despite their increased popularity, female soccer players in Germany only earn a low income from their sport. Surveys (although not representative) show that not even 20% of German female soccer players in the Women's Bundesliga and 2nd Women's Bundesliga earn a monthly salary of more than € 1,000 (50). If one follows the core assumptions of human capital theory, then it can be assumed that the majority of female soccer players will benefit (in the long term) from investments in vocational or academic education due to the comparatively low returns on income in women's soccer (3). If female soccer players consider future income and labor market opportunities after their sports career to be important, they will push for professional qualification because the expected income appears to them to be favorable for amortizing the necessary educational expenses (time, money).

However, the social structure of elite sport in general and soccer in particular is characterized by a strong orientation on the present (20). Top athletes usually exhibit a strong biographical fixation on elite sport, which leads to discounting of the future (on the concept of hyperbolic discounting, see 51). Consequently, other career areas and corresponding activities (e.g., professional education) may be neglected (52). The willingness of female soccer players to continue with their professional education, which is an individual investment decision beyond the end of their sporting career and thus over a longer planning horizon, thus collides with the players' orientation toward the present and influences their value structure. Such a time preference can lead to an extension of time investments in sports and to a restriction or complete neglect of education-related efforts.

3.2 Factors influencing starting and completing academic or vocational education

Female soccer players operate in the setting of elite sport, which is why *soccer-related factors* have to be included in the analysis. Within elite sport, sporting success is the primary goal (53). On the one hand, there are likely to be players who accept neglecting education to increase or secure their chances of sporting success, as professional qualifications can still be gained or upgraded after the end of their sporting career. On the other hand, other players will take advantage of academic or vocational education options during their sporting career to secure alternative professional career prospects for their future livelihood (7). If players have the expectation that a parallel education will have a negative impact on soccer, then it can be assumed, especially for successful female soccer players, that they will forego an education or postpone completion of it (35). With increasing sporting success, the opportunity costs of taking up vocational or academic education rise. If sporting success suffers as a result of the necessary investment in vocational or academic education, this is associated with financial losses and loss of reputation, especially for successful female soccer players.

It should also be noted that female soccer players only have a limited time budget. Due to training, competition, physiotherapy and other appointments, female soccer players are often heavily involved in sport (28, 30). Professional sport as a full-time job (53) can limit opportunities for pursuing vocational or academic education.

Educational decisions of female soccer players can also be influenced by the resources acquired during their elite sport career. For example, existing findings (e.g., 54) show that athletes with high social recognition and prominence are less likely to invest in a dual career. This is explained by the fact that there is no compelling financial necessity (35) and a later professional position in the field of sport is more likely to be secured (55). Accordingly, an (overly) optimistic assessment (overestimation) of the usability of resources accumulated in the course of a sports career (symbolic capital/reputation, see 56) could have a negative impact on the assessment of the value of academic or vocational education, which is why the influence of familiarity must be included in the analysis. It is also important to analyze the extent to which the expectation that skills acquired in elite sport ("transferable skills") (57, 58), are advantageous for starting a career has an impact on decisions and trajectories related to academic or vocational education.

It should also be examined to what extent the possible end of a soccer career influences starting and completing academic or vocational education by shifting cost-benefit relations (59). Female soccer players who are close to the anticipated end of their sporting career may make different utility trade-offs than players at the beginning of their sporting career.

In addition to soccer-related factors, *social and socio-demographic factors* must also be considered. It can be assumed that the willingness of female soccer players to pursue vocational or academic education increases with increasing support (31, 35, 60). Advice from, for example, career counselors, family members, friends or players' agents can raise players' awareness of the importance of vocational or academic education and reduce search and information costs in relation to suitable education opportunities (61).

With increasing age, the risks of a lack of education increase, as it is hardly possible to compensate for the income lost by starting a career (too) late (28). Existing studies suggest that top athletes focus on their educational careers more strongly from the age of 25 at the latest (62).

Since individual stages within school, academic or vocational education influence each other in their chronological sequence (63), the school-leaving qualification must be considered. This shows that further education in the form of a degree is easier for top athletes with a higher education entrance qualification in comparison to athletes who want to pursue vocational education (64).

It is also important to examine the extent to which nationality influences academic or vocational education. Foreign players who play in the Bundesliga or the 2nd Bundesliga in Germany are likely to be highly success-oriented and identify strongly with top-level sport (65). It can be assumed that the opportunity costs of vocational or academic education are high for these players, which may reduce their willingness to pursue it (38). In addition, language barriers and a lack of familiarity with the German education system can have a negative impact on the willingness to pursue vocational or academic education.

4 Method

4.1 Sample

From November 2021 to January 2022, an online survey was conducted among female soccer players in the German Women's Bundesliga and 2nd Women's Bundesliga. To create the questionnaire, a pre-test ($n = 5$) was carried out with active female soccer players from the third highest league in Germany (Regionalliga). There was no need to change the content of the questionnaire after the pre-test. After data cleaning, a total of $n = 200$ questionnaires (German: = 191; English: $n = 9$) were included in the analysis, which corresponds to approx. 29.6% of the addressed population. The average age of the players was 23.3 years, which is lower than the average age of the total population in both leagues of 24.3 years. This difference is because female players from the Bundesliga, who are on average older than female players from the 2nd Bundesliga, are (slightly) underrepresented in the sample (35.5%) in relation to the relevant population (42.6%) (Table 1).

TABLE 1 Description of the sample in relation to the population.

	Population		Sample	
	N	%	*N*	%
League				
Bundesliga	288	42.60	71	35.50
2nd Bundesliga	388	57.40	127	63.50
Not assignable	0	0	2	1.00
Total	676	100.00	200	100.00
Nationality				
German	539	79.70	181	90.50
Not German	137	20.30	19	9.50
Total	676	100.00	200	100.00
A-National Team				
Bundesliga	107	37.20	23	32.40
2nd Bundesliga	10	2.60	2	1.60

In addition, players who are German nationals are overrepresented in the sample, while female players from A-National Teams (of different nations) are (slightly) underrepresented (Table 1).

4.2 Measurement

To analyze the educational status, it was asked whether and, if so, in what form the female soccer players had already completed professional education (academic, vocational) or whether and, if so, in what form they are currently pursuing an education (school, academic, vocational). For further bivariate and multivariate analyses regarding factors associated with willingness to pursue vocational or academic education, the willingness to pursue an education was operationalized dichotomously (completed or currently in vocational or academic education vs. no completed and not currently in vocational or academic education). Likewise, the completion of vocational or academic education was operationalized dichotomously (completed vocational or academic education vs. no completed but currently in vocational or academic education). In order to test the possible influence of soccer on vocational or academic education, the players were asked the following question on a 5-point scale from 1 (substantially worsened) to 5 (substantially improved): *According to your own assessment, in what way has soccer influenced your vocational or academic education?* The question was to be answered in terms of both educational performance and education duration.

The independent variables were operationalized as follows: sporting success was mapped via league affiliation (Bundesliga vs. 2nd Bundesliga) and membership of the A-National Team (yes vs. no). The time commitment to soccer was considered by asking the number of hours that the players spend on soccer on average per week (excluding competitions) (28). The current relevance of a career end was assessed on a 5-point scale from 1 (not at all) to 5 (very intensively) using the following question:

How intensively are you currently dealing with the end of your top sporting career? For mapping a possible influence of self-perceived familiarity (following 30) in connection with the expected benefit of familiarity when entering a profession, both aspects were first asked separately. Familiarity was assessed on a 5-point scale from 1 (not at all known) to 5 (very well known) using the following question: *How well known do you consider yourself to be in Germany within your sport?* The possible benefits of familiarity for professional career entry were asked on a 5-point scale from 1 (strongly disagree) to 5 (strongly agree) as follows: *To what extent do you agree that being known will help when starting a professional career?* Subsequently, by multiplying the two items, the factor "advantages of being known when starting a professional career" was formed for further analyses.

Expectations of the usefulness of transferable skills (57) for career entry were assessed on a 5-point scale from 1 (strongly disagree) to 5 (strongly agree) using the following question: *To what extent do you agree that top athletes are preferred by employers because of specific characteristics they are believed to have, such as resilience, determination and the ability to work in a team?* The perceived support with regard to vocational or academic education issues was asked on a 5-point scale from 1 (not at all) to 5 (very intensively) as follows: *To what extent are you advised by the following parties in professional education-related matters?* The players had to answer this question for the following parties: family, friends, career advisors at the Olympic training centers, club/federation, German Sports Aid Foundation, players' agents. For the further analyses, an overall factor (mean) of "advice concerning vocational or academic education" ($\alpha = 0.63$) was formed. The (first) nationality was asked openly and coded dichotomously (German vs. other nationality). The highest school-leaving qualification was asked in a differentiated manner. After excluding the schoolgirls, the variable was coded dichotomously (higher education entrance qualification vs. other school-leaving qualification).

4.3 Data analyses

First, descriptive analyses were implemented on the status of vocational or academic education and the influence of soccer on vocational or academic education. Subsequently, bivariate analyses (Mann-Whitney U test; Pearson chi-square test) were carried out to test the influence of various factors on the willingness to pursue vocational or academic education. In a next step, a logistic regression model was estimated to take into account relevant factors that influence the attainment of a qualification. It should be noted that the respective effects within the nested model should not be interpreted and compared using the coefficients or odds ratios (ORs) (66, 67). Instead, the average marginal effects are calculated. The average marginal effect (AME) expresses the average influence of the independent variable on the probability of occurrence $P\ (y = 1|x)$ in a single index' (68). Multicollinearity was tested for the regression model. The variance inflation factor (VIF) did not have values higher than 4.0, which means that there is no multicollinearity between the individual explanatory variables. The number of cases per predictor was regarded as good (69). There were only a few numbers of outliers in the dataset ($n < 5\%$) (all standardized residuals were $-2{,}59 \leq \text{SResid} \leq 2{,}14$) (70);. All continuous predictors were found to follow a linear relationship to the logit of the dependent variable (using the Box-Tidwell procedure) (71);. Nagelkerke's pseudo R^2 and the Hosmer-Lemeshow adaptation test were reported for all models.

5 Results

5.1 Descriptive findings on education status and the influence of soccer

Of the 200 female soccer players, 20.5% ($n = 41$) were still schoolgirls at the time of the survey. The remaining 79.5% ($n = 159$) had completed their school education. For the analyses on pursuing and completing vocational or academic education, the schoolgirls were excluded from the analysis, as pursuing vocational or academic education is not yet relevant for them.

The educational status of the female soccer players who already have a school-leaving certificate ($n = 159$) can be seen in Table 2. 29.0% of the players have (at least) one academic degree and 20.1% have (at least) completed one vocational education. 36.5% of the players are currently studying without a preliminary academic degree or completed vocational education. If we also include the players who have already completed (at least) one academic or vocational education and are pursuing (further) studies (18.3%), then 54.8% of the female soccer players were studying at the time of the survey. 5.0% of female soccer players are in vocational education without a preliminary academic degree or completed vocational education. 9.4% of the players are neither studying nor in vocational education and have no academic degree or completed vocational education.

The transition rate—in terms of the ratio of female soccer players who are eligible to study to the players who take up studies—is 83.7%. In addition, a further 5.6% of female soccer players with a general higher education entrance qualification plan to start studying within the next 1 to 3 years.

With regard to the influence of the sporting career on vocational or academic education, 18.1% of the female players, report that soccer has (substantially) worsened their performance in vocational or academic education. 61.7% of the respondents

TABLE 2 Professional education status.

	%	*N*
Completed academic education	16.40	26
Completed academic education and currently in further academic education	12.60	20
Currently in academic education	36.50	58
Completed vocational education and currently in further academic education	5.70	9
Completed vocational education	14.40	23
Currently in vocational education	5.00	8
No academic degree or completed vocational education and currently not in vocational or academic education	9.40	15
Total	100.00	159

TABLE 3 Influence of soccer on vocational or academic education.

	%	%	%	%	%	M	SD	N
Influence of soccer on vocational or academic education (5-point Likert-scale 1 = substantially worsened, 5 = substantially improved)	1				5			
	0.60	17.50	61.70	13.70	6.50	3.08	.77	154
Influence of soccer on duration of vocational or academic education (5-point Likert-scale 1 = substantially worsened, 5 = substantially improved)	1				5			
	9.70	20.80	59.10	7.10	3.20	2.73	.86	154

report no influence while 20.2% report a (substantial) improvement. A (substantial) worsening of the duration of vocational or academic education is stated by 30.5% of the players, while 59.1% of the respondents report no influence. 10.3% of the female soccer players, state that the duration of their vocational or academic education has (substantially) improved as a result of soccer (see Table 3).

5.2 Bivariate findings on willingness for starting vocational or academic education

It is important to emphasize that, as shown in Table 2, 90.6% of the female soccer players are currently pursuing or have already completed vocational or academic education. Since only 9.4% of the players have not (yet) shown any willingness to pursue such education, the influence of possible factors on this willingness is estimated bivariate and not by means of a regression analysis.

As the results in Table 4 show, significant differences between the two groups can only be found for age and nationality. Female soccer players who are in vocational or academic education or have completed it are on average 24.92 years old, while players who are not in vocational or academic education are on average 21.27 years old. The influence has a medium effect size. Regarding nationality, it is evident that players with non-German nationality belong disproportionately to the group of players without a willingness to pursue vocational or academic education (26.67% vs. 9.40% share in the total sample). There is a (rather) weak correlation.

5.3 Multivariate findings on the completion of vocational or academic education

Logistic regression analysis (Table 5) was used to estimate which factors have an influence on whether a vocational or academic education could already be completed. Both the Hosmer-

TABLE 4 Bivariate findings on willingness for vocational or academic education.

	Completed and/or currently in vocational or academic education (n = 144)			No completed and not currently in vocational or academic education (n = 15)			Total (n = 159)			Statistics
	%	M	SD	%	M	SD	%	M	SD	
League affiliation										
Bundesliga	41.95			42.85			42.00			$\chi^2(1) = .004$; $p = .948$
2nd Bundesliga	58.05			57.15			58.00			
A-National Team										
Yes	14.58			33.33			16.40			$\chi^2(1) = 3.492$; $p = .062$
No	85.42			66.67			83.60			
Average time spent on playing soccer per week (without competition)		13.31	4.96		13.53	5.45		13.33	4.99	$U = 1,059.500$; $p = .904$
Thought of ending one's soccer career		2.72	1.26		2.20	1.32		2.67	1.27	$U = 826.000$; $p = .124$
Expected advantages of being known when starting a professional career		8.04	6.51		9.46	7.54		8.17	6.59	$U = 811.000$; $p = .621$
Expected advantages when starting a professional career through characteristics of top athletes		3.47	.88		3.43	.94		3.46	.89	$U = 907.000$; $p = .722$
Advice concerning vocational or academic education		2.09	.57		2.21	.30		2.10	.55	$U = 704.000$; $p = .081$
Age		24.92	3.86		21.27	3.08		24.57	3.94	$U = 429.500$; $p = <.001$; $r = 0.305$
Nationality										
German	92.36			73.33			90.60			$\chi^2(1) = 5.757$; $p = .016$; V = 0.190
Other nationality	7.64			26.67			9.40			
School-leaving qualification										
Higher education entrance qualification	86.11			80.00			85.50			$\chi^2(1) = .410$; $p = .522$
Other school-leaving qualification	13.89			20.00			14.50			

TABLE 5 Influencing factors on completed academic or vocational education (multiple logistic regression; odds ratios (OR), average marginal effects (AME) and the confidence interval in brackets are reported).

	Model	
	OR	AME
Soccer-related factors		
League affiliation (ref. Bundesliga)		
2nd Bundesliga	1.111 [0.248; 4.987]	0.011 [−0.144; 0.166]
A-National Team		
No	118.573 [4.687; 3,000.018]**	0.351 [0.236; 0.466]**
Average time spent on playing soccer per week	0.837 [0.725; 0.967]*	−0.018 [−0.032; −0.005]*
Thought of ending one's soccer career	0.910 [0.555; 1.492]	−0.010 [−0.061; 0.041]
Expected advantages of being known when starting a professional career	1.097 [0.955; 1.261]	0.010 [−0.005; 0.024]
Expected advantages when starting a professional career through characteristics of top athletes	1.880 [0.954; 3.705]	0.065 [−0.002; 0.132]
Social & Sociodemographic factors		
Advice concerning vocational or academic education	2.738 [0.773; 9.697]	0.104 [−0.021; 0.229]
Age	2.820 [1.938; 4.103]***	0.107 [0.094; 0.121]***
Nationality (ref. German)		
Other nationality	0.392 [.0.013; 11.669]	−0.094 [−0.423; 0.234]
School-leaving qualification (ref. Higher education entrance qualification)		
Other school-leaving qualification	478.846 [25.404; 9,025.955]***	0.461 [0.385; 0.537]***
Nagelkerkes Pseudo R^2	.691	
Hosmer-Lemeshow test	.654	
N	136	

*Significance level: $p < .05$.
**$p < .0$.
***$p < .001$.

Lemeshow test: χ (8) = 5.940, $p > .05$ and Nagelkerke's pseudo R^2 = .691 indicated a good model fit (72, 73). Thus, the model correctly predicted 84.6% of all cases. However, the confidence interval of some factors has a very high range, which makes it difficult to estimate the "true" value of the respective effect size.

If we look at the influence of soccer-related factors, we see a strong correlation depending on membership of the A-National Team. For players who are not members of the A-National Team of their respective country, the probability of having already completed their academic or vocational education increases by 35.1% (AME = 0.351). It is also clear that players who are more involved in soccer have a lower probability of having already completed their professional education. On average, the probability decreases by 1.8% (AME = −0.018) per additional hour spent on soccer per week.

There is no significant influence from the factors of "league affiliation", "thought of ending one's soccer career", "expected advantages when starting a professional career after soccer through being known" and "expected advantages when starting a professional career after soccer through characteristics of top athletes".

In terms of social and socio-demographic factors, there is a strong influence of age. If the age of the players increases by one year, the probability of having completed their academic or vocational education increases by an average of 10.7% (AME = 0.107). In addition, female soccer players who do not have a higher education entrance qualification are 46.1% (AME = 0.461) more likely to have successfully completed their professional education than female soccer players with a higher education entrance qualification.

The other factors included in the analysis—counseling and nationality—do not have a significant influence.

6 Discussion

6.1 Discussion of the results and contribution to the literature

The present study analyses the educational careers of elite female soccer players and thus follows on from the question of the extent to which soccer poses a risk for professional career after the sport career (22). This is because, in addition to financial resources and sporting success, educational qualifications and educational or vocational skills have an important influence on the quality of the transition from an active sports career into a post-sports career (74, 75). Thus, the present study responds to calls for a more athlete-centered approach in sports science research (76–78). Furthermore, the article focuses on elite female athletes. It is true that women have made substantial progress in participating in elite sport. However, sport is not free from gender discrimination (79). Professional women's sport in general, and professional women's soccer in particular, is often (still) seen as second-class and less important compared to men's sport (80). Likewise, many areas of sport science research show a gender imbalance in terms of inclusion in studies (81). By focusing on top-level women's soccer, this paper increases the visibility of women as a subject of analysis in sports science research in general and in relation to dual careers in particular. In addition, the level of knowledge regarding of academic and vocational education during the soccer career will be expanded. This addresses the sport of soccer which, despite its prominence and popularity, has often been neglected in previous studies on dual careers.

The following key findings can be deduced from the available results of the study: the players in the Women's Bundesliga and 2nd Women's Bundesliga show a very high willingness to pursue an education. Only 9.4% of female soccer players with a school-leaving certificate were not pursuing vocational or academic qualification at the time of the survey and had not yet completed a vocational or academic education. This means that most players opted for a dual career path (42) by pursuing or having pursued vocational or academic education parallel to their top-level sporting career. The high value of vocational or academic education has already been demonstrated among professional female soccer players in England (7). The willingness of female soccer players to pursue vocational or academic education is significantly higher than that of their male counterparts. As Mazurkiewicz (23) was able to show, almost half (47.6%) of soccer players in the 3rd and 4th leagues in Germany do not have a professional qualification and are not pursuing vocational or academic education. It is also striking that 71.2% of female players are studying or have already completed their studies, while the proportion among their male colleagues is only 28.9% (25). It should be noted that male soccer players in the 3rd and 4th leagues in Germany have a relatively lower level of performance compared to the female soccer players in the Women's Bundesliga and 2nd Women's Bundesliga but generate a (significantly) higher income from their sport. The average monthly income of male soccer players in the 3rd league is €10,000 (82), whereas not even 20% of female soccer players in the Women's Bundesliga and 2nd Women's Bundesliga earn a monthly salary of more than €1,000 (50). Higher financial income may mean that taking up vocational or academic education is considered less necessary for financial reasons (35) and/or the opportunity costs of vocational or academic education increase, which can also have a negative impact on the willingness to pursue education (47). The notion that the willingness of female soccer players to pursue vocational or academic education would decrease if the financial reward increased seems possible from the perspective of human capital theory (47). However, this remains speculative because, based on our data, the analysis cannot provide a valid answer.

The results also show that a higher proportion (29.0%) of female soccer players already have an academic degree compared to top athletes in Germany in general (23.7%, 28). It is also clear that the transition rate—in the sense of the ratio of those eligible to study to the actual students (so far)—of 83.7% is at a higher level compared to the total female population in Germany (77.0%, 83). The findings thus suggest that most female soccer players opt for vocational or academic education that corresponds to their school-leaving level and do not choose inadequate or low-return career paths (84).

The majority (61.70%) of female soccer players also report that soccer has or had no impact on performance in vocational or academic education. 20.2% even report a positive impact of soccer on educational performance. For some female soccer players, positive synergistic effects can even be observed. Thus, top-level sport does not necessarily have a negative impact on vocational or academic performance, as has been shown in other studies (27–29). A negative influence of soccer on performance in vocational or academic education was reported by (only) 18.1% of female soccer players. Fundamental problems with the temporal and organizational coordination between soccer and vocational or academic education, as identified among Danish female soccer players (24), cannot be identified based on our present findings. A possible reason for the overall good compatibility between soccer and vocational or academic education may lie in the comparatively moderate amount of time that the female soccer players have to invest in training. The average of 13.2 h a week is below the value of 18.4 h that German squad athletes in general have to invest on average in weekly training (28). In addition, the majority of female soccer players complete an academic education and, in comparison with vocational training, a sporting career can be better combined with studying (37, 64). Studying can be spread out over time, which reduces the average weekly load, although athletes need more time to complete their studies (28). Furthermore, other empirical findings suggest that elite sport and vocational or academic education can have a positive influence on each other (27, 85). For example, because success in one area reduces the pressure to perform in the other area or because skills learned in soccer, such as determination and willingness to perform, can help you complete vocational or academic education (27, 86).

With regard to soccer-related factors that influence the willingness to pursue or complete vocational or academic education, no difference can be identified between players in the Bundesliga and 2nd Bundesliga. In contrast, female A-National Team players show a lower willingness to pursue vocational or academic education compared to female soccer players who do not belong to the A-National Team (although not significantly) and a lower proportion have completed their education to date. This is not surprising, as the opportunity costs of education increase for female national team players if this has a negative effect on top-level sporting development (47), whereby the mere assumption of a negative influence is sufficient (35). National players are therefore more willing not to pursue vocational or academic education for the time being and/or to stretch it out. The comparatively moderate workload (13.3 h) that female soccer players have to spend on sport per week on average (excluding competition) compared to German squad athletes in general (18.4 h, 28) has no influence on their willingness to pursue vocational or academic education. However, a greater time commitment to soccer results in a higher proportion of education not yet having been completed, although the delay effect proves to be comparatively small. The thought of ending a career has no influence on vocational or academic education. For female soccer players, vocational or academic education is an important precautionary strategy or back-up plan (87) for the time after their sporting career, which does not only become important when the immediate end of their career is imminent. This finding is consistent with existing findings in women's soccer (7). However, this contradicts findings from other studies on elite sport, according to which athletes only start to think more concretely about post-sport career plans towards the end of their competitive sports career (88, 89). A possible reason for female soccer players' early focus on a dual career could, in addition to comparatively low earning potential (3, 50), also be the value of vocational or academic education. Given the very high proportion of students among female soccer players, it can be assumed that they come from middle or higher social classes. In Germany, educational careers are significantly influenced by social background (90). Educational research has empirically proven that people whose parents have a higher social status attribute a high level of benefit to professional qualifications (transgenerational status confirmation) (91, 92), which can lead to female soccer players starting vocational or academic education early. In addition, the results show that whether female soccer players consider themselves to be comparatively well-known in their sport and also assume advantages of being well-known when starting a professional career after soccer has no significant influence on the willingness to pursue or complete vocational or academic education. This also applies to the aspect of whether female players assume that top athletes have advantages when starting a professional career after soccer due to specific positive characteristics attributed to them by the employer. As female soccer players do not expect their soccer career to have a direct positive influence on their professional career, this is also likely to contribute to the fact that a high proportion of female soccer players take up—as an important precautionary strategy—vocational or academic education at an early stage. Accordingly, it should also be noted that soccer coaching qualifications were not explicitly mentioned by the soccer players in relation to vocational education. It is unclear whether the coaching qualification is not regarded by the female soccer players as a "fully-fledged" professional qualification, or whether a coaching license has not (yet) been obtained. In contrast to tennis, where a high proportion of both men and women acquire coaching licenses in order to work as a coach or head of a tennis school after their sporting career (93), a comparable professional career does not appear to be very attractive for female soccer players (94). Unlike in tennis, there are hardly any jobs for coaches at grassroots level and in recreational soccer. In addition, in Germany, coaching positions in top-level sport in general and in soccer in particular are primarily filled by men, and the proportion of female coaches in top-level sport in Germany is only around 13% (95). The lack of career prospects in soccer due to existing barriers (94) is likely to further increase the need for female soccer players to focus on a dual career at an early stage.

Finally, if we reflect on the influence of social and socio-demographic factors, a strong effect of age emerges regarding the willingness both to pursue and complete vocational or academic education. Age is a "natural" predictor of when top athletes take up and complete vocational or academic education, especially in the age range between 16 and 25 years (96). Female soccer players who have a nationality other than German show a lower propensity to pursue vocational or academic education. These players, who for example move from countries such as Austria, Switzerland or Serbia to the German Bundesliga or 2nd Bundesliga, find fewer professional leagues in their countries. It can therefore be assumed that primarily sporting (and financial) reasons are decisive for the switch, which can lead to other areas of life (in this case vocational or academic education) being neglected because it is assumed that this is the only way to achieve maximum sporting success (97, 98). Nationality has no influence on the completion of education. However, the number of players included who do not have German citizenship is small, so that no reliable statements can be made. The type of school-leaving qualification has no influence on the willingness to pursue vocational or academic education. In contrast, a higher proportion of female soccer players without a higher education entrance qualification have already completed their vocational or academic education compared to players with a higher education entrance qualification. Since female players without a higher education entrance qualification are more likely to pursue vocational or academic education, which is associated with shorter periods compared to university studies, this finding is to be expected. The intensity of advising with regard to dual career issues has no influence on the willingness to pursue or completed vocational or academic education. This is surprising insofar as, for example, the support of family and peers are seen as important resources (also) in relation to dual career issues (60, 99). One possible reason could be that due to the overall very high willingness of female players to pursue vocational or academic education, the factor of support services regarding questions of dual career planning loses relevance for female soccer players compared to other top athletes.

6.2 Practical implications

For organized sport, the following conclusions can be drawn from the findings: (i) Female soccer players are far ahead of their male colleagues in terms of willingness to pursue vocational or academic education and already completed education. Even in comparison with top athletes in other Olympic sports with similar, sometimes even lower, earning potential, the willingness to pursue education can be considered very high. This should be taken up (more strongly) by representatives of organized women's soccer and integrated into media reporting. Top sporting success combined with successful educational careers appears to be a suitable topic to differentiate from high-income men's soccer and to counteract inequality in reporting (100), although this will only be possible to a limited extent due to the media dominance of men's soccer. (ii) Against the background of the high willingness to pursue vocational or academic education, it seems advisable for clubs and federations to support this accordingly and to counteract coordination difficulties between top-level sport and professional education. This is in the own interest of soccer clubs and federations to counteract the danger of talented female soccer players leaving the game early due to coordination problems (24, 101). The focus here should be on the early career phase in particular, when there is the greatest risk of vocational or academic education being neglected. Especially for female players on the threshold of elite soccer, support for dual careers is necessary to buffer the risks of a soccer career that can end involuntarily and sooner than planned, e.g., due to injuries (102). However, previous studies indicate rather limited support from clubs (7). (iii) In the context of this study, advising has no influence on players' decisions to pursue vocational or academic education or its course. It is noticeable that the players generally hardly ever seek advice on education-related matters. Greater involvement of experts (in Germany, for example, the career advisors at the Olympic training centers) seems advisable, as they usually have specific knowledge and networks in education-related matters.

6.3 Limitations and future research

Future studies must take the limitations of the present study into account. In the present study, (i) an adequate sample could be generated both quantitatively (sample comprises almost 30% of the population) and qualitatively (good representativeness). However, female players with non-German nationality are underrepresented in the sample. One possible reason for this is that the questionnaire had to be answered "only" in German and English. In follow-up studies, the survey instrument should be made available in other languages. (ii) The female soccer players fundamentally show a very high willingness to pursue vocational or academic education. This means that it is only possible to analyze influencing factors to a limited extent due to the low variance in response behavior. To increase the heterogeneity of the sample, the analysis should be extended to other international leagues in women's soccer. (iii) The findings of the present study indicate that female soccer players succeed well in combining top-level sport and vocational or academic education. However, it was not investigated which concrete efforts players have to make and potentially also which hardships they have to accept in order to achieve this. Further studies should therefore focus on the effort and coping strategies required to complete a dual career. (iv) The present study provides indications that the level of performance or sporting success, in the sense of being a member of the A-National Team, has an influence on the willingness to pursue vocational or academic education and the course of this education. For further studies, it is advisable to operationalize sporting success in a more differentiated way. (v) Research shows that a very strong sporting identity, especially if it marginalizes other identities and values (for example, regarding education), is often associated with increased risks for the person (103, 104). Future studies on dual careers in women's soccer should therefore directly analyze the influence of Athletic Identity (105, 106) on education-related decisions by operationalizing and surveying Athletic Identity in the survey instrument Brewer. (vi) Vocational or academic education are intertemporal allocation decisions. Insofar as players break down the career period over which they make educational decisions into different intervals, the time component is considered differently in the evaluation of the educational benefit (subadditive discounting, 107). Therefore, it is important to empirically analyze how female soccer players deal with these diverging time horizons, both in terms of the present (sports career) and the future (further vocational or academic education decisions). Of particular interest is whether, and in what way, the post-sport future is already considered in the players' current actions and by which factors this is in turn influenced.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

PE: Conceptualization, Formal Analysis, Methodology, Project administration, Supervision, Validation, Writing – original draft. AG: Investigation, Software, Writing – review & editing. LL: Formal Analysis, Investigation, Methodology, Writing – review & editing. TS: Conceptualization, Supervision, Validation, Writing – review & editing.

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Menstrual cycles and the impact upon performance in elite British track and field athletes: a longitudinal study

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Objective: To assess the prevalence of menstrual disorders and the perceived effect of menstrual cycles upon performance in elite athletes.
Methodology: A longitudinal survey in the form of a questionnaire was sent to female track and field athletes at British Athletics every 6 months, over a five-year period between 1st October 2014 and 1st October 2019 in the United Kingdom (UK).
Results: 128 athletes completed an average of 4.2 ± 2.9 questionnaires across the study period. The mean age of menarche was 14.2 ± 1.4 years, 13.4 ± 1.3 years and 12.8 ± 1.4 years in endurance, power, and thrower athletes respectively ($p < 0.05$). Two-thirds (66%; $n = 82$) reported consistently regular cycles, 30% ($n = 37$) irregular at some point during the period of observation and 4% ($n = 5$) were amenorrhoeic. 87 athletes (68%) reported dysmenorrhoea and 40 (31%) menorrhagia. More than three quarters (76.8%; $n = 96$) described their cycle negatively affected performance. Amongst those who reported when the negative impact occurred ($n = 91$), 40% ($n = 36$) reported this in the late luteal phase and 35% ($n = 32$) during the early follicular phase. 79% ($n = 100$) of athletes reported at least one cyclical symptom, of which bloating, lower back and pelvic pain were most frequently experienced.
Conclusion: This data highlights the complex interrelationship between women's health and elite athletic performance. Athletes perceive a negative impact from their menstrual cycles upon performance with a desire to manage these more effectively, particularly during competition. Female reproductive health expertise in the multi-disciplinary management of elite athletes is required.

KEYWORDS
gynaecology, exercise, athletes, menstrual cycles, menstrual disorders, amenorrhea

Introduction

Over the last sixty years, the advancement of sex equality has greatly enhanced both educational and professional opportunities for women. This subsequent empowerment of women has led to evolution in societal perceptions, including the breaking of barriers and gender stereotypes. Over this time, the participation of women in elite

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sports has increased significantly. During the Tokyo Olympics in 2020, for the first time ever, there was an equal number of men's and women's events, where 49% of athletes were female, compared to the Olympics in Rome in 1960, when just 11% of the athletes were female (1). Women's involvement in research has also been historically underrepresented, and as such there is a lack of knowledge about how female physiology changes throughout the menstrual cycle, and how this may impact performance. Whilst involvement has concurrently increased in recent years, data suggest that female participants in exercise-related research make up just over a third of participants (2). Concerningly, a recent study exploring the ratio of male and female participants in sport and exercise science research in the years 2014–2020, found 63% of publications included both males and females, 31% included only males, and a mere 6% included females only testing (3).

The physiological mechanisms controlling menstruation, with different levels of oestrogen and progesterone throughout the cycle, have previously been described by this group (4). Importantly, there is a growing body of evidence demonstrating menstrual cycle disorders in competitive female athletes (4, 5). Chronic low energy availability has been deemed to be one physiological mechanism explaining such disturbances, whereby energy imbalance leads to hypothalamic amenorrhea (4). This and a wider range of health conditions related to chronic low energy availability is referred to as Relative Energy Deficiency in Sport "REDs" (6). Indeed, amenorrhea has been shown to affect up to 65% of long-distance runners and 79% of ballet dancers respectively (7, 8), compared to 5% in the general population. High levels of physical activity have been associated with increased irregularity of periods, amenorrhea and a longer menstrual cycle (9–11). Concerning elite athletes, a study looking to characterize the menstrual status, body composition, and endocrine balance in female Olympic athletes, found that 27% of participants not using hormonal contraception experienced menstrual disturbances, mainly oligomenorrhea (12). A further observational prospective study found 40% of athletes experience menstrual cycle disorder (11). There is however limited evidence on menstrual cycle disturbance, and particularly the effect of menstruation on performance in British athletes, hence the need for this study.

Athletic performance is a multifaceted concept, comprising a variety of physical, psychological, emotional, and environmental variables (13). Whilst the primary effect of the menstrual cycle is on the reproductive system, the pulsatile release of ovarian hormones can impact physiological functioning throughout the body, and as such has the potential to positively or negatively impact sporting performance throughout the menstrual cycle (14). Whilst data remains scarce, it suggests that athletic performance is inconsistent across the cycle, and symptoms of menstruation itself can impact training and performance potential (15). As women compete at every phase of the menstrual cycle, and during menstruation itself, understanding its impact on athletes' performance, and whether there are any perceived or self-reported detrimental effects caused by the menstrual cycle is essential. The aim of this study is to assess for the prevalence of menstrual disorders and the perceived effect of menstrual cycles upon performance in elite British track and field athletes.

Materials and methods

Study design

Recruitment commenced from a population of elite track and field athletes at British Athletics over a five-year period between 1st October 2014 and 1st October 2019. Participants were sent a link, if they were on the elite world-class programme or were selected for an international Great Britain senior team, to an electronic questionnaire via email every six months throughout the study period. The questionnaire, (available in Supplementary Material), ascertained data on menstrual health including age at menarche, regularity of menstruation (self-defined by athletes as either regular or irregular), the number of days of bleeding they experienced and shortest and longest time between bleeding episodes. Further questions elicited information on how heavy and painful their menstrual periods were, the presence of cyclical symptoms and whether they experienced intermenstrual bleeding. Phases of the menstrual cycle were determined as follows: before bleeding; late luteal phase, during bleeding; early follicular phase, and earlier in the cycle; late follicular phase The final questions aimed to determine whether they perceived that their menstrual cycles negatively impacted their performance.

Ethics approval

Local institutional review board approval (6476/005) from University College London was obtained for the study and data was collected as part of usual clinical care of these patients by the British Athletics medical team.

Data analysis

Athletes were categorised into three groups depending on their discipline; power, endurance or throwing to allow subgroup analysis to be performed. Power athletes included those who competed in events such as sprinting (up to and including 400 m), jumping events and hurdles. Endurance athletes included athletes who ran in events from 800 m and above. The throwing group included those who competed in throwing field events. Reporting of results follows the CHAMP statement.

SPSS version 24 software [(IBM Corp, Armonk, NY, USA)] was used for analysis. Descriptive statistical analysis was described as mean ± SD. Menstrual dysfunction and age of menarche were compared between groups using Chi-squared test or Analysis of Variance as appropriate. Statistical significance was set at $p < 0.05$.

Patient and public involvement

This study was developed as a direct response to the feedback from elite athletes regarding the impact of their menstrual cycle upon performance.

Equity, diversity and inclusion

The author group is gender balanced and consists of junior, mid-career and senior researchers from gynaecological and sports medicine disciplines; however, all members of the author group are from one country. Our study population included female athletes only from different socioeconomic backgrounds participating in elite track and field athletics at the British Athletics Institute, Therefore, findings may not be generalizable to settings with fewer resources.

Results

The questionnaire was sent to 208 athletes during the study period and 128 athletes responded at least once over the five-year period, resulting in a response rate of 61.5%. Each athlete responded a mean number of 4.2 ± 2.9 occasions throughout the study period. The mean age was 28 years ± 5.9. Two-thirds (66%; $n = 85$) of the athletes were white British, 21% ($n = 27$) were mixed and 13% ($n = 16$) were black British. Most athletes were power athletes (59%; $n = 76$), 27% ($n = 35$) were endurance athletes and 13% ($n = 17$) were throwers.

The mean age at menarche for all athletes was 13.5 ± 1.4 years. The endurance athletes had a significantly later mean age of menarche at 14.2 ± 1.4 years, compared to power athletes who had a mean menarche of 13.4 ± 1.3 years, and the throwers who were the youngest at 12.8 ± 1.4 years ($p < 0.05$). Two-thirds of the athletes reported their cycles to be regular at every time of questioning (66%; $n = 82$), 30% ($n = 37$) reported their cycles to be irregular at some point throughout the period of observation and 4% ($n = 5$) reported themselves to be amenorrhoeic. The mean self-reported shortest gap in between menstruation was 25.2 ± 14.1 days ($n = 104$), and the mean longest gap was 51.7 ± 68.8 days ($n = 110$). In those who described their cycles as regular, 43% ($n = 35$) described inter-cycle variation of >5 days in the preceding six months. When subgroup analysis was performed, a greater proportion of endurance athletes experienced menstrual irregularities (irregular or absent menstruation), compared to the power and thrower subgroups (43% vs. 29% vs. 29% respectively), although the result was not statistically significant ($p = 0.26$). The mean duration of menses was 4.8 days (±1.6). 68% of athletes ($n = 87$) reported painful menstruation and 31% ($n = 40$) reported heavy menstrual bleeding. 79% ($n = 100$) of athletes reported that they experienced at least one cyclical symptom, a full list of symptoms in Supplementary Material and Figure 1. Regarding specific symptoms, as demonstrated in Figure 1, the most frequent included bloating, lower back pain and pelvic pain, which were reported by 52% ($n = 66$), 46% ($n = 59$) and 42% ($n = 53$) of athletes respectively.

125 athletes responded, at least once during the study period, to the question regarding whether their menstrual cycle affected their performance. More than three-quarters (77%; $n = 96$) reported their performance had been negatively impacted by their cycle at some point throughout the study period, whereas 60% ($n = 75$) of athletes reported that their performance was affected at every response. When compared amongst subgroups, as depicted in Figure 2, 71%–80% of athletes reported that their menstrual cycle affected performance during at least one time of questioning, with power athletes most affected amongst the three disciplines. 71% ($n = 91$) of athletes answered the question regarding what phase of the cycle they felt their performance was affected; 40% ($n = 36$) reported it as the time before menstruation (late luteal phase) and 35% ($n = 32$) reported it was during menstruation

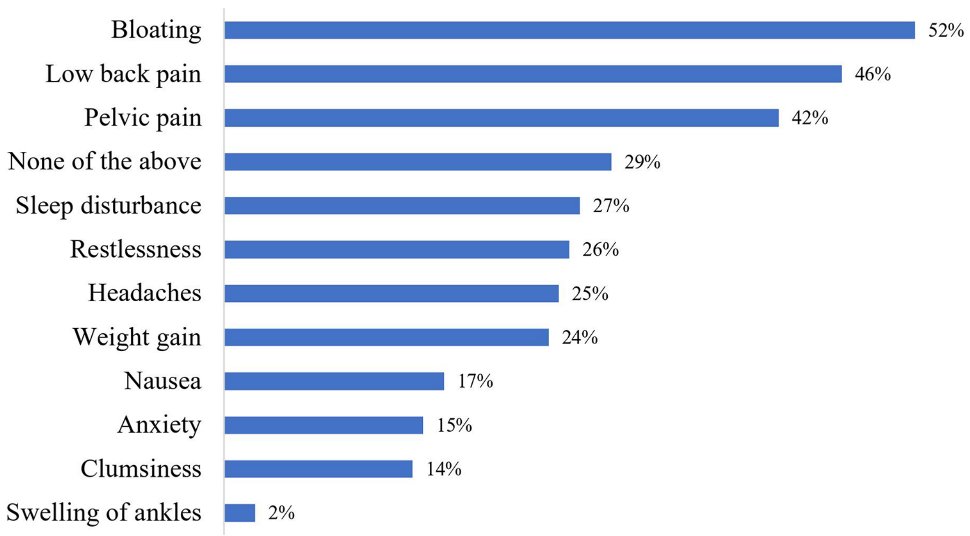

FIGURE 1
Proportion of athletes reporting specific cyclical symptoms.

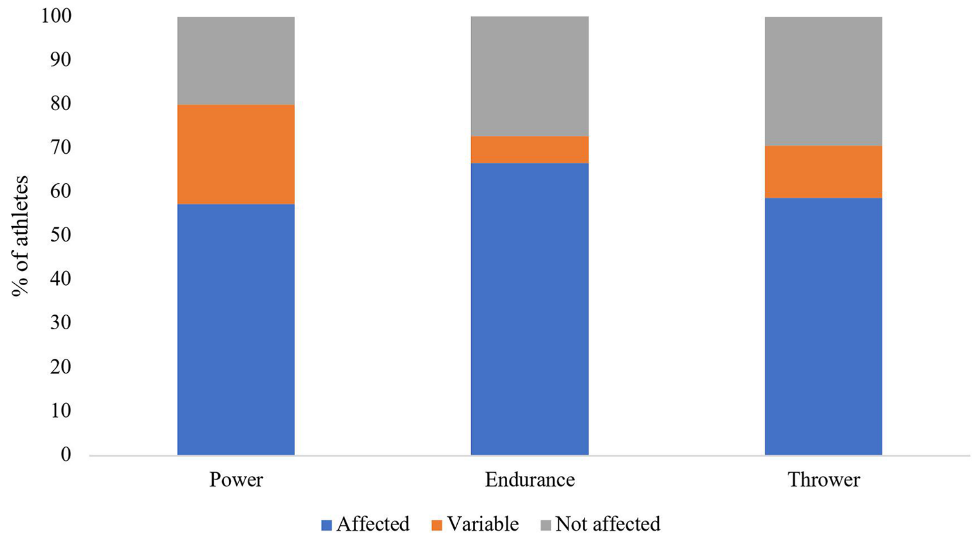

FIGURE 2
Effect of menstrual cycle on performance by event group.

(early follicular phase), whereas 15% ($n = 14$) felt it was earlier in their cycle (late follicular phase) and 10% ($n = 9$) reported that it varied. When comparing those who had regular cycles ($n = 80$) with those who had irregular cycles ($n = 41$), 79% ($n = 63$) of those with regular cycles felt their performance had been affected by their cycles, compared to 76% ($n = 31$) of those with irregular cycles ($p > 0.05$).

Approximately one quarter (26.5%, $n = 34$) of athletes were taking contraception at every point of questioning, with a further 5.5% ($n = 7$) using it at some point during the study. 39% ($n = 16$) of these 41 athletes were using the combined oral contraceptive pill (COCP), four (10%) were using a progestogen intrauterine system (IUS), and the remaining 21 (51%) were using unspecified hormonal contraception. As summarised in Figure 3, there was no significant difference in heavy menstrual bleeding, painful menstruation, irregular bleeding or cyclical symptoms between women not taking contraception compared to those taking contraception, or specifically those taking the COCP ($p > 0.05$). With regards to whether their cycles impacted their performance, in those not taking any hormonal contraception, 78% ($n = 64$) felt their performance was negatively affected, compared to 80% ($n = 32$) in those taking hormonal

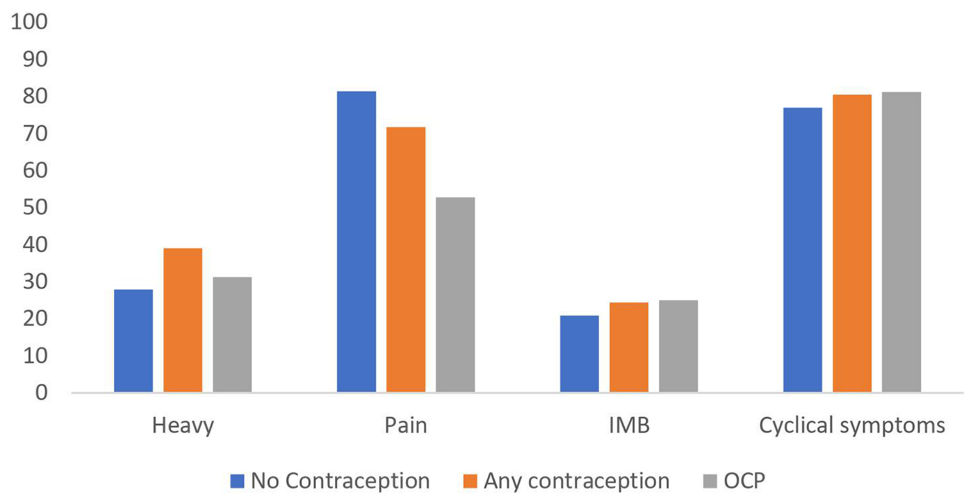

FIGURE 3
Proportion of athletes reporting symptoms of heavy menstrual bleeding, painful periods, irregular menstrual bleeding (IMB) and cyclical symptoms. (OCP, oral contraceptive pill).

contraception, and 87.5% ($n = 14$) in those specifically taking the COCP ($p > 0.05$).

Of the 83 athletes who responded to the question, 88% ($n = 70$) wanted additional input regarding the regulation of menstruation during competition. A further twelve (16%) wanted to discuss contraception, 10 (13%) wanted to discuss cyclical symptom management and 19 (24%) wanted to discuss other medical issues related to women's health.

Discussion

This study aimed to assess the prevalence of menstrual disorders and the perceived effect of menstrual cycles upon performance in British elite athletes. It found that 30% of athletes ($n = 37$) reported an irregular cycle at some point during the period of observation and 4% ($n = 5$) were amenorrhoeic. A high proportion of athletes experienced troubling symptoms related to menstruation with 68% ($n = 87$) reporting dysmenorrhea and 31% ($n = 40$) reporting menorrhagia. Furthermore, 79% ($n = 100$) of athletes reported at least one cyclical symptom. Importantly, 76.8% ($n = 96$) described their cycle negatively affected performance.

In this study, more than a third of athletes reported irregular or absent menstruation. Even in those who described their cycles as regular, 43% ($n = 35$) demonstrated inter-cycle variation of >5 days in the preceding six months, suggesting high intra-variability of menstrual cycles. Variation in cycle length of >5 days has also been observed in studies in the general population, in as many as 52% of study participants, and thus this finding may not be exclusive to athletes (16). Athletes may however have a higher acceptance of menstrual irregularity and an unrealistic perception of what constitutes a regular cycle; indeed in a recent study amongst high school female athletes, 44% of the cohort believed that not having periods was a normal response to high training demands (17). The finding that those with menstrual irregularities demonstrated higher levels of anxiety, fatigue and pain inference than those without menstrual dysfunction, exemplifies the multi-faceted impact of menstrual cycle disruptions (17). It is therefore essential to address these issues, in order to optimise athlete health and performance.

The data presented herein also shows the mean age of menarche in this population was 13.5 years, which is later than that seen in a study of more than 80,000 women in the UK, where the mean age was 12.7 years (18). This is consistent with a systematic review which assessed physical activity and age at menarche, which found that menarche is delayed by 1.13 years in athletes, compared to their non-athletic counterparts (19). Moreover, we demonstrated herein that age at menarche is also influenced by discipline, with those athletes in the throwing subcategory having a mean age at menarche of 12.8, whereas endurance athletes had a significantly later age at menarche at 14.2 years. This is in line with a recent study which found the age of menarche in specifically endurance athletes was 14 years, compared to 12.5 in the non-athletic control group (20). This is of relevance given that delayed menarche can be a sign of REDs; the hypooestrogenic state may impair longterm bone health and have implications particularly from a sports injury perpesctive (4, 6).

Clinical implications

In addition to gynaecological illness present in the general population, various mechanisms have been proposed to explain the increased rates of menstrual irregularity observed in athletes such as increased rates of polycystic ovaries (12). One of the most well researched explanations for menstrual disturbance is REDs (21). This is not a normal consequence of training load; but rather REDs describes a syndrome of interrelated health consequences which occurs when an individual's energy intake is insufficient to meet the demands of their body. It causes a range of physiological and psychological consequences, including decreased bone density, impaired immune function, menstrual dysfunction, decreased muscle strength and endurance. REDs supersedes the previously used term "female athlete triad", which only considered the interrelationship between menstrual function, bone health and low energy availability (6, 22). Athletes are at risk of problematic low energy availability because they typically have high energy requirements due to the intense physical activity in which they engage, and they may not consume enough energy to compensate for their increased energy requirements. Some athletes may intentionally restrict their energy intake in an attempt to reduce body weight or body fat in sports that emphasise low body weight or aesthetics, such as gymnastics, figure skating, and endurance sports. Menstrual dysfunction in athletes predominantly clinically manifests in two main ways depending on the age at presentation; menstrual dysfunction in adults, or delayed menarche in pre-pubertal children (4). It is crucial that coaches and womens health specialists are alerted to athletes with delayed menarche and assess for and address any health concerns related to REDs in a multidisciplinary manner using the updated REDs Clinical Assessment Tool- Version 2 from the International Olympic Committee (6).

Impact on performance

In our population, more than three-quarters of the cohort perceived that their menstrual cycle impacted their performance at some stage throughout the period of questioning, with 6 in 10 consistently reporting that it did at every visit. Three-quarters of the athletes reported that the part of their cycle where performance was negatively affected, was either before their menses, during the late luteal phase, or during their menses, in the early follicular phase. Despite the clear perception that menstrual cycles impact the performance of elite UK athletes demonstrated herein, a previous study reporting self-reported performance at different phases of the menstrual cycle amongst 241 elite athletes found no difference throughout the different phases (23). From a physiological perspective, oestrogen, which is the dominant sex hormone during the follicular phase, is thought to have beneficial effects on cardiovascular function by promoting vasodilation, whereas progesterone, the dominant hormone during the luteal phase, appears to have an antagonistic effect (15). Progesterone also has a thermogenic effect, with peak body temperature during the luteal phase (24), and a resulting negative impact on metabolic rate, causing thermoregulatory and cardiovascular strain (25). Oestrogen also promotes glucose uptake into muscles as a substrate for contraction, whereas progesterone inhibits this action (26). Finally, during exercise, oestrogen causes a preferential metabolism of free fatty acids over stored muscle glycogen, potentially preserving these stores during endurance events (15). As such, it would be logical to expect performance to be worse during periods when oestrogen levels are low, such as the late luteal or early follicular phases, which would appear to be in line with the data reported herein.

Despite these plausible physiological explanations and the findings from this study, there is no convincing clinical evidence that performance differs between phases of the menstrual cycle. Some studies found a significant increase in strength around the time of ovulation, which was attributed to the heightened oestrogen levels (27), but these results have not been replicated in other studies, such as those assessing maximum weight bench press weight and aerobic performance over 100–200 metre time trials (28). A recent meta-analysis investigating the effect of menstrual cycle phase on endurance and strength found a trivial reduction in performance during the early follicular phase compared to other phases, however due to low quality and quantities of research in this field, the results are largely inconclusive (29). Another systematic review assessed the impact of menstrual cycle phase on performance specifically in elite athletes, including 314 athletes across seven studies. The findings were inconsistent and insignificant, reaffirming that there is no clear evidence performance is affected by menstrual cycle phase (30). Clearly, there is a disparity between the self-reported perceived effect on performance throughout the menstrual cycle and actual physiological differences in performance. More high-quality data is required in this area to decipher the complex interaction between menstrual cycle phase and performance level.

To try and mitigate the potential physiological implications of fluctuating endogenous sex hormones, or at least the perception of inferior performance throughout the cycle, hormonal contraception may be used by athletes to control their cycles. Hormonal contraception can be used to delay the onset of menses until after a specific competition date, reduce cyclical symptoms or prevent iron deficiency anaemia in those with menorrhagia. By taking oral combined contraceptives in a tricyclic approach, some athletes may even be able to avoid having a withdrawal bleed during an entire competitive season. Despite the proposed benefits, there was no evidence of a perceived improvement in performance in those taking hormonal contraception in our cohort. This was confirmed by a recent meta-analysis which described a trivial, but likely negative impact of contraceptive use on athletic performance (31). The use of combined oral contraceptives has not been shown to improve muscle strength development when compared to non-users of hormonal contraceptives (32), and it has also been associated with a significant decrease in peak oxygen consumption (a marker for exercise capacity) (33). As such, whilst they may be required for family planning, or mitigating adverse symptoms of cyclical symptoms or menstruation, oral hormonal contraception should not be recommended routinely for the purpose of improving competitive performance. Our data identified that 81% of women not taking hormonal contraception reported painful menstruation, compared to 53% of those taking the COCP reporting the same symptom, although this was not statistically significant. Similarly, given the increase in women choosing to use a progestogen IUS as contraception, but also to reduce undesirable side effects such as dysmenorrhea, menorrhagia and irregular cycles, a similar pattern has emerged amongst athletes. Whilst there is good evidence progestogen IUS can improve menstrual pain in women with endometriosis (34), and improve menstrual bleeding in women with adenomyosis or fibroids (35), there is no data on the specific effects of the use of progestogen IUS on the mitigation of such symptoms in elite athletes. Moreover, there is limited data on the possible impact on athletic performance and side effects in such populations. As such, athletes should be presented with information regarding all contraceptive options, their administration, and their roles in managing a variety of gynaecological concerns which may be relevant to the individual, as well as their efficacy as a contraceptive agent to allow them to make an informed choice on contraception. There is no evidence that one particular agent should be universally recommended to elite athletes until further research has been undertaken.

Irrespective of the hormonal explanations for performance variation throughout the cycle, menses itself can cause anxiety, with the fear of flooding enough to distract them from competition and training (36). Given that 3 in 10 of the athletes presented herein describe heavy menstruation, this warrants consideration of management strategies to reduce menstrual flow or prevent menstruation in such women. Moreover, given that more than three-quarters of the athletes in this cohort reported cyclical symptoms, this reinforces the need to individualize management depending on the specific symptoms each athlete experiences. Finally, this study and others have shown menstrual dysfunction is clearly prevalent amongst athletes (9–12). It is crucial that these disturbances are not deemed acceptable and rather are investigated and managed by a multidisciplinary team throughout the athlete's career.

Strengths and limitations

Whilst this appears to be largest prospective study assessing menstrual disorders and the effect of menstrual cycles upon performance in elite British track and field athletes, it has its limitations. Firstly, the questionnaire was not validated and therefore it is debatable whether the questions were optimal to elucidate the study questions. Notably, there is currently no validated questionnaire to assess menstrual cycles in athletes or their impact on performance. The questionnaire nature of the study results in subjectivity with certain responses, particularly regarding the impact of menstruation on performance. It also introduces recall bias. Regularity of menstruation was self-defined by athletes and although an attempt to obtain objective measurements of regularity was made by asking the longest and shortest duration between menstruation, this is subject to memory bias. As the study was undertaken on a finite number of elite British athletes, the small sample size amongst some subgroups may have resulted in reduced statistical power. Moreover, because the study focuses on elite athletes solely at British Athletics, this data is only extrapolatable to elite performers. Additionally, two thirds of the population were white British, as such, it is not a representation of the general population or other ethnicities. Future prospective, multi-centre international studies should be considered to increase the sample size and minimise potential bias.

Conclusion

This study gives a unique insight into the menstrual cycles of elite British track and field athletes, by clearly highlighting the prevalence and subsequent impact of menstrual-related symptoms and irregularities. Despite the absence of high-quality data identifying any significant impact of menstrual phase upon performance, we clearly identify herein that top-level athletes perceive their performance to vary throughout the menstrual cycle, with the majority reporting inferior performance during the late luteal or early follicular phases, whilst circulating oestrogen and progesterone levels are low. The data presented underscores the need for more comprehensive support and education for female athletes regarding menstrual health, and the need for individualised, multi-disciplinary strategies to help mitigate the negative impact of menstrual dysfunction to optimise athlete health and performance.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University College London, (6476/005). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

BJ: Conceptualization, Investigation, Methodology, Writing – original draft. AL: Formal Analysis, Writing – review & editing. CB: Writing – review & editing. LK: Writing – review & editing. SS: Writing – review & editing. SD: Writing – review & editing. RC: Writing – review & editing. JB: Writing – review & editing. NP: Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2024.1296189/full#supplementary-material

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Validity and reliability of the My Jump 2 app for detecting interlimb asymmetry in young female basketball players

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Introduction: The aim of this study was to examine the validity and reliability of the My Jump 2 app for the assessment of interlimb jump asymmetry in young female basketball players.
Methods: Nine athletes (age 15 ± 0.9 years; weight 62.9 ± 5.8 kg; height 173.6 ± 6.1 cm) performed single-leg drop jumps (DJs) and both-leg drop jumps on a force plate (Kistler Quattro jump) and were simultaneously recorded on two smartphones using the My Jump 2 app. Jump height from flight time and contact time data were statistically analyzed to evaluate the validity of two different camera settings, drop jump performance, and interlimb jump asymmetry in basketball players. The testing was repeated after 1 week for test retest reliability.
Results: High test-retest reliability [intraclass correlation coefficient (ICC) > 0.88] was observed in DJ height. High correlation between the force plate and the My Jump 2 app was observed in DJ height (r = 0.99) and DJ contact time (r = 0.98). For the interlimb jump height asymmetries, mean differences were 0.6 percentages for the My Jump 2 app and the force plate, respectively (p = 0.77). Inter-device reliability revealed almost perfect correlation for the DJ height (ICC = 0.99, r = 0.98).
Conclusion: The My Jump 2 app is a valid and reliable tool to assess drop jump performance and interlimb asymmetry in young female basketball players.

KEYWORDS
physical performance, mobile application, testing, vertical jump, unilateral, muscle imbalances

1 Introduction

Basketball is a complex team sport that predominantly requires distinctive movement patterns consisting of sprints, change of direction speed, and jumping (1). Moreover, the vertical jump is one of the most common movements during a basketball game (2) but is also very important in a wide range of basketball skills, such as rebounding, blocking, dunking, shooting, and lay-ups. According to Abdelkrim et al. (3), approximately 45 vertical jump acts are performed by elite male basketball players per game. However, vertical jumps in basketball are executed from a single-leg take-off or bilaterally from a standing start (4). Therefore, it is important to understand the type of jumps performed in basketball and what their impact is on both performance and injuries. Accordingly, lower limb asymmetry in basketball can play an important role in addressing the issue of athlete's performance, injury risk, and overall biomechanics. This was confirmed in several studies in which lower limb asymmetry was related to sport performance (5, 6) and injury risk (7–9). In addition, single-leg jump height and reactive strength index are reliable tools to identify lower limb asymmetries in athletes (10). However, new studies are needed to provide more recent results for sport diagnostics and injury prevention or to confirm previous research.

The gold standard for measuring force is isokinetic dynamometers, which can be used for detecting lower limb asymmetry (11). However, an alternative solution that proved to be reliable and valid is the single-leg vertical jump that has also demonstrated good sensitivity to detect lower limb asymmetries (12, 13). Contact mats and force plates are the most used apparatus for measuring and analyzing vertical jump performance in athletes (14, 15). Although today's technology allows us to use more advanced technology for training and science, force plates can be difficult to carry on field testing. Instruments that are more portable than force plates are Optojump photoelectric cells, whose validity and reliability were also confirmed (16). Wheeler jump sensors and infra-based photocell (ADR jumping), both of which are validated, tend to be more portable and economical than Optojump and force plates (17, 18). Another valid way to measure vertical jump performance is by using accelerometers (19). In addition, the My Jump 2 app was created as an easy-to-use and portable mobile application that could precisely measure jump performance (20). The smartphone application My Jump 2 uses the camera to capture slow-motion footage of various jump tasks. By choosing the take-off and landing frame (flight time), it provides us with information regarding jump height (21). Using high-speed cameras, software, and kinematics (MOCAP) are the gold standard for measuring the jump height of athletes (22). However, the portability of the smartphone is unsurpassed. The reliability and validity of the My Jump 2 app were confirmed on the elderly (23), young amateur athletes (24, 25), sport science students (16, 26), trained athletes (27), and even football players with cerebral palsy (28). Specifically, regarding vertical jump asymmetries, Barbalho et al. (29) demonstrated good validity for detecting interlimb contact time and interlimb flight time asymmetry in soccer players using the My Jump 2 app. The primary aim of this research was to test the validity of the My Jump 2 app. The second aim of this study was to examine the use of different camera settings on the My Jump 2 app. Since the application is based on kinematics, our results provide more user-friendly approaches to testing with the My Jump 2 app.

Overall, addressing lower limb asymmetry in basketball can be very important for optimizing performance, reducing injury risk, and maintaining long-term musculoskeletal health. A low percentage of interlimb asymmetry is positively connected to low injury rate and higher performance (30–32). However, studies that aimed to determine the validity and reliability of mobile applications for testing jump asymmetries in female basketball players are lacking. Therefore, the aim of this study was to determine the validity and reliability of the My Jump 2 app for assessing the interlimb jump asymmetry in female basketball players, as well as to confirm the results of previous studies that have carried out research using the My Jump 2 app. It was hypothesized that the My Jump 2 app would show high validity for measuring interlimb asymmetry compared to force plates.

2 Methods

2.1 Participants

A sample size estimation from a previous study indicated that seven participants were required. An *a priori* power analysis with an effect size of 0.93, a power of 95, and an alpha level of 0.05 was conducted using G*Power (Version 3.1.9.4, University of Dusseldorf, Germany) (27). Nine young female basketball players participated in the study (age 15 ± 0.9 years; weight 62.9 ± 5.8 kg; height 173.6 ± 6.1 cm). The inclusion criteria were as follows: participants had to be included in basketball games and practices for at least 5 years; had been included in any training-related vertical jumps; and had no chronic or acute injury of the lower extremities in the last 6 months. The potential risks, benefits, and discomforts associated with the program were explained to the participants. All participants and their guardians agreed to take part in the study by signing an informed consent form. There is no relationship between the authors and the developers of the application.

2.2 Design

Data collection was carried out using smartphones and Kistler Quattro Jump software. Three raters were included in the testing procedure: one controlling force platform and two raters recording with the My Jump 2 app. Testing was done in the afternoon hours. A single session and 1-week separation for the test–retest reliability were performed. Data from the force plate and the My Jump 2 app were recorded simultaneously using two smartphones. Before testing, participants were familiarized with the drop jump (DJ) protocols the day before. In the familiarization phase, both PhD students (former and active athletes) demonstrated the correct technique of performing the drop jump test. Numbers were placed on the participants' shorts for later recognition and extraction of data. On the day of testing, the athletes performed a regular 10–15 min basketball warm-up (jogging and drills with a ball) with a team and set of static and dynamic stretching exercises. Moreover, a set of five DJs with both legs and five single-leg DJs with submaximal effort were done. After that, athletes were instructed to perform three DJs with both legs and three single-leg DJs. Approximately 1 min of rest was taken between each jump. The athletes were instructed to jump as high as possible. The average of the two attempts and the highest values were analyzed. The athletes did not perform forced dorsal flexion of the ankle during the flight phase. The same procedure was performed after 1 week (in the same shoes and at the same time of day).

Intra- and inter-rater reliability were done analyzing the same video. All data were collected using a 120 Hz camera system, and a 240 Hz camera system was used only for analyzing reliability between two smartphones.

2.3 My Jump 2 app

The application was installed on both the iOS operating system (iPhone 11, iOS 16) and the Android system (Xiaomi MI 9 SE, Android 11). The recording was done with a high-speed setting [240 frames per second (fps)/Hz 1,080 pixels and 120 fps/Hz 1,080 pixels, respectively] on both devices. The applications calculated the jump height from the time (flight time) between two frames (measured in ms), representing the loss of foot contact (take-off) with the ground and the recovery of that contact (landing) (26). Version v1.0 of the My Jump 2 app was used. The minimum requirements for the use of the application are Android version 8 and iOS version 12 or higher. This may vary depending on further development of the app.

The contact time and jump height for the left and right legs were analyzed (in ms); contact asymmetry was calculated as the difference between the contact times (contact) of the left and right legs; and jump height asymmetries were calculated as the difference between the flight times of the left and right legs.

For the DJ test, contact time (in ms) and jump height (in cm) data were collected. Two raters recorded all jumps simultaneously (two phones). The raters and smartphones were positioned in the frontal plane, 1.5 m from the athlete in a seated position side by side. The camera position was set at the patella (kneecap) height of the participant standing on the force plate. The device positions were set without a tripod setting for more realistic simulation and practical use of the My Jump 2 app.

2.4 Force platform

The Quattro Jump 9290BA force plate (Kistler, Winterthur, Switzerland) was used (33). Data were recorded at a sampling frequency of 500 Hz. The force plate calculated the same variables as the My Jump 2 app (jump height and contact time). Time between the take-off and landing phases was used to establish jump heights and contact times.

2.5 DJ assessment

The athletes started the DJ test in a normal upright position standing on a box height of 30 cm. This height was agreeable with the previous study suggesting drop heights near 30 cm (34) in this age and sex range (35). The rater who was assessing the force plate measurements signaled twice. The first "start" command was for the two raters recording with an app, and the second "start" was for the athlete to perform the DJ. The athlete stepped toward a force plate that was set up in front of the box, moving with both feet. The participant immediately performed a squat with a preferred knee angle. The athlete then extended their knees to jump as high as they could while pushing their body vertically (Figure 1A).

2.6 Single-leg DJ

Figure 1B displays the single-leg DJ for the left lower limb. The box height was set at 30 cm. The rater signaled twice, once for the two other raters and once for the athlete.

The athlete stepped in front of a force plate that was set up in front of the box. A single-leg jump with a preferred knee angle was performed by the participant as soon as the foot stepped in contact with the plate. The athlete then extended her knee to jump as high as she could while pushing her body vertically. This test was performed three times, alternating both legs.

2.7 Statistical analysis

Means and standard deviations were used as descriptive statistics. The Shapiro–Wilk test was used to check the data normality due to the small sample size. The asymmetry in contact time and jump height metrics were used to compare the mean differences between the devices using paired samples *t*-tests. A single measure, two-way mixed, absolute agreement parameter was chosen for the intraclass correlation coefficient (ICC) analysis for intra-rater reliability and average measures, two-way mixed, absolute agreement parameter was selected for the inter-rater reliability. An interpretation of the ICC was given as follows: <0.5 = poor reliability; 0.5–0.75 = moderate reliability; 0.75–0.9 = good reliability; and >0.90 = excellent reliability (34). Reliability between the test–retest was analyzed using the ICC. Pearson's product-moment correlation was used to test the concurrent validity of the application. In addition, Bland–Altman plots were used to visually analyze the agreement between the My Jump 2 app and force plate data. Bland–Altman plots showed the difference between the two devices plotted against the mean of the two devices. Typical error (TE) expressed as the coefficient of variation (CV%) was used in reliability measures (CV < 5% = good reliability) (36). Mean absolute percentage error (MAPE) was used for validity measures (<10% = highly accurate, >10% = good; >20% = reasonable) (37).

3 Results

Table 1 presents the inter- and intra-rater reliability in the drop jump test, with almost perfect values of consistency.

The My Jump 2 app showed a high validity with the force platform. For the interlimb asymmetry test, there were no significant differences in any of the variables for the interlimb asymmetry test between the force plate and the My Jump 2 app (Table 2). For the drop jump test, there was no significant

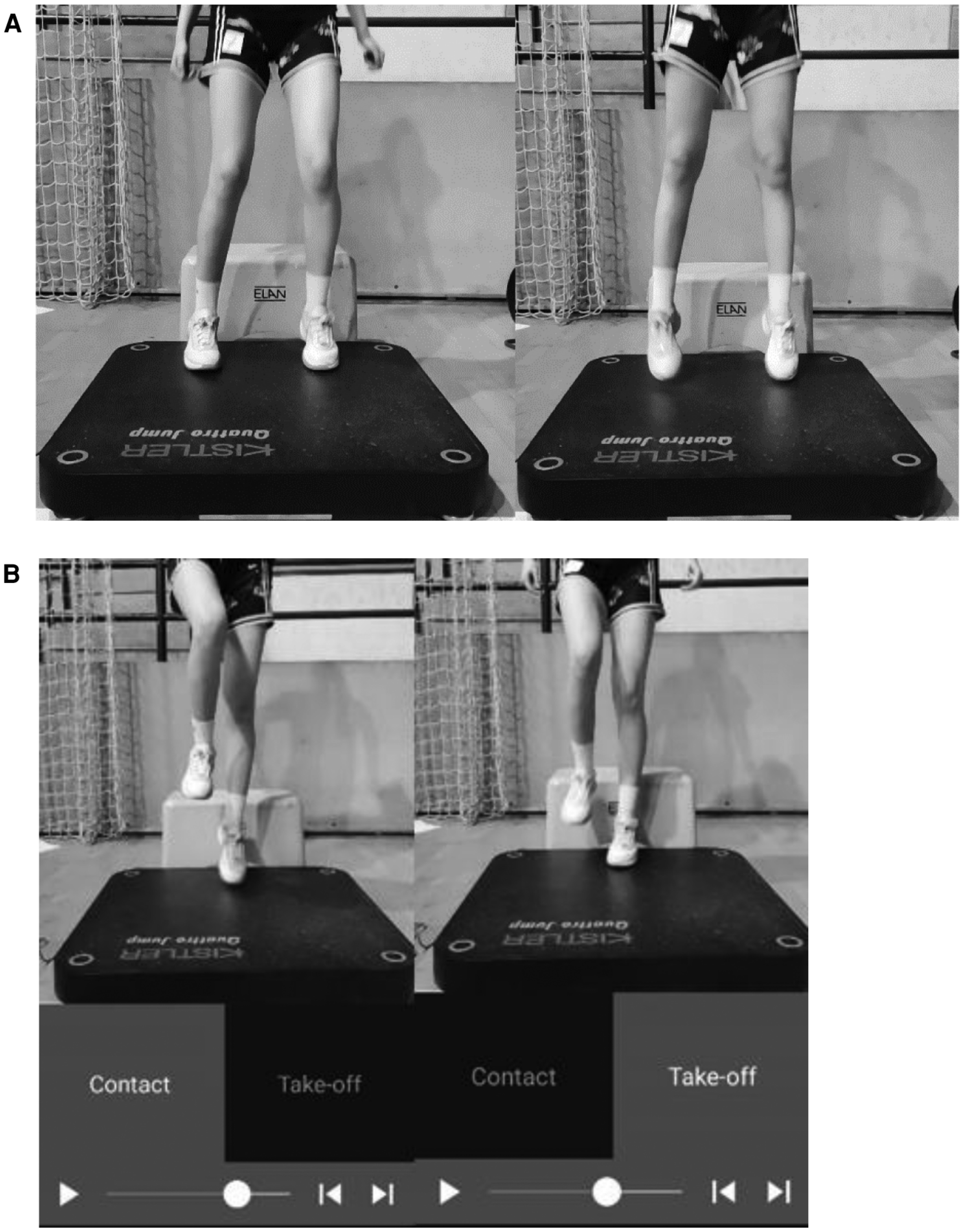

FIGURE 1
Drop jump (A) and single-leg drop jump (B).

TABLE 1 ICC of inter- and intra-rater reliability.

Variable	Rater 1 vs. Rater 2 (ICC, 95% CI)	Rater 1a vs. Rater 1b (ICC, 95% CI)
Drop jump		
Jump height (cm)	1	1
Contact time (ms)	0.998 (0.992–1)	1
Single-leg jump		
Jump height right (cm)	0.980 (0.90–0.99)	0.995 (0.979–999)
Contact time right (ms)	0.994 (0.975–0.999)	0.998 (0.993–1)
Jump height left (cm)	1	1
Contact time left (ms)	0.997 (0.987–0.999)	1

difference in jump height variable ($p = 0.97$) and the results showed a very large correlation for DJ jump height values between the two devices (ICC = 0.99; $r = 0.99$). The contact time for the drop jump test showed the largest mean difference between the application and force plate (367 vs. 385 ms, $p = 0.7$) (Table 2). The highest values are presented in Table 2.

Test–retest showed good reliability for jump height in the drop jump test (ICC = 0.88) (Table 3) and poor to moderate reliability for contact time (ICC = 0.46) (Table 3). Different camera settings showed excellent reliability for jump height (ICC = 0.99) and excellent reliability for contact time (ICC = 0.93). The MAPE for

TABLE 2 ICC and mean difference of My Jump 2 app and force plate.

Variable	My Jump 2	Force plate	MAPE	CV% (CI%)	*p*	MD	ICC (CI%)	*r*
Interlimb asymmetry								
Jump height asymmetry (%)	5.7	6.3	12.9%		0.8	0.6	0.96 (0.8–0.99)	0.93
Contact time asymmetry (%)	7.9	5.72	24.6%		0.5	2.3	0.94 (0.72–0.99)	0.90
Jump height right (cm)	12.9 (3.6)	13.2 (3.2)	6.7%		0.9	0.3	0.98 (0.91–0.99)	0.97
Contact time right (ms)	414 (104)	426 (119)	4.9%		0.8	12.1	0.98 (0.9–0.99)	0.96
Jump height left (cm)	12.79 (3.4)	13.01 (3.7)	3.7%		0.8	0.45	0.99 (0.93–0.99)	0.98
Contact time left (ms)	458 (111)	448 (113)	3.1%		0.9	9.63	0.99 (0.95–0.99)	0.99
Drop jump								
Jump height (cm)	24.82 (4.6)	24.9 (5.1)	2.6%		0.9	0.08	0.99 (0.97–0.99)	0.99
Contact time (ms)	367 (77)	385 (118)	4.8%		0.7	18.6	0.92 (0.28–0.98)	0.98
Test–retest								
	My Jump 2 Test	My Jump 2 Retest						
Drop jump (cm)	23.7 (6.5)	24.8 (4.6)		1.9 (1.4–2.3)	0.7	1.16	0.88 (0.74–0.98)	0.95
Contact time (ms)	367.3 (106)	366.9 (77)			0.9	9.96	0.6 (−0.95–0.92)	0.45
Inter-device reliability								
	120 fps	240 fps						
Drop jump (cm)	24.8 (4.6)	24.2 (4.9)		0.7 (0.5–0.8)	0.8	0.6	0.99 (0.93–0.99)	0.98
Contact time (ms)	367 (77)	357 (76)			0.8	9.9	0.93 (0.72–0.99)	0.87

Data are mean (SD).
MD, mean difference; *r*, Pearson's product-moment correlation coefficient.

TABLE 3 Mean ± SD for jump heights and contact time recorded with My Jump 2 app and force plate.

	My Jump 2	Force plate	*r*
Jump height right (1) (cm)	11.9 (3.2)	12.3 (3.3)	0.99
Contact time right (1) (ms)	409 (102)	420 (113)	0.96
Jump height right (2) (cm)	12.1 (3.1	12.5 (3.3)	0.97
Contact time right (2) (ms)	417 (88)	431 (79)	0.90
Jump height left (1) (cm)	11.2 (3.2)	11.6 (3.4)	0.98
Contact time left (1) (cm)	396 (78)	410 (96)	0.94
Jump height left (2) (cm)	12.5 (3.4)	12.7 (3.6)	0.99
Contact time left (2) (cm)	409 (82)	423 (76)	0.95
Jump height both legs (1) (cm)	21.6 (5.1)	22.1 (5.4)	0.99
Contact time both legs (1) (ms)	370 (78)	392 (84)	0.96
Jump height both legs (2) (cm)	22.5 (6)	22.9 (5.7)	0.99
Contact time both legs (2) (ms)	343 (77)	362 (74)	0.90
	120 fps	240 fps	
Drop jump (1) (cm)	23.5 (4.6)	23.3 (4.8)	0.99
Contact time (1) (cm)	379 (74)	373 (76)	0.86
Drop jump (2) (cm)	24.2 (4.6)	23.7 (4.7)	0.99
Contact time (2) (cm)	389 (77)	377 (79)	0.86

r, Pearson's product-moment correlation coefficient.

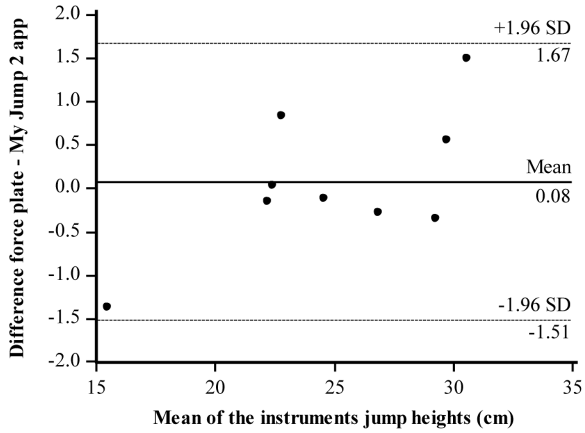

FIGURE 2
Level of agreement (Bland–Altman) with 95% limits of agreement (dashed lines) and the mean difference (solid line) between force plate and My Jump 2 app for DJ with both legs.

single-leg outcomes and for drop jumps with both legs showed a percentage error below 10%, indicating good results (Table 2). Moreover, jump height asymmetry and contact time asymmetry showed fair to poor MAPE results (>10%). The average of the two attempts measured using the My Jump 2 app and the force plate are presented in Table 3.

Bland–Altman plots regarding the jump height of both-leg DJs were illustrated between the two instruments. The Bland–Altman difference plot represents the mean of the two instruments (cm) in the *x*-axis and the difference between the force plate and My Jump 2 app in the *y*-axis. All the data points were within the 95% confidence intervals (CIs). Bland–Altman plots showing the limits of agreement for DJs between the force plate and the My Jump 2 app (Figure 2), for the right leg (Figure 3) and left leg (Figure 4), are in good agreement. There is no apparent systematic bias, as the differences are randomly scattered above and below the mean difference line. The majority of data points cluster around the zero-difference line, suggesting that the measurements from the My Jump 2 app and the force plate are in close agreement with each other. This indicates that both methods effectively measure jump height.

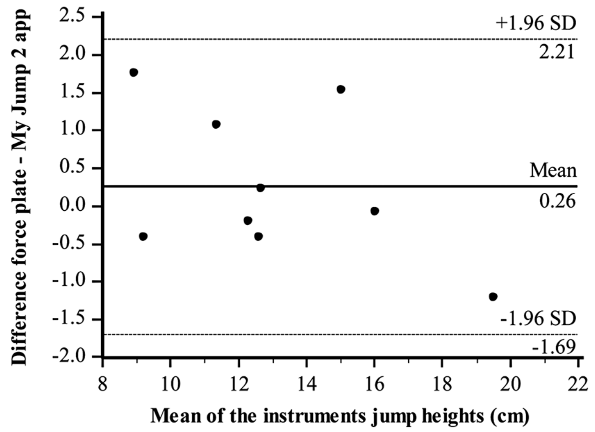

FIGURE 3
Level of agreement (Bland–Altman) with 95% limits of agreement (dotted lines) and the mean difference (solid line) between Force plate and My Jump 2 app in the jump height (right leg).

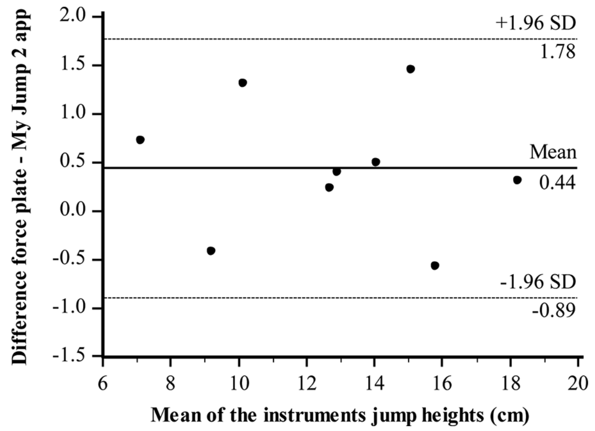

FIGURE 4
Level of agreement (Bland–Altman) with 95% limits of agreement (dotted lines) and the mean difference (solid line) between force plate and My Jump 2 app in the jump height (left leg).

4 Discussion

The purpose of this study was to examine the reliability and validity of the My Jump 2 app between one and two raters, between different camera settings, and interlimb asymmetry in female basketball players. The findings confirmed high validity and reliability in testing the jump height from flight time and contact time compared to a force platform. Moreover, different frames per second in video recording with the My Jump 2 app showed a high ICC. To the best of the authors' knowledge, no study has compared the force plate (Kistler Quattro Jump) and My Jump 2 app with young female basketball players.

Interlimb asymmetry has been identified as an essential factor in jumping performance in youth team-sport athletes (38). In fact, female basketball players who compete in higher leagues tend to have lower interlimb jump height asymmetry (39). Therefore, strengthening the weaker leg and reducing interlimb asymmetry can improve athlete's overall jumping performance (37). Our findings are consistent with previous results (29), showing high validity when comparing the My Jump 2 app and force plate in soccer players ($p = 0.91$ and $p = 0.88$) for flight time and contact time, respectively. Although there are similarities with previous research, MAPE statistics were not observed (29) and cannot be compared. In addition, results from our study showed high validity but are limited for MAPE for both jump height and contact time asymmetry (>10%). However, our findings indicate high ICC and Pearson correlation values (>0.90) for recognition of the interlimb asymmetry using the My Jump 2 app compared to the force plate in the young female basketball population. This is very important, considering coaches can evaluate lower limb asymmetries with an easy-to-use and portable device. Moreover, if it is used with a young population as a monitoring tool, it can prevent early career injuries (40).

Drop jump exercises have been proven to have a major role in enhancing explosive power in basketball players (41). The present data showed a strong correlation in DJ between the force platform and the My Jump 2 app ($r = 0.99$) for jump height ($r = 0.98$) and for contact time (MAPE <5%). Although our outcomes showed a high correlation for contact time, p-values were marginally lower for contact time asymmetry (%) and DJ contact time (ms). Our results showed similar outcomes compared to Gallardo-Fuentes et al. (27), who found a significant correlation in DJ height ($r = 0.99$) between the two already mentioned instruments. Another study identifies excellent ICC values for DJs (29) (0.97 and 0.94) for jump height and contact time, respectively. These results can be compared with ours (0.99 and 0.92) for jump height and contact time in DJs. These results can be explained by already developed applications and multiple studies that assessed the My Jump 2 app with various vertical jump tests. Comyns et al. (19) provided evidence of excellent reliability between force plates, photoelectric cells, and accelerometers but only the countermovement jump variable, drop jump, and asymmetry test were not investigated. Adding kinematics methods, such as the My Jump 2 app, for comparison in addition to these three aforementioned methods could be interesting for future findings. This could provide more proof for the reliability and diversity of instruments that can be used for measuring interlimb asymmetries and performance in athletes.

The test–retest method has shown to be an important method for calculating the reliability of a test (42–44). In this study, test–retest results in DJs in young female basketball players revealed good to excellent reliability in jump height outcomes (ICC = 0.88) and poor to moderate contact time outcomes (ICC = 0.460). The current results for jump height are in accordance with those of a previous study, which examined countermovement jumps and squat jumps instead of DJs (45). Another study (27) confirmed that the My Jump 2 app has high test–retest values for countermovement jumps, squat jumps, and

DJs ($r = 0.86–0.95$). Therefore, the My Jump 2 app was shown to be reliable for measuring jump height in athletes.

Intra- and inter-rater reliability have an important role in evaluating the consistency of an instrument in one and two assessors (46). Our findings can be compared to the results of earlier studies (29, 47) that evaluated the intra- and inter-rater reliability of the My Jump 2 app. The present results for intra- and inter-rater reliability show perfect and almost perfect correlations for all the variables tested (ICC > 0.99). Rogers et al. (47) evaluated the inter-rater reliability of the My Jump 2 app with an almost perfect correlation performing a countermovement jump (cm) (ICC = 0.99). The results of raters assessing the reliability of the My Jump 2 app can be found in the study by Barbalho et al. (29). Moreover, in their study, the intra- and inter-rater reliability yielded perfect and almost perfect correlations (ICC > 0.99 and ICC > 0.98, respectively) for single-leg DJ contact time and both-leg DJ jump height and contact time, consistent with our findings. These findings can justify the usage of mobile applications with both different raters and a single rater. It is important that the device can be used in different situations since the My Jump 2 app is mostly used in field-testing conditions and it is important that any rater can perform the testing.

Higher fps in cameras allow for more precise video analysis (48). This is because a higher fps captures more frames of movement, which can be used to track and analyze the motion of objects in the video more accurately. In addition, our study provides evidence of ICC results using two different frame settings (120 and 240 fps). To date, no study has looked specifically at the correlation between two models of smartphones and different frame rates when using the My Jump 2 app. Haynes et al. (20) discussed that the frame rate can be a limited factor in the accuracy of the My Jump 2 app. Our data indicate excellent reliability for DJ jump height (ICC = 0.99) and excellent reliability for DJ contact time (ICC = 0.93) comparing these two settings. The results provide evidence that the quality of the device is not crucial for the accuracy of the measurement in the My Jump 2 app, only the frame rate of a video, which can be either 120 or 240 fps. These findings will make the My Jump 2 app more accessible to a wider range of users.

Although we statistically managed to group the required sample size, more participants could increase the statistical power and representativeness of the study. Our sample size estimation indicated a requirement for seven participants. However, the p-values for jump height and contact time asymmetries (%) were 0.77 and 0.52, respectively. A bigger sample size may show larger differences. Furthermore, a small sample size may not provide sufficient statistical power to detect significant relationships of validity and reliability of the My Jump 2 app. Second, participants are young female basketball players who find it difficult to perform single-leg DJs due to their anthropometric characteristics, age, and technique. Our study may have been limited by the fact that some participants may not have been familiar with the single-leg DJ technique. Even though the technique was demonstrated the day before testing and participants had a familiarization phase, it was not sufficient time to learn the proper technique of the single-leg drop jump. All video recordings were done in a slow-motion setting as suggested by the My Jump 2 app guidelines. Previous research that investigated the My Jump 2 app used 120 Hz or more for data analysis. Lowering the frames per second in the camera settings for comparison analysis may yield reliable results, even when using more affordable devices.

The high correlation between the My Jump 2 app and the force plate in asymmetry tests shows strong evidence for the reliability of a low-cost app. In addition to the asymmetry variable, vertical jump performance can also be measured with high reliability. Moreover, our findings suggest that any rater with or without experience in sport science testing and minimal equipment can measure vertical jump performance with high validity and reliability. These results should encourage sport practitioners to use the My Jump 2 app to a greater extent for enhancing the overall performance of an athlete and reduce injury risk.

5 Conclusion

The My Jump 2 app is a reliable and valid instrument for assessing interlimb asymmetry, jump height, contact time, and DJ performance in young female basketball players. In addition, different camera settings proved to be reliable for assessing DJ performance. Therefore, the My Jump 2 app is a low-cost and easy-to-use instrument that basketball coaches can use to improve, monitor, and enhance female basketball players jumping performance.

Scope statement

This study investigates the validity and reliability of a mobile app designed to detect interlimb asymmetry in female basketball players. The app utilizes video analysis to assess asymmetry in key performance metrics (jump height, contact time) and aims to provide a practical tool for coaches and trainers. We compare the My Jump 2 app measurements against a force plate T (Kistler Quattro Jump) to assess concurrent validity. Moreover, we evaluate the app's intra- and inter-rater reliability and test–retest reliability through repeated measurements.

Interlimb asymmetry can impact performance and increase injury risk, especially in young female athletes. This study addresses the urgent need for reliable and accessible tools for its detection in female basketball athletes. The app's potential benefits include: Injury prevention (early identification of asymmetry can prompt corrective measures to prevent overuse injuries); Performance optimization (coaches can tailor training programs to address individual asymmetries and improve overall performance); and Accessibility (the app offers a cost-effective and convenient tool for coaches and players compared to traditional methods).

This research fills a critical gap in sports technology and aligns with the journal's focus on innovative tools for coaching female athletes and injury prevention. We believe our findings will be of significant interest to coaches, trainers, and researchers dedicated to optimizing the performance and health of female basketball players.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The present study was carried out in accordance with the Helsinki Declaration, and the studies involving humans were approved by the ethics committee of the Faculty of Sport and Physical Education, Nis, Serbia (reference no.: 04-2059/2). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

NS: Writing – original draft, Writing – review & editing. DS: Writing – original draft, Writing – review & editing. VP: Writing – original draft, Writing – review & editing. NČ: Writing – original draft, Writing – review & editing. MO: Writing – original draft, Writing – review & editing. MP: Writing – original draft, Writing – review & editing. AS: Writing – original draft, Writing – review & editing. AP: Writing – original draft, Writing – review & editing.

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Conflict of interest

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.

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Vertical jump neuromuscular performance of professional female handball players—starters vs. non-starters comparison

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Given the complex nature of the handball as a game, players are required to possess a distinct set of physical and physiological attributes to attain peak performance. With the countermovement vertical jump (CVJ) being widely implemented as a non-invasive and time-efficient testing modality in sports settings, the purpose of the present study was twofold: (a) to establish a CVJ profile of professional female handball players and (b) to examine differences in force-time metrics between starters and non-starters. Forty-two professional female handball players (e.g., SuperLeague) volunteered to participate in this study. Each athlete performed three maximum-effort CVJs with no arm swing while standing on a uni-axial force plate system sampling at 1,000 Hz. Independent *t*-tests were used to examine differences in each variable between starters and non-starters. The results revealed that starters attained superior performance within the eccentric phase of the CVJ when compared to non-starters, particularly in terms of eccentric peak velocity (-0.957 ± 0.242 vs. -0.794 ± 0.177 m·s^{-1}), eccentric mean power (320.0 ± 77.7 vs. 267.1 ± 75.2 W), and eccentric peak power (929.0 ± 388.1 vs. 684.4 ± 214.2 W). While not reaching the level of statistical significance, moderate-to-large effect sizes were observed for concentric impulse, peak velocity, and mean and peak force and power, all in favor of players included in the starting lineup ($g = 0.439–0.655$). Overall, these findings suggest that at the top-tier level of handball competition, the ability to secure a spot in a starting lineup may be possibly influenced by the athlete's eccentric performance capabilities. Thus, the development of lower-body eccentric strength and power may positively impact on-court athlete performance and ultimately help the team secure the desired game outcome.

KEYWORDS
force, power, velocity, handball, testing, athlete, biomechanics

1 Introduction

Handball is a body-contact team sport with more than 19 million participants worldwide (1). As an official Olympic sport, the game involves two teams, each comprising six players and a goalkeeper (2). Defined by its fast-paced defensive and offensive actions, the main objective of the game is to score goals through strategic positioning, one-on-one actions, and ball passing (3). This requires players to constantly engage in high-intensity activities across short distances, including jumping, sprinting, and rapid change-of-direction movements (4, 5). In addition, players need to be proficient in performing handball-specific maneuvers such as throwing, passing, blocking, and checking in order to help the team secure the winning game outcome (3).

Considering the complex on-court competitive demands, handball players are required to possess a distinct set of physical and physiological attributes to attain peak performance levels (3). In terms of anthropometric characteristics, these values often differ across playing positions (6, 7). Several previously published research reports have found that wing players are shorter in stature and have lower body mass when compared to other players (8–10). Also, wing players tend to have superior endurance (11), jumping, and sprinting abilities when compared to backcourt players and pivots (12). However, it is important to note that regardless of position-specific differences, physical abilities such as endurance (4, 5), strength (13), power (6), running speed (14), and throwing velocity (15) are key factors that contribute to a successful handball performance.

The previously mentioned differences can further extend to comparing physical and physiological performance characteristics of athletes included in the starting lineup (i.e., starters) with their substitutions (i.e., non-starters) (16). Multiple research reports focused on examining athletes participating in team sports such as basketball (17, 18), volleyball (19, 20), and rugby (21), found superior neuromuscular performance attributes in starters than non-starters. Moreover, it should be noted that these differences have been particularly evident in female athletes, with starters demonstrating greater absolute and relative peak power production capacities (17, 22). However, in terms of handball-specific research, there is a notable gap in the scientific literature focused on examining neuromuscular performance characteristics, especially on the professional level of competition.

With rapid technological growth over the last decade, the countermovement vertical jump (CVJ) performed on portable force plate systems has become a gold-standard testing modality in an applied sports setting for the assessment of lower-body neuromuscular performance characteristics (23–26). It allows sports practitioners to obtain in-depth insight into multiple force-time metrics during both eccentric and concentric phases of the jumping motion with high levels of validity and reliability (25–27). Yet, despite jumping performance being one of the key physical performance attributes that handball players need to possess to proficiently perform sport-specific movements such as throwing and blocking (3), previous studies found no differences in jump height when examining elite and amateur male and female handball players (13, 28, 29). However, it is important to note that the aforementioned studies were solely focused on observing vertical jump height as an outcome metric, suggesting that CVJ performed on innovative force plate systems could provide a comprehensive understanding of lower-body neuromuscular performance capabilities.

Therefore, alongside a considerable lack of scientific literature pertaining to female athletes, the purpose of the present study was twofold: a) to provide a comprehensive CVJ profile of professional female handball players and b) to examine differences in force-time metrics during both eccentric and concentric phases of the CVJ between the players included in the starting lineup and their substitutions. Based on previously published research reports, it is hypothesized that starters are likely to demonstrate superior performance on multiple CVJ force-time metrics.

2 Materials and methods

2.1 Participants

Forty-two professional female handball players volunteered to participate in the present study (height = 173.5 ± 4.8 cm; body mass = 66.6 ± 7.1 kg; age = 22.0 ± 4.7 years), from which sixteen were starters (height = 174.5 ± 4.2 cm; body mass = 66.1 ± 4.2 kg; age = 24.0 ± 5.0 years) and twenty-four were non-starters (height = 172.9 ± 5.0 cm; body mass = 66.6 ± 8.6 kg; age = 20.6 ± 4.1 years). The cohort of participants encompassed athletes from three teams competing at the same level of play (e.g., SuperLeague). All athletes were active members of the team at the time point of the data collection and were cleared by their medical personnel to participate in team-specific activities. The testing procedures performed in this investigation were previously approved by the University's Institutional Review Board and all participants signed an informed consent document.

2.2 Procedures

Prior to the start of the CVJ testing procedures, all athletes completed a standardized warm-up protocol composed of dynamic stretching exercises (e.g., A-skips, butt-kicks, high knees, side-to-side lunges, high-knee-pulls) administered by their respective strength and conditioning coaches. Then, each athlete stepped on a uni-axial force plate system (ForceDecks Max, VALD Performance, Brisbane, Australia) sampling at 1,000 Hz and performed three CVJs with no arm swing (i.e., hands on the hips during the entire movement) (16, 26). Strong verbal encouragement to push the ground as forcefully as possible was provided through the testing procedures to ensure that each athlete was giving maximal effort (30). The system was re-calibrated between each participant, and the average values across three jumps were used for performance analysis purposes. To minimize the possible influence of fatigue, the rest between each jump trial was 10–15 s. All testing procedures were completed within the same time of the day (17:00–19:00 h) during the in-season competitive period, >48 h following the last game. In addition, following the completion of testing procedures, the athlete's age and height were obtained from the official team roster.

2.3 Variables

The selection of the dependent variables included in this investigation was based on previously published research reports that demonstrated adequate levels of validity and reliability (23–25, 31–33). The force-time metrics examined within the eccentric phase of the CVJ were: braking phase duration and impulse, eccentric duration, peak velocity, and mean and peak force and power. The force-time metrics examined during the concentric phase of the CVJ were: concentric duration, impulse, and peak and mean force and power. Also, jump height (i.e., impulse-momentum calculation), reactive strength index (RSI)-modified (i.e., jump height divided by contraction time), and countermovement depth were derived as CVJ outcome metrics. The reduction in system mass by 20 N was selected as the start of the contraction phase and it ended at take-off, which was determined by the reduction in vertical force below 20 N. The eccentric phase was defined as the phase with a negative center of mass velocity. In addition, the braking phase started at minimum force until the end of the eccentric phase, and the impulse was calculated as the area under the ground reaction force curve (24, 34).

2.4 Statistical analysis

Descriptive statistics, means and standard deviations ($\bar{x} \pm SD$) were calculated for each dependent variable examined in the present study. Shapiro-Wilk test and Q-Q plots corroborated that the assumption of normality was not violated. Independent *t*-tests were used to examine statistically significant differences for each CVJ force-time metric of interest between starters ($n = 16$) and non-starters ($n = 24$). Due to the within-group sample sizes ($n < 20$), Hedges's g was calculated to provide the measure of the effect size ($g = 0.2$—small effect, $g = 0.5$—moderate effect, $g = 0.8$—large effect). Statistical significance was set *a priori* to $p < 0.05$. All statistical analyses were completed with SPSS (Version 26.0; IBM Corp., Armonk, NY, USA).

3 Results

Descriptive statistics for each CVJ force-time metric of interest and comparisons between starters and non-starters are presented in Table 1. Due to no statistically significant differences being found in body mass between the groups ($p = 0.556$; $g = 0.187$), the dependent variables were reported in absolute terms. The only statistically significant differences between starters and non-starters were found in eccentric peak velocity, eccentric peak power, and eccentric mean power. No other CVJ force-time metrics reached the level of statistical significance ($p > 0.05$).

4 Discussion

Upon reviewing the existing scientific literature, we can confidently affirm that this is the first study focused on examining differences in neuromuscular performance characteristics between starters and non-starters within top-tier professional female handball players. It was hypothesized that athletes included in the starting lineup are likely to display superior performance on multiple CVJ force-time metrics when compared to their substitutions. The findings of the present investigation partially align with the aforementioned hypothesis as starters did demonstrate a significantly greater eccentric peak velocity and eccentric mean and peak power. However, no significant differences were observed within the concentric phase of the CVJ as well as in outcome or strategy metrics such as vertical jump height and countermovement depth.

The obtained results are similar to some of the previously published studies comparing starters and non-starters in other team-based sports such as basketball (17, 18), volleyball (19, 20), soccer (22, 35), rugby (21) and lacrosse (36). Overall, the results of the aforementioned research reports implied superior neuromuscular performance characteristics of players included in a starting lineup when compared to their substitutions. In the context of female athletes, Becerra-Patino et al. (37) and Riley et al. (38) found that starters in soccer tend to have higher vertical jump heights than their substitutions (38.6 ± 6.1 vs. 34.4 ± 3.8 cm, respectively). Additionally, when examining a cohort of NCAA Division-I female basketball players, Gonzales et al. (17) found that starters are likely to experience improvements in both vertical jump and squat performance throughout the competitive season span, while no difference was observed within their non-starter counterparts. Specifically, starters attained greater absolute and relative peak power during the vertical jump test as well as higher average squat power (17). In addition, it is worth noting that the lack of significant differences in vertical jump height observed in the present investigation aligns with previous findings involving elite female handball players (28, 29). Thus, it can be inferred that jump height as a sole performance indicator might not be able to provide practitioners with useful information that can be used to distinguish between players based on their performance capabilities, further emphasizing the importance of an in-depth analysis approach that includes both eccentric and concentric phases of the CVJ.

When interpreting phase-specific differences in CVJ performance, it can be observed that starters had greater eccentric mean and peak power, accompanied by a greater eccentric peak velocity. Large effect sizes were observed for eccentric peak power and velocity ($g = 0.803–0.845$), while eccentric mean power demonstrated a moderate-to-large effect size magnitude ($g = 0.695$). Considering that *power = force × velocity* (39), these results imply that superior eccentric power observed within the athletes included in the starting lineup is primarily attained by an increase in eccentric velocity rather than eccentric force. Also, while eccentric force remains an important factor, in this instance successful performance may be more contingent on the ability to exert a certain amount of force at a maximal velocity, which resembles the on-court competitive demands (40). Furthermore, Spiteri et al. (41) highlighted a considerable impact of eccentric strength on the overall athlete's strength profile. A strong association ($r = -0.79–0.89$) was found between multiple eccentric force-time metrics and performance on change-of-direction tests (i.e., *T*-test and 505 test) within a

TABLE 1 Countermovement vertical jump profile of professional female handball players and comparison between starters and non-starters.

Variable [unit]	All players	Non-starters	Starters	*p*-value	Effect size
Eccentric phase					
Braking phase duration [s]	0.294 ± 0.087	0.296 ± 0.089	0.290 ± 0.084	0.809	0.007
Eccentric braking impulse [N·s]	31.3 ± 10.1	29.4 ± 9.8	34.1 ± 10.2	0.153	0.472
Eccentric duration [s]	0.499 ± 0.102	0.507 ± 0.108	0.487 ± 0.096	0.540	0.193
Eccentric peak velocity [$m \cdot s^{-1}$]	−0.859 ± 0.218	−0.794 ± 0.177	−0.957 ± 0.242*	0.018	0.803
Eccentric peak force [N]	1,521.5 ± 240.3	1,461.9 ± 231.7	1,610.8 ± 231.7	0.054	0.643
Eccentric mean force [N]	660.4 ± 67.7	655.2 ± 78.7	668.2 ± 48.1	0.558	0.188
Eccentric peak power [W]	782.3 ± 315.8	684.4 ± 214.2	929.0 ± 388.1*	0.014	0.845
Eccentric mean power [W]	288.3 ± 79.6	267.1 ± 75.2	320.0 ± 77.7*	0.038	0.695
Concentric phase					
Concentric duration [s]	0.235 ± 0.039	0.237 ± 0.043	0.231 ± 0.035	0.660	0.028
Concentric impulse [N·s]	153.3 ± 18.6	149.6 ± 19.2	158.7 ± 16.7	0.130	0.496
Concentric peak velocity [$m \cdot s^{-1}$]	2.38 ± 0.16	2.35 ± 0.14	2.44 ± 0.18	0.103	0.578
Concentric peak force [N]	1,643.1 ± 211.1	1,602.3 ± 209.6	1,704.0 ± 204.4	0.136	0.489
Concentric mean force [N]	1,328.8 ± 141.3	1,304.2 ± 146.9	1,365.8 ± 127.8	0.180	0.439
Concentric peak power [W]	2,938.9 ± 374.1	2,871.8 ± 360.9	3,039.5 ± 382.4	0.168	0.455
Concentric mean power [W]	1,684.9 ± 255.8	1,621.0 ± 213.5	1,780.7 ± 289.8	0.052	0.655
Other					
Contraction time [s]	0.734 ± 131.5	0.744 ± 0.141	0.718 ± 0.117	0.538	0.196
Jump height [cm]	26.7 ± 4.0	25.8 ± 3.4	27.9 ± 4.6	0.107	0.542
RSI-modified [ratio]	0.376 ± 0.091	0.356 ± 0.089	0.407 ± 0.087	0.083	0.058
Countermovement depth [cm]	−21.6 ± 5.5	−20.8 ± 5.8	−22.8 ± 5.0	0.271	0.362

RSI, reactive strength index.
*significantly different when compared to non-starters ($p < 0.05$).

cohort of NCAA Division-I basketball players (42). These results further confirm the findings from a recently published study involving professional female handball players, which revealed a positive relationship between CVJ neuromuscular performance metrics and horizontal deceleration performance, encompassing maximal and average deceleration and maximal approach velocity (2). Combined, these results underscore the importance of the eccentric phase of CVJ in the execution of various handball-specific movements. Therefore, given the intermittent multidirectional nature of the handball game (3), it can be assumed that players with superior eccentric muscle qualities can perform offensive and defensive actions more effectively, particularly those that require players to decelerate quickly to create elevation for jump throws or change movement direction to create space for strategic ball positioning. Therefore, such players are more likely to secure a spot in a team's starting line-up.

Despite not reaching the level of statistical significance, it is still important to recognize that the differences in the majority of force-time metrics between starters and non-starters within the concentric phase of the CVJ were moderate in magnitude ($g = 0.439–0.655$). Specifically, concentric impulse, peak velocity, and mean and peak force and power were slightly greater for starters when compared to non-starters. When taking into account that both groups had almost identical body mass, we can assume that a development of CVJ concentric strength and power capabilities cannot be underestimated and may still offer a competitive edge in certain instances that may help player secure the spot in starting lineup (e.g., establishing a better position on the court during body-contact offensive actions). Also, it should be noted that the magnitudes of the aforementioned force-time metrics align with the ones recorded in similar studies conducted on elite female handball players (2), suggesting that attaining the observed levels of strength and power is a required to compete on this level of play. Thus, analyzing the concentric phase of CVJ can still be beneficial when determining the starting team lineup, especially considering that maximal strength provides the foundation for developing all other components of strength, including eccentric strength and power (42).

Despite offering valuable insight into the neuromuscular performance characteristics of professional female handball players, this study is not without limitations. The cohort of participants was solely based on studying female athletes, which may limit the applicability of the observed findings to male athlete counterparts. Also, future research is warranted to examine if these findings apply to other competitive levels (e.g., amateur or Olympic). In addition, further research is warranted to examine the impact of maturation status, tactical-technical knowledge of the game, and playing position on differentiating between players included in the starting lineup and their substitutions.

In summary, the findings of the present study reveal that the ability to secure a spot in the starting lineup at the professional level of female handball competition may be influenced by an athlete's eccentric performance characteristics (i.e., eccentric peak velocity and eccentric mean and peak power). Also, alongside providing normative ranges for CVJ performance assessment that coaches, sports scientists, and strength and conditioning practitioners can use when developing training regimens, these results further emphasize the importance of the development of lower-body eccentric strength and power characteristics. When considering the on-court competitive demands, they may positively impact various aspects of the game such as throwing velocity, blocks, throws, and holds, and ultimately improve overall team performance and increase the likelihood of securing the desired game outcome.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of Kansas Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

KR: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. DC: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. JA: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. DC: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. DM: Methodology, Writing – original draft, Writing – review & editing. OK: Writing – original draft, Writing – review & editing. AF: Supervision, Writing – original draft, Writing – review & editing.

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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.

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Patterns of energy availability and carbohydrate intake differentiate between adaptable and problematic low energy availability in female athletes

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Background: Problematic low energy availability (EA) is the underlying culprit of relative energy deficiency in sport (REDs), and its consequences have been suggested to be exacerbated when accompanied by low carbohydrate (CHO) intakes.
Objectives: This study compared dietary intake, nutrition status and occurrence of REDs symptoms in groups of female athletes, displaying different patterns of EA and CHO intake.
Methods: Female athletes (*n* = 41, median age 20.4 years) from various sports weighed and recorded their food intake and training for 7 consecutive days via a photo-assisted mobile application. Participants were divided into four groups based on patterns of EA and CHO intakes: sufficient to optimal EA and sufficient to optimal CHO intake (SEA + SCHO), SEA and low CHO intake (SEA + LCHO), low energy availability and SCHO (LEA + SCHO), and LEA and LCHO (LEA + LCHO). SEA patterns were characterised by EA ≥30 and LEA by EA <30 kcal/kg fat free mass, and SCHO patterns characterised by CHO intake ≥3.0 and LCHO <3.0 g/kg body weight for most of the registered days. Body composition was measured with dual energy x-ray absorptiometry, resting metabolic rate with indirect calorimetry and serum blood samples were collected for evaluation of nutrition status. Behavioural risk factors and self-reported symptoms of REDs were assessed with the Low Energy Availability in Females Questionnaire, Eating Disorder Examination Questionnaire Short (EDE-QS), Exercise Addiction Inventory, and Muscle Dysmorphic Disorder Inventory.
Results: In total, 36.6% were categorised as SEA + SCHO, of which 5/16 were ball sport, 7/10 endurance, 1/7 aesthetic, 2/5 weight-class, and 0/3 weight-class athletes. Of LEA + LCHO athletes (19.5% of all), 50% came from ball sports. Aesthetic and endurance athletes reported the greatest training demands, with weekly training hours higher for aesthetic compared to ball sports (13.1 ± 5.7 vs. 6.7 ± 3.4 h, *p* = 0.012). Two LEA + LCHO and one SEA + LCHO athlete exceeded the EDE-QS cutoff. LEA + LCHO evaluated their sleep and energy levels as worse, and both LEA groups rated their recovery as worse compared to SEA + SCHO.
Conclusion: Repeated exposures to LEA and LCHO are associated with a cluster of negative implications in female athletes. In terms of nutrition strategies, sufficient EA and CHO intakes appear to be pivotal in preventing REDs.

KEYWORDS
sport nutrition, energy availability, relative energy deficiency, female athlete, nutrition status

1 Introduction

Energy availability (EA) refers to the residual dietary energy that is left for basic functions of the body after exercise energy expenditure (EEE) has been accounted for (1). Sufficient EA is fundamental for health and sport performance, while low EA (LEA) puts athletes at risk of relative energy deficiency in sport (REDs) (2–4). As outlined in the 2023 consensus update from the International Olympic Committee (IOC) (4), REDs is an umbrella term describing various health and performance decrements that may occur due to problematic LEA. Problematic LEA results from prolonged and/or severe exposure to LEA and disrupts function of one or more of the body systems. Exercise capacity, recovery, training adaptations, and other performance outcomes are consequently impaired. Conversely, adaptable LEA is short term and/or more benign LEA exposure, with little or no negative impact on health and performance. Whether a given scenario falls under adaptable or problematic LEA may be influenced by moderating factors, such as individual characteristics, athletes' relationship with food and exercise, and nutrient composition of their diets (4, 5).

Early laboratory-based work in non-athletic females suggested that LEA, and resultant menstrual dysfunctions, occurred when EA went below 30 kcal/kg/fat free mass (FFM) (6, 7). Since then, this value has commonly been used as a cutoff for LEA. In recent years, the use of such a universal LEA cutoff has been debated for several reasons. That includes individual differences in endocrine and metabolic responses to LEA, and the distinction that has now been made between problematic and adaptable LEA (4, 8, 9). Although scientific understanding of REDs and its physiological consequences has vastly increased in the past decade, the degree of LEA (i.e., duration, magnitude and frequency) needed for it to be problematic remains unknown (4). However, recent intervention studies have found that as little as 1–2 weeks of exposure to LEA may be detrimental for health and performance outcomes in athletes across sports (10–12). Accumulating evidence also suggests that only a few consecutive days of insufficient or restricted carbohydrate (CHO) intake (<3.0 g/kg), with or without LEA, can impair physiological function and training adaptation (13–15). This is alarming given that athletes, and females especially, often fail to meet CHO requirements or intentionally restrict CHO intake (16–18). Also of note is that chronic CHO restriction often tends to modulate intakes of other important macro- and micronutrients (19). In contrast, nutrition periodisation often involves tailoring energy and/or CHO intake to training demands and/or stimulate fat oxidation capacity, or other training adaptations, by "training low" (e.g., in a fasted or CHO depleted state) (20, 21). This all comes down to the currently ill-defined threshold between beneficial versus harmful dietary modifications and behaviours in athletic populations.

Bearing the disparities between adaptable and problematic LEA in mind, not only average EA but also day-to-day variations deserve special consideration in real-life situations. Such variations or patterns have been described in a few small ($n < 15$) single sport and case studies (22–25) but not in larger cross-sectional investigations. Therefore, the aim of the present study was to compare dietary intake, nutrition status and occurrence of REDs symptoms, between groups displaying different patterns of EA and CHO intake.

2 Methods

2.1 Study population

This study used data from a larger cross-sectional research project on REDs in high-level Icelandic athletes aged ≥15 years. The eligibility criteria and recruitment of participants have been described in detail elsewhere (26). The athletes initially responded to an online questionnaire in 2021 (July–December) consisting of the Low Energy Availability in Females Questionnaire (LEAF-Q) (27) and additional background questions. The measurement phase was between April and September 2022. Of the 56 female athletes that participated in the measurement phase, 48 logged their dietary intake and training via a photo-assisted mobile application. Seven participants provided insufficient registration (<5 days dietary intake recorded and/or no training session registered) for determination of EA. Therefore, 41 athletes were included in the present analysis. For most participants ($n = 35$), 7 days of registered dietary intake and training were available. Participants with 6 ($n = 5$) or 5 ($n = 1$) days were also included. The athletes came from five different sport groups, using definitions suggested by another study (28): ball (39%); endurance (24.4%); aesthetic (17.1%); weight-class (12.2%); and power sports (7.3%).

2.2 Energy availability

2.2.1 Digital food and training records

Participants recorded their dietary intake and training for 7 consecutive days. Weighed amounts and descriptions of all foods eaten in addition to photographs of foods taken/served as well as leftovers were registered via a mobile application (app). The app is in Icelandic and was originally developed for a study on eating behaviours in children and their parents (29) but was subsequently adapted to fit the needs of the present study, mainly by adding a training record and a more detailed logging option for exact amounts of foods consumed. Participants received individual encoded login information and detailed instructions on how to use the app. All were verbally informed about the aims of this registration, and the importance of not changing what, when and how much they ate because of their participation in the study.

The athletes logged all food, drinks other than still water, dietary supplements, and ergogenic aids. Similar to the remote food photography method used in a previous study on athletes (22), before and after photos of meals and snacks were taken (directly in the app or uploaded from the photo gallery) and kitchen scales (provided if needed) were used to weigh each food/meal item. Assessment of dietary intakes from the photographs was based on a validated method (30). In cases where food weighing and/or photographing was not possible, participants were asked to provide written information, such as a description of what was

FIGURE 1
Examples of before and after photos of meals from the food records. The examples are random and from six different individuals.

ordered from restaurant menus. They also had the option to include additional information or photos, e.g., of ingredient lists or labels on food packaging. The use of sport foods and supplements was manually derived from the app registrations, using descriptions provided by the IOC (31). The app did not provide any calculations or feedback to participants, but they could see an overview of meals and meal timings they had logged. Examples of before and after photos from meals are provided in Figure 1.

During the same period, participants reported training sessions, their duration and rated perceived exertion based on the Borg rating scale in the app (32). If a training watch or global positioning system (GPS) device was used, participants were asked to register the highest heart rate reached during the session and type of measurement (e.g., watch/wrist or chest strap). Lastly, the participants were asked to write a short description of the training session, where they could also add a photo of their training plan/workout description.

2.2.2 Body composition and resting metabolic rate

Body composition, including FFM, was measured in a rested and fasted state via whole-body dual energy x-ray absorptiometry (DXA). The FFM index (FFMI) was calculated by dividing the total FFM (kg) by height squared (m^2) (33). Most participants ($n = 36$) had a valid assessment of fasted resting metabolic rate (RMR), conducted via indirect calorimetry (ventilated hood). For those, the RMR ratio was calculated by dividing the measured value with the estimated value from the Cunningham formula (34). RMR ratio <0.90 is among suggested secondary markers of REDs (35, 36). DXA and RMR measurement procedures have been described in detail elsewhere (26).

2.2.3 Energy availability and nutrient intake calculations

All food records were coded by the same nutritionist. The data were then transported into the ICEFOOD calculation programme, which is based on the Icelandic food composition database (ISGEM), for energy and nutrient intake calculations. ICEFOOD was initially developed for the national diet survey in Iceland in 2002 and has also been used for more recent surveys as well as for research purposes (37, 38). As part of the data cleansing process, coding and calculations were thoroughly checked and any evident errors corrected by the research team. In accordance with Icelandic and Nordic nutrition recommendations (39, 40), low intakes of micronutrients were defined as vitamin D <15 µg, iron <15 mg, folate <300 µg, and vitamin B12 <2 µg.

Registered training hours and number of sessions were derived from the training records. Weekly training hours and sessions for athletes who registered 5 or 6 days in the app were calculated by dividing the number of training hours/sessions by number of registered days and then multiplied by seven. For comparison, athletes were asked how many hours (on average) they usually trained per week, before starting the registration via questionnaire. EEE was estimated from the training logs based on reported exercise mode, intensity or perceived exertion, and duration, as described by Heikura et al. (41). Each training session, or parts of it, was assigned a relevant metabolic equivalent (MET) value for the type and intensity of the activity (42). MET scores were then multiplied by the session/activity duration for the calculation of total EEE. RMR, either measured (if valid measures were available) or estimated via the Cunningham formula (34), was subtracted from total EEE to yield energy cost of the workout alone.

Daily EA was calculated using the following formula (1):

$$\text{Energy availability} = \frac{\text{Energy intake (kcal)} - \text{Exercise energy expenditure (kcal)}}{\text{Fat free mass (kg)}}$$

2.2.4 Categorisation based on energy availability and carbohydrate intake patterns

Based on a graphical presentation of individual day-to-day patterns of EA and nutrient intake [Supplementary Information

(SI)], participants were manually divided into four groups based on patterns of EA and CHO intake:

1. SEA + SCHO: sufficient to optimal energy availability + sufficient to optimal carbohydrate intake.
2. SEA + LCHO: sufficient to optimal energy availability + low carbohydrate intake.
3. LEA + SCHO: low energy availability + sufficient to optimal carbohydrate intake.
4. LEA + LCHO: low energy availability + low carbohydrate intake.

SEA patterns were characterised by EA ≥30 kcal/kg and LEA by EA <30 kcal/kg FFM for most days (≥5 out of 7 or ≥4 out of 5–6 days). SCHO patterns were characterised by CHO intake ≥3.0 and LCHO <3.0 g/kg for most days (≥4 out of 7 or ≥3 out of 5–6 days). The categorisation was further confirmed by calculated averages, where the two LEA groups had an average EA <30 kcal/kg FFM/day and those with sufficient to optimal EA averaged ≥30 kcal/kg FFM/day. Likewise, the groups with LCHO had an average CHO intake <3.0 g/kg/day and the SCHO groups averaged ≥3.0 g/kg/day.

2.3 Serum nutrition status

Fasted serum blood samples were collected and analysed as described earlier (26). Ferritin, iron, and total iron binding capacity (TIBC) were measured for the evaluation of iron status, and 25-hydroxyvitamin D (25-OH-Vitamin D) for vitamin D status. Using the laboratory reference values, low ferritin (adolescents <12 µg/L, adults <15 µg/L), low iron (<10 µmol/L), and high TIBC (>70 µmol/L) served as indicators of iron deficiency. In addition, transferrin saturation (TSAT) was calculated using the following formula: (iron/TIBC) × 100, with TSAT <20% considered low (43). Vitamin D insufficiency is defined as serum 25-OH-Vitamin D concentrations <50 nmol/L, and concentrations <30 nmol/L are a marker of vitamin D deficiency (40). The prevalence of concentrations below 80 nmol/L, an often-used definition of insufficiency in athletes (3, 44), was also evaluated. Other measured markers of nutrition status were calcium (reference range: 2.15–2.6 mmol/L), magnesium (reference range: 0.74–0.99 mmol/L), and vitamin B12 (reference range: 142–725 pmol/L).

2.4 Self-reported symptoms of LEA

2.4.1 Low Energy Availability Questionnaire

The Low Energy Availability in Females Questionnaire (LEAF-Q) was used to screen for physiological symptoms of REDs. Total score of ≥8, injury sub-score ≥2, gastrointestinal (GI) sub-score ≥2, and menstrual sub-score ≥4 are the established cutoffs for LEAF-Q (27).

LEAF-Q also assesses menstrual disturbances (oligomenorrhea or amenorrhoea) and use of contraceptives. Athletes with <9 menses in the past 12 months, in absence of hormonal contraceptive use, were defined as having menstrual disturbances, and those currently using hormonal contraceptives were defined as contraceptive users (45). Menstrual function was not defined for one athlete due to perimenopausal age (>45 years).

LEAF-Q was supplemented by questions retrieved from the recently developed Low Energy Availability in Males Questionnaire (LEAM-Q) (46). The LEAM-Q-derived categories concerned dizziness, thermoregulation at rest, fatigue (lethargy, tiredness, lack of concentration in general), fitness (body pain, muscle stiffness, physical exhaustion, and vulnerability to injuries), sleep, recovery (physical recovery and perceived training progress), and energy levels (training readiness, perceived happiness, and energetic levels). Scores for LEAM-Q-derived measures were calculated according to the initial scoring key. Validated LEAM-Q cutoffs, other than for male-specific sex drive, are currently lacking but higher scores indicate a worse outcome (46).

2.4.2 Disordered eating, compulsive exercise, and muscle dysmorphia

All participants responded to the Eating Disorder Examination—Questionnaire Short (EDE-QS) (47), Exercise Addiction Inventory (EAI) (48), and Muscle Dysmorphic Disorder Inventory (MDDI) (49). The established cutoffs are ≥15 for EDE-QS and ≥39 for MDDI. An EAI score ≥24 indicates a risk of compulsive exercise, 13–23 some symptoms, and 6–12 no symptoms.

2.5 Data analysis

Statistical analyses were conducted using IBM SPSS statistics 29.0.1.1, with significance set to $\alpha<0.05$. Distributions of all data were checked using the Shapiro–Wilk test and visual inspection of Q-Q plots. Continuous variables were summarised as mean ± SD for normally distributed data, and medians with 25th and 75th interquartile ranges (IQR) for non-parametric data. Cross-tabulation and Pearson chi-square statistics were used for the evaluation of categorical data, including the occurrence of LEAF-Q, EDE-QS, EAI, and MDDI scores above cutoff.

Participant training characteristics, dietary intakes, and questionnaire scores were compared with one-way analysis of variance (ANOVA) and Kruskal–Wallis statistics. The independent samples *t*-test was used to compare differences in nutrient intake between athletes using sport foods and supplements compared to non-users. Body composition and nutrition status were compared based on EA + CHO categorisation (fixed factor) and adjusted for age using analysis of covariance (ANCOVA). When appropriate, Bonferroni *post hoc* for multiple comparisons was applied. For pairwise comparisons, mean differences (MD) and confidence intervals (95% CI) were reported for parametric data, and effect size ($r = Z/\sqrt{n}$) for non-parametric outcomes with threshold values set at 0.1 (small effects), 0.3 (moderate), and 0.5 (large) (50).

3 Results

3.1 Participant characteristics

Participant characteristics, with age adjusted comparisons, are summarised in Table 1. The age range was 15–48 years but did not differ between the EA + CHO groups (Kruskal–Wallis H = 1.227,

TABLE 1 Participant characteristics.

		EA + CHO groups				Age adjusted ANCOVA		
	All $n = 41$	SEA + SCHO $n = 15$	SEA + LCHO $n = 9$	LEA + SCHO $n = 9$	LEA + LCHO $n = 8$	F	p-value	ηp^2
Age	20.4 (17.9–27.0)	22.3 (16.7–31.5)	20.3 (17.7–23.6)	19.8 (17.7–25.0)	22.2 (20.1–31.3)	—	—	—
Body weight (kg)	65.7 ± 10.8	59.7 ± 9.3	75.6 ± 12.5	61.7 ± 5.4	70.4 ± 5.6	7.406	<0.001	0.382
BMI (kg/m^2)	22.9 ± 3.3	21.4 ± 2.8	26.1 ± 3.5	21.5 ± 2.0	23.6 ± 2.6	6.814	<0.001	0.362
DXA FFM (kg)	45.5 ± 4.6	43.0 ± 4.0	47.6 ± 4.7	45.1 ± 2.6	48.4 ± 5.0	4.313	0.011	0.264
DXA FFMI (kg/m^2)	15.9 ± 1.1	15.4 ± 1.2	16.5 ± 0.9	15.7 ± 1.0	16.1 ± 0.9	3.003	0.043	0.200
DXA fat mass (kg)	17.4 ± 7.3	14.1 ± 6.0	24.8 ± 8.2	13.8 ± 3.1	19.1 ± 5.5	7.058	<0.001	0.370
DXA fat%	25.7 ± 6.8	23.0 ± 6.4	32.4 ± 5.6	22.3 ± 3.3	27.0 ± 6.8	6.010	0.002	0.334
DXA whole-body BMD Z-score	1.3 ± 1.0	1.1 ± 1.1	1.1 ± 1.1	1.7 ± 1.0	1.4 ± 0.9	1.035	0.389	0.079
RMR (kcal)[a]	1,637 ± 217	1,591 ± 227	1,702 ± 224	1,600 ± 266	1,691 ± 149	0.876	0.464	0.078
RMR/FFM (kcal/kg FFM)[a]	35.8 ± 3.8	36.5 ± 3.6	35.8 ± 2.7	35.1 ± 5.3	35.2 ± 4.1	0.224	0.879	0.021
RMR ratio[a,b]	1.08 ± 0.11	1.09 ± 0.11	1.10 ± 0.09	1.06 ± 0.17	1.08 ± 0.10	0.141	0.935	0.013
	$n = 40$	$n = 14$	$n = 9$	$n = 9$	$n = 8$			
Menstrual function								
Normal menstruation n (%)	21 (52.5)	7 (50.0)	3 (33.3)	8 (88.9)	3 (37.5)			
Menstrual disturbances n (%)	7 (17.5)	4 (28.6)	1 (11.1)	0	2 (25.0)			
Contraceptive use n (%)	12 (30.0)	3 (21.4)	5 (55.6)	1 (11.1)	3 (37.5)			

Categorical data are presented as n and within-group frequencies (%), parametric continuous variables as means ± SD and nonparametric as median (25p–75p interquartile range). BMI, body mass index; DXA, dual energy X-ray absorptiometry; FFM, fat free mass; FFMI, FFM index (total FFM/height squared); BMD, bone mineral density. Energy availability (EA) and carbohydrate (CHO) groups = SEA + SCHO, sufficient to optimal EA and sufficient to optimal CHO intake; SEA + LCHO, sufficient to optimal EA and low CHO intake; LEA + SCHO, low EA and sufficient to optimal CHO; LEA + LCHO, low EA and low CHO intake. Menstrual function was defined based on responses to the Low Energy Availability in Females Questionnaire (LEAF-Q).

[a]RMR measured via indirect calorimetry (valid measure available for 36 participants).

[b]Calculated RMR ratio: measured RMR/estimated via the Cunningham formula.

$p = 0.747$). The SEA + LCHO group had a higher body weight (BW) compared to the LEA + SCHO [MD = 14.0 kg (2.2–25.8), $p = 0.013$] and SEA + SCHO groups [MD = 16.4 kg (5.7–27.1), $p < 0.001$]. Group differences were observed for FFM and FFMI and *post hoc* analyses revealed that the SEA + LCHO group had a higher FFMI compared to the SEA + SCHO group [MD = 1.2 kg/m^2 (0.06–2.4), $p = 0.034$]. The SEA + LCHO group also had the highest body fat percentage and differed significantly from the LEA + SCHO [MD = 10.1% (2.4–17.8), $p = 0.005$] and SEA + SCHO groups [MD = 9.2% (2.2–16.2), $p = 0.005$] but not from the LEA + LCHO group. No group differences were observed for whole-body bone mineral density (BMD) Z scores and RMR. One athlete, in the SEA + SCHO group, had a RMR ratio <0.90. Of the athletes aged <45 years, 30% were using hormonal contraceptives, either oral contraceptive pills ($n = 9$) or other forms: ring, coil, and injections ($n = 3$). Previous (i.e., not current) use of oral contraceptives was reported by 10 (25%) athletes. Current amenorrhoea was reported by one athlete, and that athlete was categorised as LEA + LCHO and not taking contraceptives. A considerably larger proportion ($n = 13$) had a history of amenorrhoea and six reported current oligomenorrhea.

EA + CHO categorisation and training characteristics of the five sports groups are shown in Table 2. Most participants were categorised as SEA + SCHO (36.6%), of whom 70% were the endurance and 31.3% were the ball sport athletes. Moreover, half ($n = 8/16$) of the ball sport athletes had patterns characterised by LEA and that was accompanied by LCHO in four of them. Four out of seven aesthetic athletes but none of the weight-class athletes had LEA patterns.

Between-sport group differences were observed for weekly number of training hours and daily EEE. Multiple comparisons were not significant for EEE after Bonferroni corrections were applied. However, average training hours from the training records were higher in aesthetic athletes than ball sport athletes [MD = 6.4 h (0.95–11.8), $p = 0.012$]. The weekly number of training hours, derived from the questionnaire, was also higher in aesthetic sports compared to ball [MD = 6.0 h (1.3–10.7), $p = 0.005$] and weight-class [MD = 6.4 h (0.4–12.4), $p = 0.030$] sports.

3.2 Energy availability and dietary intake

In addition to differences in CHO intake, intakes of protein, fat, and fibre differed by groups (Table 3). More specifically, the LEA + LCHO group had the lowest relative intake of all macronutrients and the SEA + SCHO group had the highest. The average protein intake differed between SEA + SCHO and LEA + LCHO [MD = 0.6 g/kg (0.04–1.1), $p = 0.028$]. SEA + SCHO also had higher fat intakes compared to SEA + LCHO [MD = 0.4 g/kg (0.1–0.7), $p = 0.004$] and LEA + LCHO [MD = 0.6 g/kg (0.3–0.9), $p < 0.001$]. Finally, fibre intake was higher in SEA + SCHO compared to LEA + LCHO [MD = 0.2 g/kg (0.02–0.47), $p = 0.028$].

A total of 36 (87.8%) athletes used sport foods and/or supplements, of whom, two used vitamins and minerals only. Vitamin D intake was <15 µg in 82.9% of all athletes but 12 (29.3%) took supplements with vitamin D and their total intake averaged at 19.5 µg compared to 5.1 µg in those who did not supplement. Vitamins without D were taken by 5 (12.2%) and

TABLE 2 EA + CHO categorisation, weekly training load, and EEE.

Variable	Ball $n = 16$	Endurance $n = 10$	Aesthetic $n = 7$	Weight-class $n = 5$	Power $n = 3$	F/H[a]	*p*-value
EA + CHO groups						—	—
SEA + SCHO *n* (%)	5 (31.3)	7 (70.0)	1 (14.3)	2 (40.0)	0		
SEA + LCHO *n* (%)	3 (18.8)	0	2 (28.6)	3 (60.0)	1 (33.3)		
LEA + SCHO *n* (%)	4 (25.0)	2 (20.0)	3 (42.9)	0	0		
LEA + LCHO *n* (%)	4 (25.0)	1 (10.0)	1 (14.3)	0	2 (66.7)		
Weekly training sessions (min–max)	5.6 ± 2.3 (2–10)	7.9 ± 2.4 (5–12)	8.0 ± 4.2 (3–14)	4.8 ± 1.6 (2–7)	5.7 ± 2.3 (3–7)	2.195	0.089
Training hours/week							
From questionnaire	9.7 ± 3.2	12.4 ± 3.6	15.7 ± 4.6	9.3 ± 2.2	11.2 ± 1.6	4.368	0.006
From training diary	6.7 ± 3.4	10.6 ± 3.7	13.1 ± 5.7	6.3 ± 3.1	8.7 ± 4.7	4.116	0.008
Average daily EEE							
kcal	322 (210–564)	473 (372–710)	595 (351–758)	286 (153–365)	374 (258–)	11.425	0.022
kcal/kg FFM	6.6 (4.9–12.0)	9.7 (8.6–16.6)	12.6 (8.0–17.0)	5.9 (4.0–7.9)	7.3 (5.7–)	12.579	0.014

Categorical data are presented as *n* and within-sport group frequencies (%), parametric continuous variables as means ± SD and nonparametric as median (25p–75p interquartile range). Ball: Football, handball, basketball, volleyball, badminton; Endurance: middle to long distance running, swimming, cycling; Aesthetic: gymnastics, figure skating, ballroom dancing, ballet; Weight-class: wrestling, powerlifting, karate; Power: sprinting, throwing, and jumping events, alpine skiing. FFM, fat free mass; EEE, exercise energy expenditure. Energy availability (EA) and carbohydrate (CHO) groups = SEA + SCHO, sufficient to optimal EA and sufficient to optimal CHO intake; SEA + LCHO, sufficient to optimal EA and low CHO intake; LEA + SCHO, low EA and sufficient to optimal CHO; LEA + LCHO, low EA and low CHO intake.
[a]ANOVA (*F* values) and Kruskal Wallis (H-Values) group comparisons.

TABLE 3 Seven-day average energy availability and dietary intakes, with one-way ANOVA comparisons between EA + CHO groups.

		EA + CHO groups				ANOVA		
	All $n = 41$	SEA + SCHO $n = 15$	SEA + LCHO $n = 9$	LEA + SCHO $n = 9$	LEA + LCHO $n = 8$	F	*p*-value	ηp^2
Energy availability (kcal/kg FFM)	35.5 ± 10.0	45.1 ± 6.5	36.1 ± 5.8	29.6 ± 2.5	23.3 ± 5.5	31.354	<0.001	0.718
Energy intake								
kcal	2,043 ± 362	2,341 ± 303	2,001 ± 335	1,926 ± 178	1,661 ± 145	12.593	<0.001	0.505
kcal/kg	31.9 ± 7.7	39.7 ± 5.4	26.7 ± 4.3	31.4 ± 4.0	23.6 ± 1.8	29.660	<0.001	0.706
kcal from sport foods/supplements	142 ± 126	157 ± 139	191 ± 169	86 ± 67	121 ± 79	1.210	0.320	0.089
Carbohydrate intake								
g	212 ± 54	257 ± 55	187 ± 36	207 ± 14	161 ± 24	11.905	<0.001	0.491
g/kg	3.3 ± 1.1	4.3 ± 0.9	2.5 ± 0.4	3.4 ± 0.4	2.3 ± 0.4	26.668	<0.001	0.684
g from sport foods/supplements	10.8 ± 9.9	12.1 ± 11.1	14.9 ± 11.9	6.0 ± 6.0	9.2 ± 7.4	1.386	0.262	0.101
Protein intake								
g	106 ± 25	112 ± 26	115 ± 28	95 ± 14	96 ± 22	1.930	0.142	0.135
g/kg	1.6 ± 0.5	1.9 ± 0.6	1.6 ± 0.4	1.5 ± 0.2	1.4 ± 0.3	3.631	0.022	0.227
g from sport foods/supplements	15.7 ± 15.4	15.2 ± 16.2	22.7 ± 20.2	11.4 ± 10.5	13.8 ± 12.1	0.887	0.457	0.067
Fat intake								
g	81 ± 18	90 ± 20	84 ± 18	75 ± 12	67 ± 10	4.059	0.014	0.248
g/kg	1.3 ± 0.3	1.5 ± 0.3	1.1 ± 0.2	1.2 ± 0.2	1.0 ± 0.1	9.882	<0.001	0.445
g from sport foods/supplements	3.7 ± 3.9	4.9 ± 4.9	4.4 ± 4.5	1.8 ± 1.6	2.5 ± 1.4	1.617	0.202	0.116
Fibre intake								
g	21.1 ± 10.0	26.4 ± 13.6	18.5 ± 5.6	20.5 ± 6.2	14.7 ± 3.4	3.127	0.037	0.202
g/kg	0.3 ± 0.2	0.5 ± 0.3	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	3.895	0.016	0.240
g from sport foods/supplements	1.0 ± 1.8	1.6 ± 2.4	0.7 ± 1.7	0.3 ± 0.5	1.0 ± 1.6	0.994	0.406	0.075
Vitamin D intake (μg)								
Total	9.3 ± 9.1	10.9 ± 11.5	11.7 ± 10.2	7.5 ± 6.2	5.7 ± 3.3	0.903	0.449	0.068
From supplements	4.4 ± 8.7	5.8 ± 11.4	6.4 ± 9.7	2.4 ± 5.7	1.6 ± 3.1	0.721	0.546	0.055
Iron intake (mg)	12.9 ± 4.5	14.3 ± 3.9	11.2 ± 2.9	14.4 ± 6.7	10.4 ± 2.1	2.326	0.091	0.159
Folate intake (μg)	350 ± 138	386 ± 108	313 ± 158	387 ± 165	278 ± 116	1.578	0.211	0.113
Vitamin B12 intake (μg)	6.2 ± 3.7	7.0 ± 4.1	6.9 ± 5.2	4.8 ± 1.2	5.1 ± 2.0	1.039	0.387	0.078

Data are presented as mean ± SD.
Energy availability (EA) and carbohydrate (CHO) groups: SEA + SCHO, sufficient to optimal EA and sufficient to optimal CHO intake; SEA + LCHO, sufficient to optimal EA and low CHO intake; LEA + SCHO, low EA and sufficient to optimal CHO; LEA + LCHO, low EA and low CHO intake.

TABLE 4 Serum nutrition status.

Dependent variables	EA + CHO groups					Age adjusted ANCOVA		
	ALL $n = 41$	SEA + SCHO $n = 15$	SEA + LCHO $n = 9$	LEA + SCHO $n = 9$	LEA + LCHO $n = 8$	F	*p*-value	ηp^2
25-OH-Vitamin D (nmol/L)	66.3 ± 20.2	70.1 ± 12.9	68.7 ± 25.3	66.2 ± 20.1	56.5 ± 25.7	0.802	0.501	0.063
Vitamin B12 (pmol/L)	481 ± 197	460 ± 187	505 ± 267	505 ± 209	468 ± 131	0.250	0.861	0.020
Fe (µmol/L)	17.1 ± 7.6	18.1 ± 7.7	16.4 ± 9.1	16.3 ± 9.1	16.9 ± 4.7	0.058	0.981	0.005
Ferritin (µg/L)	50.4 ± 32.8	54.5 ± 29.7	54.4 ± 39.5	42.6 ± 35.9	46.9 ± 31.0	0.286	0.835	0.023
TIBC (µmol/L)	59.9 ± 9.4	56.9 ± 8.0	58.8 ± 9.4	64.7 ± 11.5	61.1 ± 8.4	1.318	0.284	0.102
Transferrin saturation (%)	29.9 ± 14.2	32.6 ± 13.8	29.2 ± 18.9	27.2 ± 15.6	28.2 ± 9.2	0.212	0.887	0.018
Calcium (mmol/L)	2.36 ± 0.07	2.35 ± 0.79	2.34 ± 0.06	2.40 ± 0.06	2.34 ± 0.04	1.345	0.275	0.101
Magnesium (mmol/L)	0.84 ± 0.04	0.84 ± 0.05	0.84 ± 0.04	0.84 ± 0.03	0.83 ± 0.05	0.219	0.882	0.018

Fe, iron; TIBC, total iron binding capacity. Energy availability (EA) and carbohydrate (CHO) groups = SEA + SCHO, sufficient to optimal EA and sufficient to optimal CHO intake; SEA + LCHO, sufficient to optimal EA and low CHO intake; LEA + SCHO, low EA and sufficient to optimal CHO; LEA + LCHO, low EA and low CHO intake. Data presented as mean ± SD for each EA + CHO group.

minerals or electrolytes by 11 (26.8%). Iron intake was <15 mg in 78% of all athletes, but supplements with iron were taken by 4 (9.8%). Folate intake was <300 µg in 46.3% of all. None had low intakes of vitamin B12.

In total, 32 (78%) athletes used protein supplements and/or protein-enriched products. Of them, 27 (65.9%) used protein-enriched dairy or ready to serve protein drinks, 13 (31.7%) used protein powders, and 21 (51.2%) used protein bars or snacks. The average protein intake of those who used protein products was 1.7 g/kg (range 1.0–3.1) compared to 1.3 g/kg (range 0.8–1.8) for those who did not ($p = 0.019$). The use of energy drinks and/or pre-workout products was reported by 14 (34.1%) athletes, exogenous CHO, such as sport drinks, gels, and bars, by 10 (24.4%) and ergogenic aids such as creatine by 4 (9.8%). The contribution of sport foods and supplements to the total protein intake ranged between 12% in the LEA + SCHO group and 19.7% in the SEA + LCHO group. Similarly, sport foods and supplements contributed 2.9 (LEA + SCHO) to 8.0% (SEA + LCHO) to the total CHO intake.

3.3 Serum nutrition status

Between-group differences were not observed for nutrition status (Table 4). None of the SEA + SCHO athletes had vitamin D deficiency or insufficiency, but one in the LEA + LCHO group was deficient (<30 nmol/L) and three were insufficient (<50 nmol/L). Moreover, three athletes in the LEA + SCHO group and two in the SEA + LCHO group were deficient in vitamin D. Of all participants, 31 (75.6%) had vitamin D concentrations below the frequently used cutoff for insufficiency in athletes, i.e., 80 nmol/L. No apparent differences were found in vitamin D status between those who used vitamin D supplements and those who did not (66.7 ± 21.7 vs. 65.3 ± 16.9 nmol/L, $p = 0.838$). Ferritin was below reference for age in five (12.2%) participants, and was accompanied by low iron and/or high TIBC in four. In addition, six athletes had low levels of iron only, of which four were normally menstruating. Of those five with low ferritin, three were normally menstruating. TSAT was <20% in 10 athletes, with no apparent group differences. No athlete was deficient in vitamin B12, magnesium, and calcium.

3.4 Self-reported symptoms of LEA

3.4.1 Low Energy Availability Questionnaire

The median LEAF-Q total score for all athletes was 6 (IQR: 4–10) with 41.5% scoring above the cutoff (≥8). Moreover, 58.5% scored above the injury (≥2), 43.9% above the gastrointestinal cutoff (≥2) and 26.8% above the menstrual score (≥4) cutoffs, with no apparent differences between EA + CHO groups (Pearson's chi-square $p > 0.05$ for all). All 7 athletes with menstrual disturbances scored above the menstrual cutoff, and so did 2 out of the 12 contraceptive users.

ANOVA and the Kruskal–Wallis test showed the differences between EA + CHO groups in calculated LEAM-Q-derived sleep, recovery, and energy levels scores (Table 5). Pairwise Bonferroni *post-hoc* tests revealed that LEA + LCHO had higher median sleep scores ($r = 0.50$, $p = 0.007$) and higher mean energy level scores [MD = 3.2 (0.5–5.9), $p = 0.013$] compared to SEA + SCHO. Both LEA + LCHO and LEA + SCHO had higher recovery scores compared to SEA + SCHO ($r = 0.43$, $p = 0.030$; and $r = 0.51$, $p = 0.007$, respectively).

3.4.2 Disordered eating, compulsive exercise, and muscle dysmorphia

Between-group differences were observed for the median EDE-QS score (Kruskal–Wallis H = 11.469, $p = 0.009$), with the LEA + LCHO scoring higher compared to SEA + SCHO (Figure 2). In contrast, EAI and MDDI scores did not differ significantly between groups.

Of the participants, three (7.3%) reached the EDE-QS, five (12.2%) the EAI, and four (9.8%) the MDDI cutoff. Two LEA + LCHO athletes reached the EDE-QS and MDDI cutoffs, and one of them was also considered at risk of compulsive exercise, according to the EAI. Both those athletes had menstrual disturbances. One athlete in the SEA + LCHO group exceeded the EDE-QS cutoff only and had menstrual disturbances. Two athletes (SEA + LCHO and SEA + SCHO) scored above the MDDI cutoff only; of them, one had menstrual disturbances and one was using hormonal contraceptives. Four athletes scored above the EAI cutoff only (LEA + SCHO $n = 2$, SEA + SCHO $n = 1$, SEA + LCHO $n = 1$); of them, one had menstrual disturbances and one was a contraceptive user.

TABLE 5 Between-group comparison of LEAF-Q- and LEAM-Q-derived scores.

	EA + CHO groups				Kruskal–Wallis/ANOVA	
Questionnaire measures	SEA + SCHO *n* = 15	SEA + LCHO *n* = 9	LEA + SCHO *n* = 9	LEA + LCHO *n* = 8	H	*p*-value
LEAF-Q total	6.0 (3.0–12.0)	7.0 (3.0–9.5)	5.0 (3.0–8.0)	9.0 (6.0–14.3)	4.650	0.199
LEAF-Q injury	0.0 (0.0–5.0)	2.0 (0.0–3.5)	2.0 (0.0–4.0)	2.5 (0.5–3.8)	0.476	0.924
LEAF-Q gastro-intestinal	2.0 (1.0–3.0)	2.0 (1.0–3.0)	1.0 (1.0–2.0)	3.0 (1.5–5.5)	6.866	0.076
LEAF-Q menstrual	2.5 (0.0–4.0)	2.0 (0.5–3.0)	1.0 (0.5–3.0)	3.0 (0.5–7.8)	1.970	0.579
Dizziness[a]	1.0 (0.0–3.0)	2.0 (0.5–3.0)	1.0 (0.5–3.5)	2.0 (1.3–3.0)	3.488	0.322
Thermoregulation[a]	1.0 (0.0–2.0)	1.0 (0.0–2.0)	2.0 (1.0–4.5)	3.5 (1.3–5.8)	7.829	0.050
Sleep[a]	1.0 (1.0–4.0)	5.0 (1.0–6.0)	5.0 (2.0–7.5)	6.5 (3.3–10.8)	12.012	0.007
Recovery[a]	2.0 (1.0–4.0)	4.0 (1.5–5.0)	5.0 (4.0–7.0)	5.0 (4.0–5.0)	13.830	0.003
					F	*p*-value
Fatigue[a]	3.8 ± 2.6	6.2 ± 4.3	6.2 ± 3.9	7.9 ± 3.4	2.687	0.060
Fitness[a]	4.7 ± 3.3	5.8 ± 3.0	6.9 ± 5.0	7.9 ± 3.2	1.548	0.218
Energy levels[a]	1.9 ± 2.0	4.2 ± 1.7	4.3 ± 3.2	5.1 ± 1.8	4.600	0.008

Energy availability (EA) and carbohydrate (CHO) groups = SEA + SCHO, sufficient to optimal EA and sufficient to optimal CHO intake; SEA + LCHO, sufficient to optimal EA and low CHO intake; LEA + SCHO, low EA and sufficient to optimal CHO; LEA + LCHO, low EA and low CHO intake.

[a]Data presented as median (interquartile range, p25–p75) for nonparametric and mean ± SD for parametric measures. LEAF-Q, Low Energy Availability in Females Questionnaire; scores derived from LEAM-Q, Low Energy Availability in Males Questionnaire.

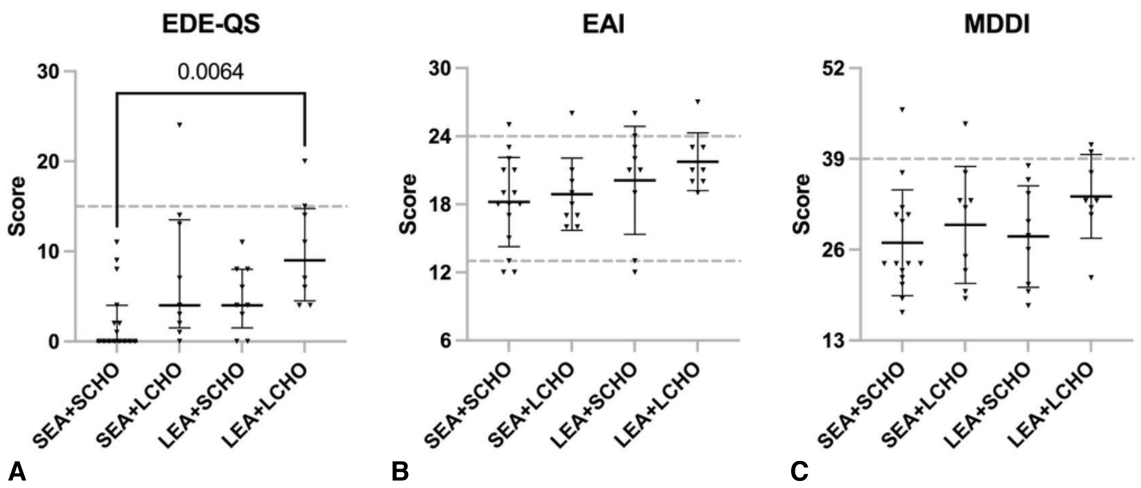

FIGURE 2
Scores on (A) Eating Disorder Examination - Questionnaire Short (EDE-QS, median with 25p–75p interquartile range), (B) Exercise Addiction Inventory (EAI, mean ± SD), and (C) Muscle Dysmorphic Disorder Inventory (MDDI, mean ± SD) for the four energy availability (EA) and carbohydrate (CHO) groups = SEA + SCHO, sufficient to optimal EA and sufficient to optimal CHO intake; SEA + LCHO, sufficient to optimal EA and low CHO intake; LEA + SCHO, low EA and sufficient to optimal CHO; LEA + LCHO, low EA and low CHO intake. The EDE-QS cut-off score is ≥15; *the EAI cut-off is ≥24 while scores between 13 and 23 indicate some symptoms and 6 and 12 no symptoms; the MDDI cut-off is ≥39.*

4 Discussion

The aim of the present study was to compare dietary intake, nutrition status, and occurrence of REDs (problematic LEA) symptoms between groups of female athletes displaying different patterns of EA and CHO intake in real-life situations. The findings suggest that athletes with patterns of LEA and LCHO are at greater risk of developing REDs than the other three groups.

Moreover, low CHO intakes were often accompanied by low intakes of other macro- and micronutrients that are essential for exercise capacity, training adaptation, and overall health.

4.1 Within-group characteristics

Approximately 60% of participants in this study came from ball and endurance sports, with the latter sport group often referred to as being at high-risk of REDs and disordered eating due to pressure to be thin or beliefs that a lower body weight leads to better performances (4, 51). Interestingly, 70% of the endurance athletes had both sufficient to optimal EA and CHO, compared to one-third of the ball sport athletes. Moreover, 50% of the athletes with LEA + LCHO patterns were ball sport athletes. The lower number of athletes from the three other sport groups challenge further investigation of sport-specific risk. Yet our findings support that occurrence of REDs is not limited to certain types of sports; moreover, that individual characteristics and various external factors appear to have a bigger impact than type or nature of the training *per se*. What eventually dictates the onset of REDs is insufficient energy intake in relation to training demands (4, 52). Indeed, the training characteristics of participants varied substantially, with the highest number of training hours reported by aesthetic athletes and the lowest by ball and weight-class athletes. Therefore, it appears that the relatively high occurrence of LEA + LCHO in the ball and power sports is not explained by greater training demands or EEE, but rather reasons such as unawareness of energy/nutrition requirements or dietary restrictions (53). In comparison, five out of nine LEA + SCHO athletes were from aesthetic and endurance sports where EEE is often very high. Accordingly, Melin et al. (54) reported a 7-day average EEE of 1,222 kcal and total EE of 3,266 kcal in endurance athletes displaying LEA. Moreover, Brown et al. (55) reported a 7-day average total EE of ∼2,800 kcal and EA of 26 kcal/kg FFM in pre-professional female dancers.

Nutrition periodisation, characterised by adaptable LEA and CHO intakes tailored to the demands of training, is a common practice in endurance and other sports (20, 21). While athletes were not asked if they periodised their nutrition or were following a specific diet, such approaches were likely adhered to by some of the LEA + SCHO athletes. Athletes with high EEE and long training days may also have prioritised CHO intake, while challenged by limited eating opportunities and/or inability to fulfil total energy requirements (51).

Body composition, primarily body fat percentage, differed between the EA + CHO groups. More specifically, the SEA + LCHO group had higher body fat levels compared to the LEA + SCHO and SEA + SCHO groups but not the LEA + LCHO group. However, the cross-sectional nature of this study limits the possibility to investigate potential causal relationships of this finding with REDs. Sport-specific training adaptations and physiological demands, genetics and a plethora of individual factors influence adiposity (56). Theoretically, the observed group differences in body fat levels could be rooted in energy conservation, including reduction in energy metabolism in response to prolonged or repeated LEA and/or LCHO exposure (57). In contrast, no differences were seen for RMR and whole-body BMD.

4.2 Energy availability and dietary intake

This study built on the assumption that more frequent exposure to LEA and LCHO could better predict the risk of problematic LEA compared to calculated averages alone (22).

For all participants, the average CHO intake was marginally higher than the 3.0 g/kg BW cutoff used for the categorisation but varied considerably between days for many. Indeed, CHO requirements are subject to change based on training demands and it is of great importance for athletes to be aware of it and ensure that CHO intake is sufficient for the work required (58). Low or restricted intakes of CHO also increase the likelihood of insufficient intakes of other essential nutrients as well. Nutrients work in synergy to support metabolism and other body functions, and any modifications of athletes' diet must therefore be well considered to avoid nutrient inadequacies or deficiencies (19). Current sport-specific nutrition recommendations for protein are 1.2–2.0 g/kg BW (59, 60). The average protein intake of all athletes in the two SCHO groups exceeded 1.0 g/kg BW while there were a few cases with average intakes <1.0 g/kg BW in both LCHO groups. Thus, exposure to LEA and LCHO appears to modulate protein intake, which may consequentially result in missed opportunities for recovery and training adaptations (59, 60). No group differences were found in energy and macronutrient intakes from sport foods and supplements, which suggests that such products were often used to compensate low dietary intakes or seen as a convenient solution. In accordance, poor diet is among potential reasons for using supplements, with ∼30% of track and field athletes reporting this reason (61). Moreover, dietary restrictions seemed to be primarily focused on food sources but not sport foods and supplements, perhaps due to beliefs that the latter is healthier and/or provides athletic advantages (31). In agreement with the literature (62), vitamin D and iron intakes were below the recommended intakes for the majority of all athletes, and this points towards important room for improvement in favour of bone health and wellbeing.

4.3 Nutrition status

The IOC has listed adequate vitamin D status (>30 ng/mL/∼80 nmol/L) as critical, especially for athletes at risk and/or those recovering from REDs, for the sake of bone health and reduced risk of bone stress injuries (4). The role of vitamin D in skeletal muscle function and sport performance has also been highlighted (63). Of all participants, only 25% reached adequate intake levels for athletes. Moreover, half of the LEA + LCHO athletes had vitamin D insufficiency or deficiency (<50 nmol/L) compared to none of SEA + SCHO. Measurements in this study were conducted at one time point between April and September, with majority of the females in the larger research project measured in the spring/early summer (April–June). In Iceland and the other Nordic countries, it is recommended to supplement vitamin D, especially in the wintertime (40). It is thus possible that those who took vitamin D supplements in the wintertime had recently stopped or taken a break from supplementation in the springtime. That could indeed explain why those who currently took vitamin D supplements did not have higher serum concentrations compared to those who did not report current use. Moreover, seasonal variation in vitamin D status among elite athletes has been reported in the literature, with highest levels measured in the late summer but lowest in late winter (64). Therefore, and given that many barely exceeded 50 nmol/L, it is possible that the incidence of deficiency for vitamin D would have been different if measurements had been taken at other seasons. Accordingly, major determinants of vitamin D status are sun exposure, supplementation and regular intake of foods high in vitamin D (40). Although between EA + CHO group differences were not significant, low levels in the LEA + LCHO group spark a special worry in terms of long-term bone health. Moreover, based on the presented data, many of the participating athletes would benefit from yearlong vitamin D supplementation.

It has been suggested that suboptimal iron status can be either a cause or consequence of REDs, although this remains to be supported by more robust scientific evidence (65).

The present study found no group differences for any of the iron markers. The design of this study, and the fact that it includes females with variable menstrual function, does not allow for deep evaluation of the interrelations between iron status and occurrence of REDs. However, the findings point out that potential relationships (or lack thereof) of iron metabolism with REDs are likely complicated by menstrual characteristics and/or use of contraceptives in females. Accordingly, low iron and ferritin levels were predominantly found in normally menstruating females. It has been well established that menstruation is a primary non-exercise-related cause of iron loss in females, and therefore ferritin levels are commonly lower in females than males (66). Moreover, exercise-related factors, such as haemolysis, haematuria, and gastrointestinal bleeding, contribute towards increased blood loss, while elevated post-exercise hepcidin levels potentially impair iron absorption from meals consumed soon after exercise (67). Whether iron status is directly linked to REDs or not, it holds a key role in oxygen transport, fuel utilisation, and other key functions, and is therefore extremely important for athletic performance. Moreover, co-occurrence of problematic LEA and iron deficiency can make a bad situation considerably worse (68).

4.4 Self-reported symptoms of LEA

4.4.1 Low Energy Availability Questionnaire

Despite a tendency towards highest total LEAF-Q score in the LEA + LCHO group, no differences were observed in any of the LEAF-Q scores between EA + CHO groups. The most likely explanation of this is that the LEAF-Q was initially designed and validated for use in female endurance athletes (27) and does not account for between-sport differences in injury risk and physiological demands. Moreover, contraceptive use limits the utility of the menstrual subscale (69, 70). The LEAF-Q does, however, allow for determination of menstrual function and use of contraceptives (45), as was done in this study, and appears suitable to define those at low or no risk of REDs (69). The only athlete who reported current amenorrhoea was in the LEA + LCHO group, while the remaining six athletes with menstrual disturbances reported oligomenorrhea. Menstrual disturbances, amenorrhoea especially, are a red flag for REDs in females (4); however, apart from pregnancy and contraceptive use, other possible reasons for disturbances could not be ruled out based on the collected data. We do, however, echo the importance of interpreting LEAF-Q outcomes in relation to sport-specific factors and use of contraceptives (27, 69, 70).

Observed group differences in response to many of the LEAM-Q-derived items indicate that problematic LEA is reflected in self-reported outcomes, such as sleep, recovery, training readiness, and general energy levels. LEA + LCHO athletes rated their sleep and energy levels as worse and were less ready to perform during training sessions than SEA + SCHO athletes. Moreover, both LEA groups rated their recovery as worse compared to the SEA + SCHO group, with large effect sizes. That is in agreement with reports from qualitative investigations based on in-depth interviews with female athletes (71). To the best of our knowledge, this is the first study to evaluate scoring on the LEAM-Q-derived items in relation to EA assessments. In the initial LEAM-Q validation attempt in males (46), scoring on the LEAM-Q was validated against objective physiological measures but not calculated EA. Although further research on the validity of these aspects when screening for REDs in male and female athletes alike is warranted, the presented findings provide insight on potential subjective outcomes to look for when screening for REDs in female athletes.

4.4.2 Disordered eating, compulsive exercise, and muscle dysmorphia

Previously, we have reported associations of self-reported disordered eating, compulsive exercise, and muscle dysmorphia with symptoms of REDs in male and female athletes (26). In accordance, here the LEA + LCHO group scored highest on the EDE-QS, with two out of nine exceeding the questionnaire cutoff. Those two also exceeded the MDDI cutoff, and one of them was also considered at risk of compulsive exercise according to EAI. One athlete in the SEA + LCHO group scored above the EDE-QS cutoff compared to none from the two SCHO groups.

Accordingly, disordered eating and eating disorders are generally considered a special risk factor of REDs (4), and CHO avoidance is among the potential symptoms of disordered eating (72). Although between-group differences were only observed for EDE-QS scores, there are indications that multifactorial body image concerns and disordered eating behaviours are among external modulators of energy availability. Moreover, as outlined previously (26), the drive for thinness and aesthetic physique are not mutually exclusive. Our results are also in agreement with studies reporting that the association of compulsive exercise with REDs is diminished by the absence of disordered or otherwise insufficient eating habits (73).

4.5 Limitations

The present study has some limitations. First, due to its explorative nature, it should first and foremost be regarded as a step towards further understanding of the intersection between adaptable and problematic LEA. Therefore, a larger and/or better controlled study (e.g., in terms of sport groups) with other outcomes, such as site-specific bone mineral density (i.e., not only whole body) and the primary REDs indicators recently suggested by the IOC (4, 36), could have resulted in somewhat different or more comprehensive findings. It should be acknowledged that some errors in evaluating dietary intake and energy expenditure are inevitable. However, we strived to limit such errors by using a photo-assisted mobile application that was specially tailored for the convenient reporting of dietary intake and training. Accordingly, it has been suggested that the replacement of traditional approaches with digital applications may reduce chances of dietary intake misreporting and even, importantly, reduce participant burden (74). We had one-on-

one discussions with each athlete to ensure they were fully informed about the aims of this reporting, and the importance of not making changes to their routines due to participation in the study. It must also be clearly stated that MET scores do not provide precise individualised estimates of EEE, as they were primarily designed for the standardisation of physical activity intensities (42). Extracting measured but not estimated RMR from total energy expenditure to yield energy cost of exercise alone, as was done for most participants in this study, partly compensates for this limitation (75). Also important is that coding, calculations, and cleansing of nutrition and training data were performed by well-trained experts who each had their separate task in the process. Therefore, any potential errors should apply to estimations for all participants, which allows for reliable comparisons. Seven days is only a snapshot of the individuals' life and does not provide information on potential variations between weeks, months, or training periods. That, in addition to the study design, does not allow for any conclusions on causality. Finally, selection bias and other considerations for the greater research project have been addressed elsewhere (26).

5 Conclusion

The findings suggest that patterns of low energy availability and low carbohydrate intakes increase the risk of REDs in female athletes. Moreover, that athletes displaying such patterns also have insufficient intakes of other macro- and micronutrients to support health and performance. The highest occurrence of apparently intentional causes of problematic LEA, such as dietary restrictions and disordered eating, but not greatest training demands, was observed among LEA + LCHO athletes. Contrarily, some LEA + SCHO cases might predominantly relate to unintentional mismatch between energy intake and high energy expenditure. Larger studies, powered to identify true statistical and clinically important differences and including evaluation of primary indicators of problematic LEA, are needed to confirm the findings. While occasional LEA and LCHO exposure is unlikely to be harmful and can potentially stimulate training adaptations, repeated exposures to LEA and LCHO should be avoided as they are associated with a cluster of negative implications in female athletes.

Data availability statement

The data relevant to this study is included in the article and/or supplemental material. Requests to access the datasets should be directed to the corresponding author: biva@hi.is.

Ethics statement

The studies involving humans were approved by the Icelandic Ethics Committee (VSNb2021050006/03.01). The studies were conducted in accordance with the local legislation and institutional requirements. All participants and parents/legal guardians of those under 18 years of age provided written informed consent prior to participation.

Author contributions

BV: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing. SG: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. ET: Software, Writing – review & editing. AO: Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2024.1390558/full#supplementary-material

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Menstrual cycle tracking in professional volleyball athletes

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Introduction: The menstrual cycle may affect well-being and physical performance of elite female athletes by interfering with the function of multiple physiological systems. The aim of this study was to characterize the symptoms of the menstrual cycle and their frequency in elite female volleyball players.
Methods: Twenty professional female volleyball players were instructed to track their menstrual symptoms over the course of the first German national league season using the FitrWoman® tracking app. The app recorded the cycle length, duration, and intensity of the period as well as the occurrence and frequency of frequent cycle symptoms. The reported symptoms were then categorized into four categories (frequently, sometimes, rare, never) in order to create an individual Menstrual Symptom index (MSi) for each athlete.
Results: The most frequently occurring symptoms among all players without hormonal contraception (non-HC; $n = 15$) were "stomach cramps" ($n = 15$), "sleep disturbances" ($n = 11$), and "tiredness" ($n = 11$). The average number of symptoms counted per cycle was 11.8 (±17.7) and the average calculated MSi within the team was 12.9 (±10.7) points for non-HC users. The HC players ($n = 4$) also regularly experienced symptoms such as "sleep disturbances" or "tendered breasts". The most common symptoms "stomach cramps" and "disturbed sleep" occurred more frequently during menstruation, while symptoms such as "bloating", "cravings" or "tendered breasts" did also peak before menstruation.
Discussion: Menstrual cycle symptoms can be highly individual within a professional sports team. The calculation of the MSi seems to be a simple and accessible method to describe and overview the intensity and prevalence of symptoms in top female athletes in sports games.

KEYWORDS
menstrual cycle, volleyball, well-being, elite athletes, symptoms

1 Introduction

In the last few years, attention towards the menstrual cycle and how it possibly influences performance and well-being in elite female sports has rapidly increased (1). The menstrual cycle represents a biological rhythm, which primarily regulates female reproductive function and is traditionally divided into phases based on hormonal fluctuations (2). Mechanisms underlying hormonal fluctuations are also believed to be the cause of regularly appearing symptoms (3), often referred as menstrual cycle symptoms (MCS) (4). A systematic review by Taim and colleagues shows a high variation in prevalence of different symptoms among athletes. For example, "abdominal cramps" is reported by between 47.5% and 70.0% of athletes during the premenstrual and menstruation phases in different studies (5). MCS are believed to have a negative impact on athletes' perceived performance (6, 7). Antero et al. found a negative correlation between the presence of MCS and the perceived performance of elite athletes (6), while in another study involving Australian elite athletes, 50.0% reported a negative influence of menstrual cycle phases on their performance during training, which increased to 56.5% for competition days (8). To reduce these irregularities and symptoms during the menstrual cycle, hormonal contraceptives (HC) are often prescribed (9, 10). But also women using HC experience recurring symptoms, despite not having a natural menstrual cycle (6, 9, 10). Most athletes with a natural cycle report the highest prevalence and influence of symptoms during the premenstrual and menstruation phases (3, 6, 8, 10). A higher prevalence of symptoms before menstruation can be associated with the premenstrual syndrome (PMS), which is characterized by a combination of physical and psychological symptoms before the onset of menstruation and during menstruation. These symptoms include "depressed mood", "anxiety or tension", "irritability", and "lack of energy" among others (11). In a non-athlete population, prevalence of PMS in studies ranges from 32.6% to 62.9% and seems to be dependent on the country in which the study was performed (12). For an athlete population, Taim et al. show a prevalence of PMS between 8.6% and 59.6% across seven studies (5). The high variations in prevalence could also be due to the different definitions used for PMS (5). For professional athletes, PMS is more likely to influence performance compared to non-professional athletes (13). Another risk factor for reduced performance due to PMS is the presence of the symptoms "difficulty in concentration" or "fatigue/lack of energy" (13). Even though studies report a decreased perceived performance mostly in the premenstrual or menstruation phase (6, 8), objective data regarding performance fluctuations during menstrual cycle remains equivocal (14). Nevertheless, MCS are an important factor in athletes' well-being and perceived performance. Tracking menstrual cycle could help coaches access important information about their athletes if desired. However, integrating menstrual cycle considerations into practice and lifestyle can be challenging. Alongside to limitations in resources and knowledge, there is a high degree of intra- and inter-individual variability in menstrual cycle parameters. Adapting strategies can be even more challenging considering menstrual cycle disturbances which are more prevalent in elite athletes (5, 15, 16). Athletes in general have a higher risk of experiencing anovulatory cycles and menstrual disturbances, including oligomenorrhea, luteal phase defects, primary and secondary amenorrhea among others (5, 17, 18). This could be due to high levels of stress and excessive exercise in combination with restricted diet (19, 20), leading to a low energy availability (LEA) (21). Further research is needed to explore effective strategies for prevention and management, including communication with coaches and other team members, since many athletes report a lack of structured communication, fundamental knowledge, and the feeling that their coaches would not understand them when talking about menstrual cycle (22–25). Hence, menstrual cycle still appears to be a taboo topic. While menstrual cycle tracking provides valuable insights, its utility may be limited due to the necessity of accurately determining menstrual phases, which requires consideration of hormonal fluctuations and other physiological factors (26, 27). This is not always feasible in training environment due to financial and methodological constraints. Julian and Sargent suggest that using both menstruation diaries and well-being tracking measures together may provide a useful tool for predicting individual athletes' menstrual phases and cycle duration in a training environment while minimizing individual effort (16). Bruinvels et al. introduced a method to quantify prevalence and occurrence of symptoms in a single value called Menstrual Symptom index (MSi) which includes both frequency and number of symptoms (4). This measure could help to assess the impact of MCS in a sports team and to quickly screen a team for potential need for interventions (4). There is still a notable gap in available data concerning the variability of symptoms and comprehensive tracking information among an entire professional female sports team. Therefore, the present study aimed to examine the monthly recurring symptoms of an elite female volleyball team over four to twenty months via, among others, the MSi introduced by Bruinvels et al. (4).

2 Materials and methods

2.1 Study design

An observational design was used to obtain an overview of the variety of MCS of an elite female volleyball team. Data on the timing of menstrual bleeding and occurring symptoms were collected during the 2019/2020 and 2020/2021 competitive seasons. Players using HC also reported symptoms and their data regarding withdrawal bleeding as, even though they do not have a natural cycle, we expected them not to be free from recurring symptoms (6, 9, 10).

2.2 Participants

Twenty elite female volleyball athletes between 19.2 and 27.7 years (age 24.5 ± 2.0 years; BMI 22.8 ± 1.6 kg/m^2) from the first German national league participated in the study. Not all athletes were tracked for the same period due to changes in the team setup, e.g., when the player's club contract ended. For example, athlete VB05 was tracked for 20 months whereas athlete VB10 was tracked for nine months. The exact participation durations and the corresponding numbers of cycles between two bleedings can be found in Table 1. One athlete (VB18) was excluded from all symptom-based descriptions because she did not report at least one complete cycle during her measurement period.

Moreover, four athletes were using different HC. VB01 was using a vaginal ring, VB03 used a hormonal intra-uterine device (IUD), while VB08 and VB11 were both using a combined oral contraceptive pill (Maxime and Cedia20, respectively). Although HC users do not have a biological menstruation, all athletes were asked to report recurring symptoms and data regarding the withdrawal bleeding in order to explore the scope of symptoms in a representative athlete population.

The players gave their informed consent before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki and the protocol was approved by the local Ethics Committee (2021-30, 28 June 2021).

2.3 Tracking tool

The data was assembled through an application called FitrWoman® (28), which has been used in previous studies to track the menstrual cycle (4, 24, 29). The app includes a calendar that gives an overview of the previous and current cycle phase. Below the calendar view, athletes can directly log bleeding intensities (including none, spotting, light, medium, heavy). Moreover, the athletes can track their symptoms in the app by choosing symptoms out of a selection of eighteen MCS ("stomach cramps", "fatigue", "bloating", "muscle ache", "heavy legs", "disturbed sleep", "cravings", "tendered breasts", "headache", "diarrhea", "stressed", "irritability", "weak", "high temperature", "poor concentration", "constipation", "increased breathing", and "nausea"). In addition, there is also a "notes" section to track symptoms that are not listed within the app or to write comments about special events. Participants were instructed to fill out the report every evening before sleeping, providing information on the occurrence of every symptom experienced—independently of the menstruation phase—as well as data regarding menstruation and for athletes using HC reporting data with respect to withdrawal bleeding.

By tracking the exact days of menstruation of each athlete for at least four months, the approximation of the participant's individual cycle occurrence were calculated (30, 31). "Phase 1" represents the duration of the menstruation bleeding and is, therefore, called "menstruation". "Phase 2" lasts from the end of menstruation until the individual's middle of the cycle (calculated ovulation) and is labeled "follicular phase". "Phase 3" counts the days from the middle point of the individual cycle to the start of the next menstrual bleeding, representing "luteal phase". In order to classify symptoms further, in this study a fourth phase ("late luteal phase") was additionally calculated, referring to the last five days of a cycle similarly to Solli et al. (3). As athletes using HC do not experience a natural menstrual cycle, no menstrual phases were calculated for this group.

2.4 Menstrual Symptom index (MSi)

The symptom data were classified according to a classification system suggested by Bruinvels et al. (4). The symptoms of every individual cycle were listed and categorized into four categories based on the frequency: "often" if the symptom appeared in every menstrual cycle (3 points), "sometimes" if the symptom appeared in every second cycle (2 points), "rare" if the symptom appeared in less than every second cycle (1 point), and "never" (0 points). The points of every symptom were summarized, resulting in a score ranging from zero points (all symptoms "never") to a maximum score of 54 points (every symptom "often"). In this study, there were no additional symptoms which were entered manually through the comment section.

For athletes using HC, an equivalent calculation was performed based on data regarding withdrawal bleeding. The MSi has been developed for eumenorrheic athletes only and should therefore not be used for athletes on HC. Nevertheless, since current research shows, that HC users are not free from symptoms (6, 9, 10), in this study a similar calculation was performed for athletes on HC to describe all athletes of the team in a comparable manner.

2.5 Statistical analysis

All data is provided on the descriptive level showing mean values (*M*) with standard deviations (*SD*) calculated by using Microsoft Excel (Version 2211). Figures were created using GraphPad Prism (Version 10.1.0). Descriptive values regarding cycle data only includes athletes with a natural cycle, which means excluding VB01, VB03, VB08, and VB11. Additionally, we excluded VB18 for all calculations because no fully reported cycle was available.

3 Results

The athletes' characteristics are presented in Table 1. The counts of noticed symptoms per cycle ranged from 0.3 (±0.6) symptoms to 61.0 (±13.1) symptoms per cycle. On average, athletes reported 10.0 (±15.6) symptoms per cycle. The measured cycles varied in length among the athletes without HC from 64.7 (±21.6) days to the shortest cycle length of 23.0 (±6.0) days (Table 1). The longest menstruation length was 9.8 (±5.8) days. The shortest period length was 2.3 (±1.2) days.

Figure 1 shows the percentage of athletes without HC experiencing the different symptoms for at least once during the measurement period. All athletes experienced "stomach cramps" at least once. "Disturbed sleep" and "fatigue" were reported by 73.3% of all athletes at least once. "Nausea" was the least frequently reported symptom, occurring in only one case.

Additional information is provided in Figure 2 which includes the frequency of the symptoms. The most common symptom, "stomach cramps", was experienced "often" by only one athlete resulting in 5.3% of athletes. "Headache" and "heavy legs", on the other hand, were experienced "often" together in three athletes. Also, all four HC users regularly reported symptoms. VB1 (vaginal ring), VB03 (hormonal coil), and VB08 (oral contraceptive) experienced "tendered breasts" the most, whereas VB11 (oral contraceptive) experienced "fatigue" regularly.

Total reports of symptoms were the highest during the "menstruation" (0.79 symptoms per day) followed by "late luteal phase", "follicular phase", and "luteal phase" (0.08, 0.09, and 0.00 symptoms per day, respectively). Figure 3 shows the absolute number of symptoms among the different cycle phases of

TABLE 1 Participants' demographic and menstrual cycle characteristics.

Athlete	Measurement span (months)	Number of full cycles measured	Contraception	Cycle length (days)	Bleeding length (days)	Symptoms per cycle	MSi	Symptoms occurring often
VB01	16.5	17	Vaginal ring	28.0 ± 1.1	3.5 ± 0.9	3.5 ± 2.2	8	0
VB02	16	17		27.7 ± 11.4	4.7 ± 1.3	0.3 ± 0.6	2	0
VB03	16.5	18	Hormone IUD	27.7 ± 1.8	4.6 ± 1.1	1.9 ± 3.5	9	0
VB04	16.5	18		27.6 ± 2.5	6.8 ± 1.7	14 ± 9.1	22	4
VB05	20	18		31.6 ± 2.9	5.6 ± 1.8	1.5 ± 2.2	5	0
VB06	16	16		29.8 ± 7.3	2.8 ± 1.5	0.1 ± 0.3	1	0
VB07	17	9		53.9 ± 46.7	3.6 ± 0.7	1.0 ± 1.6	8	0
VB08	11	6	OC	53.3 ± 25.7	4.0 ± 1.4	6.7 ± 10.1	9	0
VB09	9.5	9		32.4 ± 13.0	4.9 ± 2.5	6.6 ± 5.8	16	0
VB10	9	10		26.6 ± 2.4	5.0 ± 1.1	2.9 ± 3.2	6	0
VB11	9	6	OC	45.0 ± 22.9	9.8 ± 5.8	10.0 ± 16.2	18	0
VB12	8	7		30.4 ± 1.3	4.8 ± 0.7	7.6 ± 6.8	15	0
VB13	8	8		27.6 ± 6.0	3.9 ± 0.9	28.0 ± 16.4	19	2
VB14	8	5		45.0 ± 33.6	4.7 ± 1.6	1.4 ± 2.0	4	0
VB15	7	3		64.7 ± 21.6	6.3 ± 0.5	61.0 ± 13.1	34	8
VB16	4	3		23.0 ± 6.0	6.0 ± 1.4	39.7 ± 8.5	33	8
VB17	4	2		27.0 ± 2.8	2.3 ± 1.2	1.5 ± 2.1	4	0
VB18	4	0		n/a	1.5 ± 0.7	1.0 ± 0.0	n/a	0
VB19	4	3		26.7 ± 1.2	3.3 ± 1.3	3.7 ± 1.5	6	0
VB20	4	2		35.5 ± 10.6	3.3 ± 2.1	8.0 ± 5.7	18	2
Mean score (M)	10.1	8.4		34.9 ± 11.6	4.6 ± 1.8	10.0 ± 15.6	12.5 ± 9.7	1.1

Team demographics and menstrual cycle characteristics of each female athlete. Cycle length in months, period length, and symptoms per cycle are all shown as mean values with standard deviation. Bleeding length refers to both menstrual and withdrawal phase bleeding. HC, hormonal contraception; MSi, menstrual symptom index; OC, oral contraceptives/contraception; IUD, intra-uterine device.

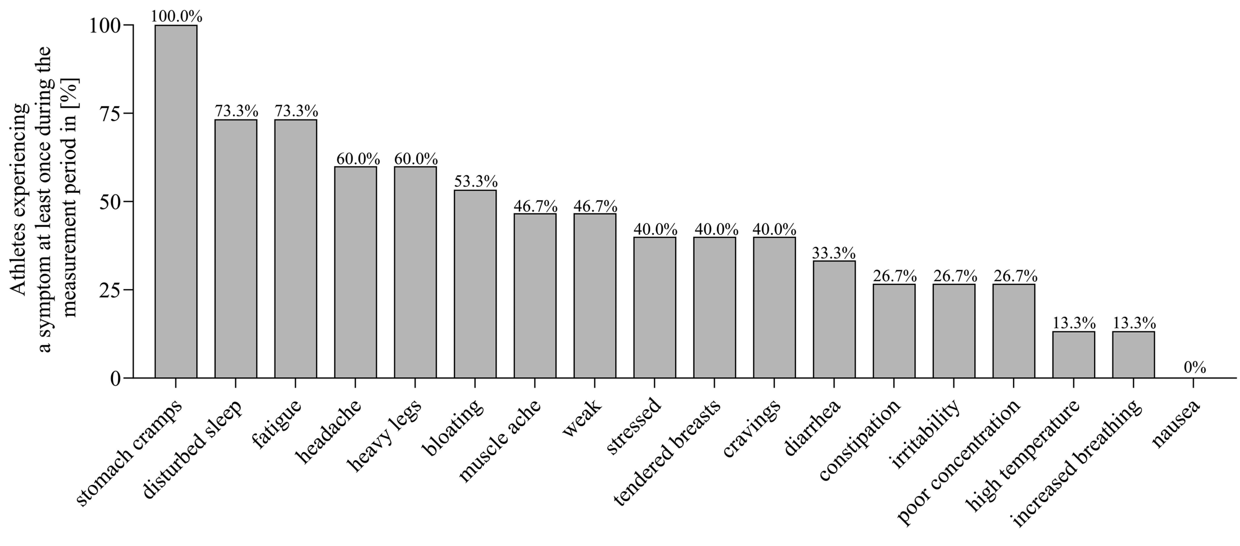

FIGURE 1
Prevalence of symptoms reported at least once during the individual measurement period among all athletes without hormonal contraception.

"menstruation", "follicular phase", "early luteal phase", and "late luteal phase". When considering single symptoms, thirteen out of eighteen symptoms were more frequent during "menstruation".

The mean number of reported symptoms per cycle was 11.8 (±17.7). The lowest MSi score was one point (VB06) and the highest MSi scores were 34 and 33 points (VB15 and VB16, respectively) out of a maximum of 54 points (every symptom often). Figure 4 shows the individual MSi scores for all athletes including non-HC users (mean score 12.5 ± 10.7) and the equivalent calculations for HC users (mean score 11.05 ± 4.7 points).

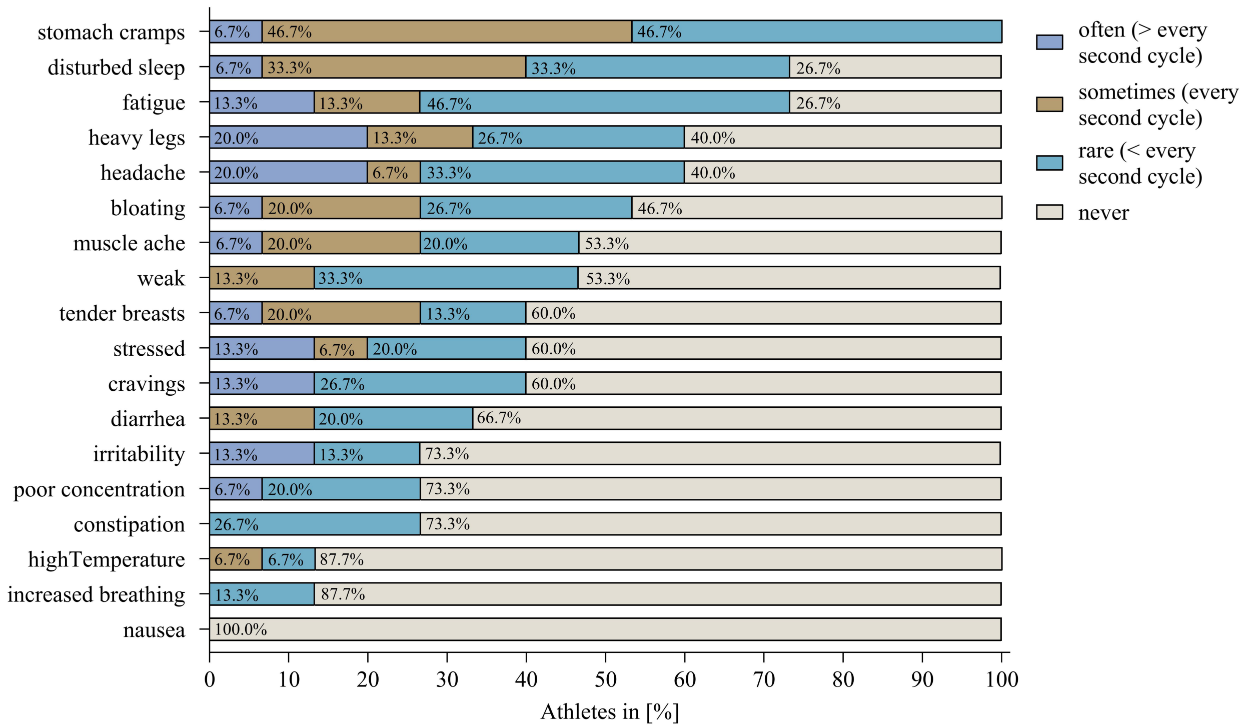

FIGURE 2
The percentage of athletes without hormonal contraception reporting the respective symptom in the frequency categories: “often”, “sometimes”, “rare”, and “never”.

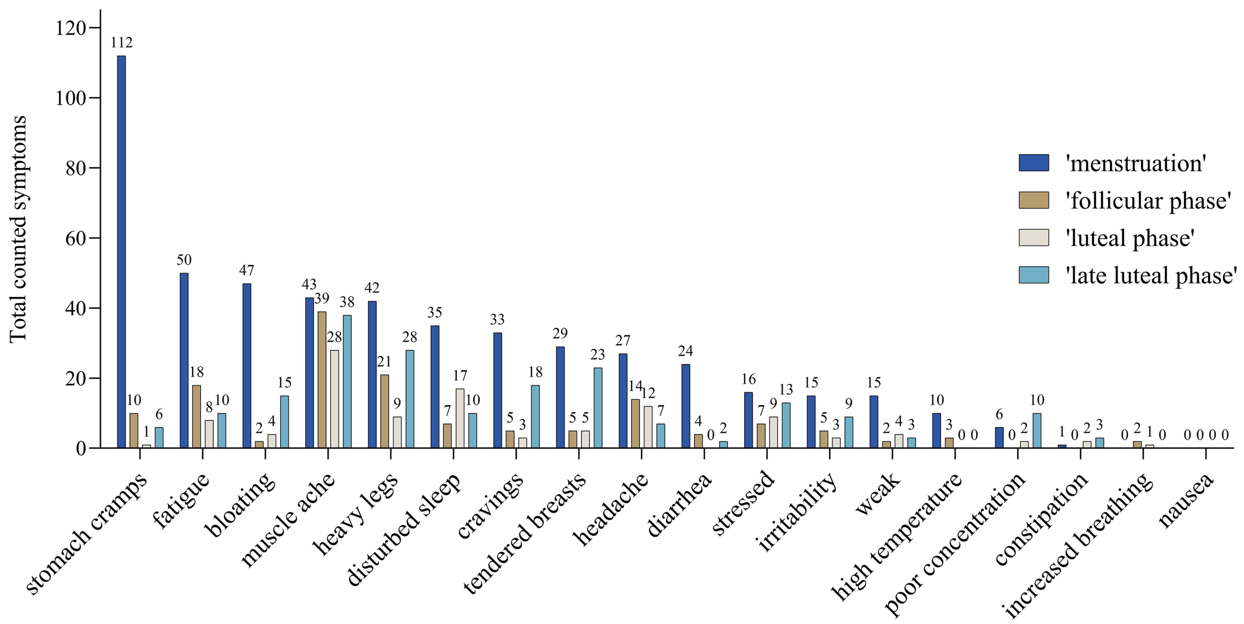

FIGURE 3
Number of counted symptoms of all athletes without hormonal contraception occurring in the different calculated cycle phases: “menstruation” (blue), “follicular phase” (brown), “luteal phase” (grey), and “late luteal phase” (light blue) which refers to the last five days of the cycle. The number, e.g., 47 of the symptom “bloating” refers to 47 reports during menstruation phase.

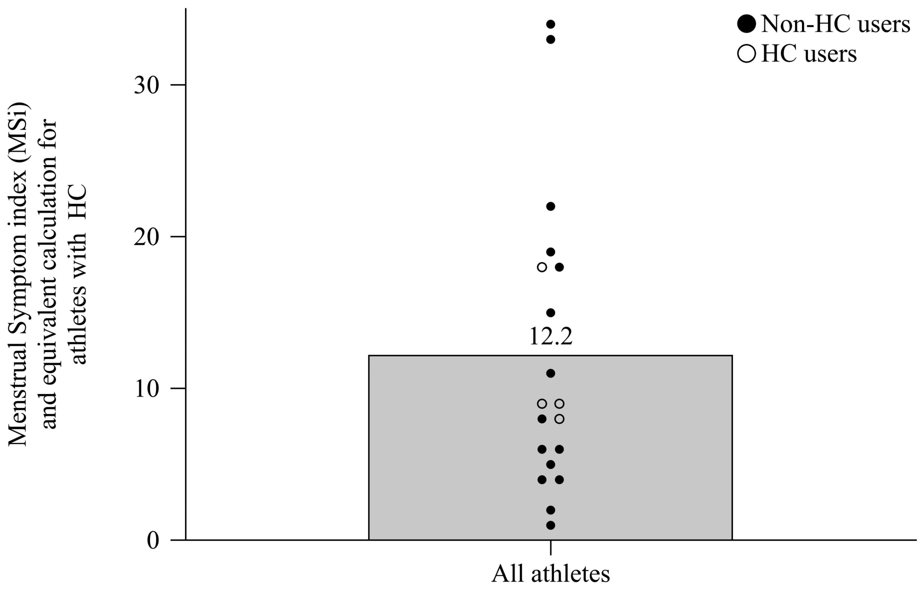

FIGURE 4
The MSi scores from all athletes without hormonal contraception and the equivalent calculation for athletes with hormonal contraception shown as mean and individual scores.

4 Discussion

The aim of the study was to describe an elite volleyball team by their recurring symptoms and their menstruation tracking data. Findings of this study illustrate the diversity of symptoms and menstrual cycle characteristics, e.g., cycle length, among an elite female volleyball team. Variations in symptom recurrence was shown for non-HC users as well as HC users. Out of 18 symptoms, 6 were reported by more than half of all non-HC athletes. The most commonly reported MCS among the team in this study were "stomach cramps", "disturbed sleep", "bloating", "fatigue", and "heavy legs". "Stomach cramps" and "bloating" were predominantly tracked during the menstruation itself. A recent study from Kullik et al. investigates the symptom prevalence in active women and athletes in Germany (32). In their study, the most prevalent symptoms are "cravings/increased appetite", "mood changes/anxiety", and "tiredness/fatigue". This could be because the study includes women with HC. The authors did find a small positive relationship between the use of HC and anxiety as well as with sleep behavior (32). Athletes using HC also experience regular symptoms such as "tendered breasts" and "fatigue", which were both reported by all HC users at least once. This finding supports current research, that shows negative symptoms (e.g., "stomach cramps", "back pain", and "headaches") in both non-HC users and HC users (6, 10, 33).

To overview symptom prevalence and frequency, a quantification method called MSi (minimum 0 points, maximum 54 points) was used. In this study the mean MSi was 12.5 points (±10.7), which is comparable with the mean MSi score from physical active women in the study of Bruinvels et al. (4) reporting 17.9 ± 10.1 points for active German women. A study of Kullik et al. reports a slightly higher MSi of 20.1 ± 10.2 points for active women including athletes in Germany (32). Differences could be due to the investigated population or due to differences in methodology. Kullik et al. (32) included both non-elite and elite athletes with and without HC. Athletes could differ from active women due to the higher load in training and exercise, which may have an impact on the menstrual cycle physiology (20). Additionally, the symptom definition was slightly adapted which could cause differences. Individual data of the MSi shows a high variation. One female athlete experienced a very low MSi score of one point. Nevertheless, there were also two athletes suffering from an MSi score of 33 respectively 34 points out of the maximum 54 points. When carrying out an equivalent calculation for HC users, all four athletes showed at least 8 points, which, again, supports current research (6, 9, 10), that HC users are not free from symptoms. However, due to the low number of athletes using HC in this study, the interpretation of the results is limited. Additionally, in this study there is no information available about the individual history of HC. Some athletes may have started HC to manage symptoms (9, 33). Martin et al. (34) investigated symptoms in both HC and non-HC users and concluded, that HC users are more likely to report positive effects in form of reduced symptoms after starting contraception. Furthermore, we do not know if some of the symptoms reported in this study might also be side-effects of the contraceptive use (4).

By finding a solutional approach for specific recurring symptoms, well-being of athletes might be improved. Around 58% of elite Australian female athletes feel that the menstrual cycle harms their performance (9). In addition, women with a higher number and frequency of symptoms are more likely to miss training or competition (4). By noticing regularities within one athlete regarding the time and occurrence of a symptom, it would be possible to adapt solutional approaches in daily life. For example, a reason for these abdominal symptoms could be that, in this phase, the endometrial lining is shed as menstrual bleeding resulting in discomfort (35). Tsai suggests that a yoga intervention could significantly reduce abdominal swelling, breast tenderness, abdominal cramps, and cold sweats (36). Another approach to minimize "stomach cramps" could be avoiding behaviors that increase inflammatory responses, for example, not drinking alcohol or minimizing the consumption of processed foods in the "late luteal phase", as increased hs-CRP levels can cause premenstrual symptoms (37). By adapting nutrition or supplementing micronutrients, e.g., vitamin D or calcium, PMS might be reduced as well (38–42). In this regard, Farpour et al. demonstrate that PMS symptoms are more pronounced with a diet high in salt and sugar or a Western mixed diet (43). On the other hand, food such as vegetables and a low-fat, high-fiber diet can reduce the duration and intensity of PMS symptoms (37). A recent meta-analysis shows that omega-3 fatty acids were efficient in reducing the severity of PMS-symptoms (44).

Interestingly, studies show, that poor sleep quality is associated with menstrual disturbances such as PMS or dysmenorrhea (45). "Disturbed sleep" also seemed to be one of the most reported symptoms in this study (73.3% of athletes). This finding is in line with the systematic review of Taim et al. where insomnia/hypersomnia is one of the most common affective symptom with a prevalence of 53.3% (46.3–60.3%) in athletes (5). Sleep is important for recovery from the waking period through repair processes and regeneration (46). Therefore, sleep influences sporting performance in direct and indirect ways, e.g., by impacting symptom prevalence, neurophysiology, and cognitive function (47, 48).

In this study, we did not validate menstrual cycle phases, but instead, we performed a calculated approximation to categorize cycle phases in order to put symptoms into a temporal context. In agreement with current research (3, 6, 8, 10), in this study 15 out of 18 symptoms were more common during "menstruation" (0.79 symptoms per day) compared to the calculated "follicular phase" (0.08 symptoms per day), "luteal phase" (0.09 symptoms per day), and "late luteal phase" (0.00 symptoms per day). Having more symptoms during menstruation could mean a greater influence on training, days missing training, and perceived performance compared to other phases with less reported symptoms (49).

In this study, cycle length was calculated by tracking menstrual bleeding of athletes during 4-20 months. A study comparing athletes with non-athletes found a higher incidence of irregular periods and heavy menstrual bleeding in athletes but no significant differences in the gynecological health including, e.g., pelvic pain (11). Although cycle lengths can vary in a normal menstrual cycle, a continuously prolonged menstrual cycle (e.g., longer than 35 days) is called "oligomenorrhea" (27, 50). Compared to a non-exercising population, athletes are more likely to have irregular cycles or menstrual cycle abnormalities (5, 51). Findings of this study illustrate the diversity of symptoms and menstrual cycle characteristics, e.g., cycle length. Out of 20 athletes, only 6 athletes had a natural cycle that was between 25 and 35 days with less than six days of variation during the measurement period. Six athletes reported a mean cycle length of over 35 days. In this study, the high mean values in the cycle length all appear to result from inconsistencies in the individual cycle lengths, e.g., VB07 reported no menstruation for 170 days at one point of the measurement but also had a longer period with cycle length between 25 and 35 days. VB15 was an exception with a consistent, long cycle in general. One athlete (VB18) had no complete cycle over the four-month measurement period at all. The athlete started the measurement at the onset of her menstruation but reported no second menstruation. Therefore, we were not able to calculate cycle length. Irregularities of cycle length in this study could be due to varying workloads during the season. In sports, oligomenorrhea and amenorrhea are often related to relative energy deficiency in sport (RED-S) resulting from a high training load and an insufficient dietary energy intake (21, 51). RED-S is associated with many health risks and with an decrease in performance (52, 53). However, it is possible that athletes do not feel any risk at the moment or are not aware of the consequences due to lack of adequate information, acceptance, and shame (25, 35, 49, 54). Fahrenholtz et al. show improvements of the regularity of menstrual cycle and also in LEA through an education-centered nutrition intervention in female athletes. These results were still visible in a 12 months follow-up (55).

Even though menstrual symptoms have consistently shown to be present in athletes (5), a study from McHaffie et al. (54) shows that coaches are not able to sufficiently notice the athletes' MCS, even though coaches report, that they feel athletes would talk to them if there was a need (54). Communication about menstruation between coaches and athletes still seem to be insufficient (8, 22–25, 56). A reason could be, that some athletes think that their coaches are not sufficiently informed (24) and that they would not be capable of helping them (25, 54). Interestingly, even though most coaches are male (57), studies have shown, that athletes tend to prefer communicating with female coaches (9, 23, 56). Additionally, some studies showed that some athletes feel there is no discrete or easy way to start communication (8). Taim et al. propose to foster a safe space by implementing a structured way of communication (58). Therefore, tracking could be used to get an idea about an athlete's well-being, open communication, and to suggest strategies to improve the athlete's well-being and training capacity. Even though some athletes do not feel that they need more specific support (54), talking about the menstrual cycle and forming an open environment seems to be generally appreciated (25). As this study shows, tracking symptoms can be kept easy and could help to obtain an overview of an athlete's personal experience. Some athletes are influenced more by their MCS than others and, thus, may need more support (54). Using the MSi score (4), medical support staff can get a good general view of their athletes' needs and well-being. The method is easy to integrate into a daily sport's routine and results regarding symptom severity and frequency has been shown to correlate with the risk of missing training or competition (4). By continuously tracking symptoms and evaluating the MSi regularly, symptom management can be controlled and adapted.

This study focused on the variations and fluctuations that a practitioner must take into consideration in a team. This study only included tracking MCS and menstrual bleeding (or withdrawal bleeding for HC users, respectively) for one club. The characteristics of this team may not be indicative of other teams and results may not be applicable for other sport teams. Future studies should investigate multiple teams to facilitate comparative analysis. Additionally, we did not include any influencing factors that may occur in elite sports, e.g., training load or traveling. It would be interesting to explore the factors that might influence cycle irregularities, but also the type or severity of a symptom. This also involves conducting a more comprehensive investigation of athletes using HC. As Bergström et al. showed, some coaches do not know, where to start adapting training strategies to menstrual cycle (22). Getting an overview could be a start and further information could help to implement changes in an athlete's lifestyle to improve their well-being and performance. In addition, tracking menstrual bleeding is not sufficient to measure the exact menstrual phases for the individual athletes. To determine menstrual cycle phases with certainty, it is inevitable to measure hormone concentrations and to determine ovulation (27), which were not conducted in this study. Julian and Sargent recommend using hormonal measurements, temperature measuring, and ovulation kits in research. But due to restricted resources and due to practicability they recommend using diaries and tracking systems in real life training settings (16). However, calculating menstrual cycle phases do not acknowledge the challenges of accurately determine phases. Nevertheless, this study aimed to test and describe a real life setting where hormonal testing is not available. Tracking methods are more accessible, non-invasive, and show a better acceptance among athletes (16).

5 Conclusion

In summary, the MCS and their frequency were found to vary widely between the athletes of an elite female volleyball team. Some of the athletes rarely recognized any symptoms while others suffered a high number of symptoms during their menstrual cycle. In addition, the cycle length varied between the athletes and within the individual athlete even in athletes using HC. By tracking menstrual cycle, athletes can develop personalized healthcare plans to enhance their well-being and comfort. Additionally, coaches can adjust training schedule according to an athletés menstrual cycle to optimize recovery and to support an athlete's well-being, including monitoring their health. Tracking menstrual cycle may also facilitate communication between athletes and sports staff by identifying individual needs for support. Future research should investigate individual solutions for every team athlete, such as management strategies regarding MCS and strategies for improving menstrual health. Therefore, more information is needed about parameters influencing menstrual cycles such as adequate regeneration, load decrement, nutrition, stress management and the use of suitable contraceptives, if desired. Tracking MCS and quantifying them by calculating an MSi score could offer a practical solution for sport practitioners to better understand menstrual cycles of their athletes.

Data availability statement

The original data can be made available on reasonable request. Requests to access the datasets should be directed to Andrea Roffler, roffler@sport.uni-frankfurt.de.

Ethics statement

The studies involving humans were approved by Prof. Dr. Klein, Ethics Board Faculty of Psychology and Sports Sciences, Goethe-University Frankfurt (2021-30). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AR: Data curation, Methodology, Visualization, Writing – original draft. M-TF: Writing – review & editing. HDH: Writing – review & editing. KK: Conceptualization, Data curation, Writing – original draft. KZ: Conceptualization, Data curation, Methodology, Visualization, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

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.

The author(s) declared that they were an editorial board member of Frontiers at the time of submission. This had no impact on the peer review process and the final decision.

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Antecedents and consequences of South African female athletes' trust in the coach

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The purpose of this study was to investigate female South African school athletes' trust in their coaches in relation to their perceptions of the coaches' justice, benevolence, integrity, competence, commitment to coach, willingness to cooperate, and performance. A quantitative cross-sectional research design was used in this study. The results showed that there was a large correlation between trust in the coach and the following factors: perceived justice ($r = .504$, $p < .01$), perceived integrity ($r = .511$, $p < .01$), and perceived competence ($r = .534$, $p < .01$). Furthermore, multiple regression analysis results revealed that perceived justice was the only significant predictor of trust in the coach as it had a higher beta value ($\beta = .17$, $p < .05$) than the other variables. This study shows that coaches should demonstrate fairness in their decision-making by providing players with incentives, opportunities to play, friendly relationships, and places of preference.

KEYWORDS

performance, competence, justice, athletes, coaching

Introduction

The coach–athlete relationship (CAR) has been the subject of significant scholarly interest in the realm of sports coaching (1–3). This could be because the relationship between coaches and their athletes is thought to be the most fundamental structure in sport. Without a coach, an athlete might not be able to perform to the best of their abilities, and the coach exists solely to assist the athlete. Coaches and athletes have close bonds based on communication, reciprocity, and mutual trust (4). Previous research on CAR has revealed that trust is a key indicator of a close relationship between coaches and athletes (1, 2). Mayer et al. (5) define trust as "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" (p. 712). Vulnerability here alludes to the risk that could arise if the trustee fails to perform to expectations. For instance, athletes who engage in potentially dangerous sports techniques expose themselves to vulnerability and demonstrate trust through their willingness to take a risk and follow the coach's instructions (6).

When coaches and athletes engage in direct and frequent encounters, athletes will have greater faith in the coach if they feel that the coach will keep their end of the bargain (7). Coaches have significant power over athletes, being able to set goals for them, monitor their training, and manage their playing time (8). Research has found that athletes were more likely to trust a coach who they saw as possessing justice, benevolence, integrity, and competence (6). Justice may be categorised into distributive, procedural, and interactional components (9, 10). In the coaching context, distributive justice refers to the benefits that players look for, such as chances to practise and become experts at their chosen sport, playing time, desired positions and statuses, and so on. Procedural justice can be described as the need for the coach to consistently apply appropriate criteria when allocating rewards to the team members. Interactional justice includes a coach's cordial and courteous interactions with athletes both individually and as a group, outlining the processes involved in reward distribution (6).

Benevolence is the degree to which a coach shows kindness, loyalty to the athlete's interests and welfare, and consideration of the athlete's needs (6, 11). That is, in order for the athlete to have faith in the coach, the athlete needs to think that the coach acts out of kindness towards the athlete rather than out of a desire to benefit personally from the athlete's successes (6). Integrity "entails the ability (of the coach) to both determine, as well as engage in morally correct behaviour regardless of external pressures" (12). There are several examples in sports where coaches have either broken the law, cheated, or pushed their players to do so. When an athlete witnesses that kind of behaviour in their coach, it casts doubt on the coach's integrity and erodes the player's trust. Competence refers to having the necessary skills to perform tasks within a certain field (6). In the relationship between a coach's skill and athletes' trust in them, coaching competency can be seen as a crucial component. Indeed, studies have found that athletes are more likely to trust a coach who they see as having great coaching skills (7).

Furthermore, empirical evidence has shown that perceived performance is directly impacted by the outcomes (i.e., willingness to cooperate and commitment to coach) of a coach's trust (6). Indeed, previous studies found that increased cooperation and dedication to the leader are also influenced by trust, and these factors ultimately affect performance (6, 13). Therefore, better performance is thus the result of a higher acceptance of the performance norms and a higher level of commitment to the coach (6). Research has demonstrated that trust fosters cooperative behaviour in people, teams, and institutions (5). In sports, athletes' willingness to cooperate with the coach and other team members in carrying out the coach's instructions is a function of their acceptance of the coach's judgements and guidance. To put it another way, team members who trust their coach are more likely to accept directions and be eager to do as instructed. On the other hand, team members with little faith in the coach are unlikely to collaborate effectively (6).

Research has shown that there are few studies that address the subtleties of how gender oppressions function and whether or not they are being overcome in various sociocultural situations in Africa (14). Although a number of studies have been carried out on athletes' trust in coaches and its outcomes (4, 6, 7), there is a dearth of data in the context of South Africa, amounting to one study conducted in a South African university setting (13). Their findings showed that athletes' trust in the coach was mostly explained by perceptions of benevolence, competence, justice, and integrity. Given that many young, aspirational female athletes view sports as a potential professional career trajectory and trust their coach to help them succeed (13), more research in this area is necessary. Furthermore, such a relationship between the coach and athlete that is influenced by many factors including gender should be explored in more depth and more holistically (15). Against this background, the purpose of this study was to investigate female South African school athletes' trust in their coaches in relation to their perceptions of the coaches' justice, benevolence, integrity, competence, commitment to coach, willingness to cooperate, and performance.

Materials and methods

Research design and sample

A quantitative cross-sectional research design was used in this study. The study's sample consisted of 265 school-going female athletes ($M_{age} = 14.55 \pm 2.99$ years) from four public schools. All of the study's participants were purposefully chosen because they had been involved in sport.

Research instrument

The Athlete's Trust in Coach Leadership Questionnaire developed by Zhang and Chelladurai (6) was used to collect data. The questionnaire consists of 24 items grouped into the following eight subscales: trust in the leader (2 items), perceived justice (3 items), perceived benevolence (3 items), perceived integrity (4 items), perceived competence (5 items), commitment (2 items), willingness to cooperate (2 items), and perceived performance (3 items). The response format for all of the sub-scales' items is a 7-point Likert scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*). The overall Cronbach's alpha coefficient value was 0.943, indicating that the questionnaire was reliable (16).

Data collection procedure

Prior to data collection, the researcher obtained ethics clearance from the Tshwane University of Technology's Faculty Committee for Research Ethics and Research Ethics Committee. The researcher also sought permission to carry out the study from the Department of Basic Education in Pretoria, South Africa. Prior to data collection, parental consent forms were signed, and the participants signed assent forms. The participants were informed that their participation was voluntary, that there would be no repercussions if they stopped participating at any point, and that their responses would be anonymous and confidential. The researcher visited participants in the data-gathering process on prearranged dates at their schools and gave them questionnaires. Participants took eight to ten minutes to complete the questionnaires.

Data analysis

The data was analysed with the Statistical Package for the Social Sciences (SPSS), version 28. A significance level of 0.05 was chosen.

The Pearson correlation coefficient (*r*) was used to examine relationships between variables and a multiple regression analysis was conducted to predict female athletes' trust in their coach based on their commitment to coach; willingness to cooperate; and perceptions of the latter's justice, benevolence, integrity, competence, and performance. The Cronbach's alpha coefficient was used to examine the instrument's internal consistency.

Results

Table 1 displays the correlations between trust in the coach and other factors (perceived justice, perceived benevolence, perceived integrity, perceived competence, commitment to coach, willingness to cooperate, and perceived performance). Trust in the coach was significantly correlated with commitment to coach ($r = .396$, $p < .01$), perceived performance ($r = .405$, $p < .01$), willingness to cooperate ($r = .469$, $p < .01$), and perceived benevolence ($r = .487$, $p < .01$), although the correlations were of medium strength. Furthermore, there was a large correlation between trust in the coach and the following factors: perceived justice ($r = .504$, $p < .01$), perceived integrity ($r = .511$, $p < .01$), and perceived competence ($r = .534$, $p < .01$).

Table 2 shows the results of the multiple regression analysis predicting the female athletes' trust in their coach based on perceived justice, perceived benevolence, perceived integrity, perceived competence, commitment to coach, willingness to cooperate, and perceived performance. The final model was significant [$F_{(7,254)} = 20.72$, $p < .001$] and explained 36% of the total variance in the trust in the coach (adjusted $R^2 = .35$). Perceived justice was the only significant predictor of trust in the coach as it had a higher beta value ($\beta = .17$, $p < .05$) than the other variables.

Discussion

The findings indicate a strong relationship between trust in the coach and perceived competence. This result corroborates that of Zhang and Chelladurai (6), who discovered that an athlete's faith in their coach is influenced by coaching competency. This study highlights the benefits of coaching competency and athlete trust in the coach-athlete relationship and illuminates how teams view coaching competency. Competency in coaching seems to convey to players that the coach is respectable, reliable, and trustworthy (7). A strong relationship was also found between trust in the coach and perceived integrity. This finding highlights that coaches need to act ethically to earn athletes' trust.

The results show that trust in the coach was significantly correlated with perceived justice. The results of the multiple regression analysis indicate that among the female athletes, perceived justice was the only factor that predicted their trust in their coaches. This finding supports Zhang and Chelladurai's (6) findings, which suggested that trust in the coach had an impact on perceived justice. When an athlete considers her coach's decision-making to be fair, she is likely to be committed to the team. This suggests that building an equitable and respectful relationship with others is crucial to earning an athlete's trust. By prioritising treating athletes fairly, coaches can cultivate trust and, consequently, enhance athletes' performance (17).

The findings showed a significant relationship between coaches' levels of trust and both commitment to the coach and performance improvement. The more committed athletes are to

TABLE 2 Antecedents of trust in the coach.

	B	SE B	β	t	Sig.
(Constant)	.586	.381		1.537	.126
Perceived justice	.186	.088	.168	2.123	.035*
Perceived benevolence	.150	.081	.140	1.849	.066
Perceived integrity	.123	.100	.105	1.229	.220
Perceived competence	.136	.108	.120	1.269	.206
Commitment to coach	.065	.073	.063	.895	.371
Willingness to cooperate	.104	.077	.100	1.346	.179
Perceived performance	.053	.086	.043	.614	.540

B, unstandardized coefficient; SE B, standard error; β, standardized beta.
*$p < 0.05$.

TABLE 1 Correlation analysis between studied variables.

	1	2	3	4	5	6	7	8
1. Trust in the coach	–	.504**	.487**	.511**	.534**	.396**	.469**	.405**
2. Perceived justice		–	.600**	.670**	.724**	.387**	.591**	.447**
3. Perceived benevolence			–	.702**	.675**	.426**	.513**	.470**
4. Perceived integrity				–	.688**	.549**	.552**	.586**
5. Perceived competence					–	.579**	.704**	.568**
6. Commitment to coach						–	.548**	.612**
7. Willingness to cooperate							–	.527**
8. Perceived performance								–

**$p < .01$.

their coach, the more they accept the coach's performance expectations and, consequently, the better their performance is (6). Thus, higher levels of dedication to the coach could increase the likelihood of acceptance and improvements in performance. Trust is a crucial component of high-achieving teams that is rewarded with exceptional performance from athletes. Athletes are more inclined to work hard and try their hardest to fulfil their responsibilities the more committed they are to their coach. Contrastingly, tensions on a team arising from an athlete's insufficient commitment can lower both individual and team performance (17). Lee et al. (4) have reported that the quality of the leader-player relationship being not good can lead to poor results since there is a lack of dedication, trust, and cooperation.

The present data show that trust in the coach was significantly correlated with willingness to cooperate. Athletes with a high level of trust in their coach are more inclined to cooperate with the coach and, as a result, more likely to perform better (17). Furthermore, the findings show that trust in the coach was significantly related to perceived benevolence. This outcome suggests that coaches must demonstrate via suitable leadership actions that they care about the athletes' well-being as well as the task at hand (6, 13). For athletes to have faith in their coach, they need to think that the coach acts out of kindness towards the athlete rather than purely out of a desire to benefit personally from the athlete's successes.

This study has a few notable limitations. First, its cross-sectional design has inherent limitations because interpersonal trust grows over time and thus conclusions cannot be drawn about the causal relationship between the constructs (6). Second, the athletes were from school settings where competition is low, and the interaction between coaches and athletes was limited by a short season. Third, the study did not include other demographic information variables that might have affected the findings, such as the coach's gender (male or female), the type of sport, individual or team sports, the athletes' playing experience, and the frequency of training.

Conclusion

This study highlights significant relationships between trust in the coach and several factors: perceived justice, perceived integrity, and perceived competence. Of all of the perceived characteristics, justice was the only significant factor that predicted female athletes' trust in their coach. This study demonstrates that coaches should exhibit fairness when making decisions. They can do so by, for example, giving players incentives, chances to play, cordial relationships, and desirable positions and statuses. Coaches could also individualise the care and encouragement they provide to every athlete.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Tshwane University of Technology Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

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Comparative perceptions of sexual harassment among athletes across different competitive levels

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Purpose: Despite evidence that sports arenas are grooming ground for sexual harassment, consensus is still lacking what this term constitutes. The aim of this study is to examine how athletes of different levels and non-athletes perceive sexual harassment in sports through the lens of the Institutional Theory.
Method: Hundred and thirty pre-service physical education teachers (competitive and non-competitive athletes) and 53 Olympic athletes, rated 27 items divided into four levels of sexual harassment regarding men coaches' behaviors towards women athletes, on a scale of 1 (does not constitute sexual harassment) to 4 (constitutes sexual harassment to a great extent).
Findings: Non-Olympic athletes rated the behaviors as constituting sexual harassment to a greater degree than Olympic athletes, in all categories, as did women participants compared to man. Both genders rated *sexual harassment and exploitation* as the most severe factor followed by *Sexist behavior*, yet the more competitive the athletes, the less they perceived such behaviors as disturbing. The *Professional contact* factor was rated as the least disturbing, with women rating it as less disturbing than men.
Conclusions: The study underscores the ambiguity surrounding the definition of sexual harassment in sports, emphasizing the necessity for clear boundaries to establish acceptable behavior. Such clarity is essential to ensure that all athletes feel safe within the sporting environment. It emphasizes the importance of zero tolerance for all harassing behaviors, regardless of severity, and the implementation of comprehensive policies and training programs in sport organizations. Moving forward, promoting respect, safety, and awareness, along with ongoing research and evaluation, are crucial for creating inclusive and safe sporting environments.

KEYWORDS
sexual harassment, exploitation, coach-athlete relationships, pre-service physical education students, safe sport

Introduction

Sexual harassment in the sports arena

As a microcosm of society, sports arenas are saturated with incidents of sexual harassment that have a significant impact on athletes in all areas of sports, performance levels, and countries (1–3). The men dominated sports environment encompasses a permissive rape culture and serves as a breeding ground for sexual harassment (4). Some sociological theories even emphasize that the sports arena encourages sexual violence, especially towards younger and older women, yet also towards their man counterparts (5, 6).

Yet ambiguity can be seen in the literature regarding the definition of the term *sexual harassment* and how it is measured. Indeed, universally accepted definitions are lacking for terms such as *sexual harassment*, *abuse*, *exploitation*, *assault*, *harm*, and *violence*, which could be verbal, physical, or emotional. It is also possible for some concepts to overlap or be used synonymously (7). Sexual harassment is considered an illegal act that is perceived as unwarranted, disturbing, threatening, insulting, or offensive (1). It is also generally agreed that sexual harassment involves unwanted sexual attention (8). Brackenridge and Fasting [(9), p.36] define sexual harassment as "unwanted attention on the basis of sex (lewd comments, pinching, touching or caressing, sexual jokes, etc.)" According to Vertommen and colleagues (10), *mild sexual violence*, *moderate sexual violence*, and *severe sexual violence* are three discrete categories. In addition to the intensity of the sexually violent act, scholars also address the frequency of the phenomenon, defining it as *mild* when it occurs only once, or as *severe* when occurring repeatedly (11).

It is well established in the literature that sexual harassment in sports has far-reaching implications, for both athletes, teams, and the integrity of the sports arena in general [e.g., (12–16)]. For example, studies indicate that sexual harassment can lead athletes to being preoccupied with thoughts about the incident (17). The Larry Nassar sexual abuse case involving USA Gymnastics and Michigan State University, for example, has received extensive attention in the literature in recent years [see e.g., (16)]. This case sparked significant public outcry, as it involved an extreme instance in which the team doctor of the United States women's national gymnastics team was accused of hundreds of sexual assaults against woman gymnasts (18). From another perspective, recent findings demonstrate, for example, that among woman students specializing in sports management who experienced sexual harassment, satisfaction with the specialization was lower (19). Women athletes may develop negative attitudes towards men in general, while perceiving their relationship with their coach as ruined. Some athletes may switch to a different field of sports, or even drop out of their elite-level sport or sport activity due to this phenomenon (17). Furthermore, sexual harassment has been found to negatively impact the participation and achievements of younger and older women in sports, in turn harming their quality of life (20). At this point, it is important to emphasize that although most of the literature addressing sexual harassment in sports focuses on abuse perpetrated by men, cases of sexual harassment by women have also been documented (21).

Early studies examined the types of sexual harassment that occur in the sports arena, while attempting to identify the source of harassment. For example, Volkwein and colleagues (22) found that 2% of American women college athletes had been sexually harassed by their coaches, and that nearly one in every five had been subjected to sexist or derogatory remarks. In another study conducted in the UK, one-fourth of the women participants had experienced at least one of the following by their men coaches: demeaning language, verbal intrusion, or physical contact (23). In a study conducted in Belgium, more than one-fifth of the women participants reported that they had experienced at least one of the following behaviors by their coaches: flirting (with them and/or with another team member), making sexual comments about them, and staring (24). As we will discuss later, the lack of gender equality in the sports arena, coupled with the dominant man hegemony in this environment, places women in a particularly vulnerable position regarding their potential experiences of sexual abuse.

Differences in sexual harassment experiences from the institutional theory perspective

According to the Institutional Theory, which was first introduced in the late 1970s, collective actions are subconsciously impacted by embedded structures, normative social expectations, and cognitive understandings – and to a greater degree than by rational decision making (25–27). One key concept of the Institutional Theory is that both employees and the organization construct a shared understanding of reality through social construction (28). In response to these social constructions, the organization establishes rules and regulations, laws and professional norms, and an ethical code of conduct (27). An organization is characterized by its work patterns, environment, members, and methods – that define how its members should behave in order to control its functioning and production, and as a means for establishing legitimacy and recognition. Specifically, norms develop over time, in an informal and gradual process, during which the members of the organization learn to recognize which behaviors are acceptable and necessary for effectively carrying out their duties (29).

In recent years, observing sports organizations from an institutional perspective has gained momentum, leading to a significant increase in applying the Institutional Theory in sports literature, including studies on sports management (26). Studies have also applied the Institutional Theory as a framework – in an attempt to examine differences between genders within the sports context (30) and address the phenomena of sexual harassment and sexism in the sports arena (3). This concept is particularly relevant in competitive sports, where behaviors such as grooming become institutionalized, as part of the athletes' development process that is perceived as legitimate (31).

Sexual violence does not always arise from issues of desire; it can also occur as an attempt to dominate another party. This is clearer when previous literature emphasizes that coach-athlete relationships should be viewed as relationships of dominance-submission between the parties (32). Coach-athlete relationships, particularly those involving youth athletes, are fertile ground for sexual violence, as a common feature in these arenas is the abuse of power in positions of trust and responsibility (33). Sexual violence can also be perpetuated by unequal power relations between coaches and athletes, or between senior and junior athletes. It is not surprising, then, that in cases of child sexual abuse, the asymmetry in power relations between the parties plays an even more significant role (33).

Not only that, but another aspect that characterizes the sports arena is the increased preoccupation with body aesthetics and the strict nutrition required of athletes to meet performance or social expectations in this environment [see, e.g., (34)]. These elements may also create fertile ground for excessive preoccupation with body care and its externalization, thus serving as an additional catalyst for normalizing an atmosphere of sexual harassment in the sports arena. Norms of this kind, which originate from the practices and cultures within the sports arena, become even clearer when examining the aspects of "cultivation" that many abusers define as part of their medical interventions. This is particularly evident in contexts such as the gymnastics arena in the USA (16), where the use of the "care" framework for some of the care practices was defined by many abusers as part of medical interventions.

It could also be assumed that women athletes may experience sexual harassment differently than men ones. The sports environment is characterized by gender inequality, a predominantly masculine arena in which women athletes are considered distinctly inferior to men ones; in turn, this has created a slippery slope that may have led to the institutionalization of sexual harassment against women athletes. Cunningham and Sagas (30) addresses the inherent nature of gender inequality in sports, arguing that Inequality is an institutionalized element within sport arrangements. In many cases, this inequality is identified with the man hegemony that dominates the sports arena [e.g., (35)]. There is therefore fertile ground for sexual harassment in this arena, especially as man dominated organizations and professions have a high prevalence of sexual harassment and sexism incidents (3). As a result, it is not surprising that women experience more sexual harassment than men (10). Earlier findings have also demonstrated this empirically within the Israeli context (36).

In the context of sports, the term *grooming* emphasizes a strategy whereby coaches strive to build their athletes' trust in them, as a means for consciously persuading them to engage in sexual acts (9, 33, 37). A study conducted by Bisgaard and Støckel (38), using the athletes' own words (i.e., realistic narrative), offers an in-depth understanding of sexual harassment and abuse in sports.

These narratives indicate how such grooming behaviors are often incorporated into the daily culture and practices of sports. The particularly close athlete-coach relationship that exists in competitive sports institutionalizes the phenomena of *nurturing*, and in turn, enables the legitimization of the sexual harassment phenomenon in this arena. In this context, while *sexual harassment* is a non-normative phenomenon, the abuse itself may be perceived by the victim as acceptable (9). The scoping review conducted by Gaedicke and colleagues (33) illustrates – inter alia – how certain aspects of the grooming process within the coach-athlete context contribute to this phenomenon. For example, they point out how building a friendship between coaches and athletes may blur the lines between legitimate behavior on both sides. They also found that the grooming process "normalizes" behaviors of sexual harassment and sexual exploitation – especially through the coach-athlete trust and interdependence that develop.

As competitive and high-achieving sports have been found to provide fertile ground for grooming relationships between coaches and athletes (37), this phenomenon seems to have become institutionalized in the sports arena, and its prevalence is likely to continue to exist. It has long been recognized that the broader context in which sports operate is critical to understanding how norms and culture shape practices within the sports arena. The coach-athlete literature, particularly the "darker side" work of Bartholomew and colleagues (39), focuses on need-thwarting practices in this environment. This underscores the importance of understanding the context in which athletes operate to comprehend grooming phenomena as a foundation for experiences of sexual harassment in the sporting environment. Owton and Sparkes (37), for example, empirically demonstrate how an athlete who was groomed by her coach experienced sexual abuse in the continuation of their relationship. Through their autoethnographic research focusing on this woman athlete, they illustrate how structural conditions and power relations in the sports arena create an "enabling" context for the phenomena of sexual abuse and exploitation. However, due to current efforts to educate and raise awareness through social media and women speaking out, it is likely that these efforts will help reduce the phenomenon of sexual harassment in sports. Recent studies reveal that the "MeToo" campaign has far-reaching consequences for exposing this issue and narrowing its prevalence in the sports arena (40, 41) similar to its impact in other social arenas. Additionally, the voices of athletes regarding cases of sexual harassment in sports contribute to changing the scope of the phenomenon. A prominent example can be identified in the reports of U.S. Gymnastics athletes in recent years. When athletes speak out about issues of sexual abuse in sports, media attention increases, and the cases gain significant public resonance (16). However, previous studies emphasize that the manner of media coverage is also crucial in avoiding the over-reporting of information about these abuse cases, which can inadvertently victimize the athletes through a victimization lens (16). No less importantly, previous literature emphasizes the institutional deficiencies that allow, or at least do not fully prevent, the occurrence of this phenomenon and highlights the importance of the institutional regulations required by decision-makers to minimize it (42). There is a clear consensus that it is the role of policy makers to ensure the necessary legislation and implementation to optimally address the issue of sexual harassment in sports (42).

In high-achieving sports, coaches and athletes have particularly close relationships, with the former having vast control and influence over the latter. While such power enables successful athletic performance, it also provides fertile ground for sexual harassment and exploitation (43–45). As such, athletes of varying levels of participation could perceive sexual harassment differently. Furthermore, the literature highlights a culture of silencing and nurturing that encourages athletes to accept and even defend sexual abuse as normal occurrences (3), resulting in the under-reporting of such incidents in competitive sports. In this context, it is important to emphasize the power structure of the sports institution, where the majority of women athletes are accompanied by men coaches, and the majority of man athletes are accompanied by men coaches as well. The institutionalized heterosexual norm creates power dynamics that place women athletes at a significantly higher risk of sexual harassment and abuse than man athletes.

Based on this literature review, the aim of this study is to understand how pre-service physical education (PE) teachers, coaches, and athletes of different levels perceive sexual harassment of men coaches toward women athletes, with an emphasis on differences in perceptions between men and women – examined in light of the Institutional Theory. We assume that women athletes will be affected by sexual harassment differently than man athletes. As such, we present the following two research hypotheses:

H1: Pre-service PE teachers who participate in competitive sports will perceive sexual harassment more severely than those who are Olympic athletes and those who do not participate in competitive sports.

H2: Women athletes and non-athletes will express a different interpretation than men athletes/non-athletes on whether or not specific behaviours from men coaches are sexual harassment.

This study addresses a critical gap in our understanding of how sexual harassment is perceived within the sporting community. By examining the perceptions of pre-service physical education teachers, coaches, and athletes at different competitive levels, this research provides a comprehensive analysis of how sexual harassment is understood and interpreted across the spectrum of sports involvement. The inclusion of both men and women participants allows for a nuanced exploration of gender differences in these perceptions, offering valuable insights into how experiences and socialization within sports contexts may influence attitudes towards sexual harassment.

This research is particularly significant in its application of Institutional Theory to examine how organizational structures and norms within the sports world may shape perceptions of sexual harassment. By comparing the views of non-competitive physical education students, those engaged in competitive sports, and elite Olympic athletes, the study illuminates how different levels of immersion in sporting institutions may affect one's understanding and recognition of sexual harassment. This multi-level approach not only contributes novel findings to the existing literature but also has important implications for policy development and educational initiatives aimed at preventing sexual harassment in sports. The focus on pre-service physical education teachers and coaches is especially valuable, as these individuals will play pivotal roles in shaping future sporting environments and fostering safe, inclusive spaces for athletes of all levels.

Methodology

Participants

The study included 183 participants (119, 65% women, 64, 65% men), aged 18–49 ($M = 26.46$; SD ± 5.72), comprised of 53 Olympic athletes, and 130 pre-service PE teachers from a college of education in Israel who were categorized as either competitive athletes ($n = 83$) or non-competitive athletes/non-athletes ($n = 47$).

Olympic athletes are those who compete at the highest level in their sport, striving for qualification and success in the Olympic Games, which requires rigorous training and dedication. Non-Olympic athletes, on the other hand, may participate in various sports at different levels without the specific goal of competing in the Olympics, often focusing on recreational, amateur, or local competitions. In the group of *Olympic athletes*, 60.6% participated in martial arts, 12.1% in swimming, 6.1% in team ball games, and 3% in track and field; the remaining 18.2% participated in other fields of sports. On average, they had begun engaging in sports at the age of 7.25 (SD ± 3.57) and had retired from competitive sports at the average age of 26.14 (SD ± 5.88). At the time of the study, 34% had been competitive athletes in the past and were currently working as coaches – with 50.9% of them working as coaches in the fields of artistic gymnastics, tennis, judo, basketball, swimming, weightlifting, cycling, Olympic shooting, gymnastics, water polo, rock climbing, and triathlons.

Competitive athletes are primarily driven by the desire to win and improve performance, often engaging in structured training regimens and participating in organized events, whereas, non-competitive athletes participate in sports for enjoyment, fitness, and social interaction, emphasizing personal fulfillment over competitive outcomes. In the group of *competitive athletes*, 75% participated in team ball games, 7.1% in martial arts, 7.1% in track and field, and 3.6% in swimming; the remaining 7.1% participated in other fields of sports. On average, they had begun engaging in sports aged 10.7 (SD ± 4.53). At the time of the study, 39.3% were working as competitive sports coaches.

Non-Olympic athletes engage in sports or physical activities for enjoyment, fitness, or competition at various levels but do not aim for Olympic qualification, whereas non-athletes, do not participate in sports regularly and may prioritize other interests, often leading a more sedentary lifestyle. In this group of *non-competitive athletes* (or non-athletes), 53.9% reported that they had been involved in competitive sports in the past. On average, they had begun engaging in sports at the average age of 9.58 (SD ± 4.37) and had retired from competitive sports at the average age of 17.67 (SD ± 3.1). At the time of the study, 64.7% of this group were working as non-competitive sports coaches. The pre-service PE teachers who were non-athletes was relatively bigger than the other two groups in the study. These future teachers will hopefully be able to instill relevant values in their school students. Therefore, clarifying their perceptions is imperative with a follow up educational program.

Questionnaire

First, the participants were asked a number of general background questions, such as age and gender, followed by questions regarding their athletic experience, including type of sport, athletic level of performance, and years of experience. Next the participants were asked questions about what they consider to be *sexual harassment.* The original questionnaire was compiled by Volkwein et al. (22) in a study on 200 student-athletes at three colleges in the USA. The questionnaire was later translated into Hebrew in Israel and validated in a study on pre-service PE teachers (46). The questionnaire includes 27 items regarding a man coach's behavior towards a woman athlete. For each item, the participants were asked to rate the extent to which they perceive this behavior as constituting sexual harassment, on a scale of 1 (not at all) to 4 (to a great extent), or alternatively 5 (don't know) – a rating that was not included in the statistical analyses. Using the Varimax method, Fejgin and Hanegby (46) conducted factor analysis, resulting in the following four dimensions:

1. Factor 1. *Severe harassment and exploitation* (10 items) 0.873.
2. Factor 2. *Between concern and interest* (6 items) 0.854.
3. Factor 3. *Sexist behavior* (5 items) 0.834.
4. Factor 4. *Professional contact* (6 items) 0.790.

The first factor, *Severe harassment and exploitation*, relates to physical expressions (such as pinching the athlete's butt or kissing her on the mouth) and verbal behaviors (such as sexual suggestions or expressing an interest in the athlete's sex life.) In this study, the internal reliability of this factor was found to be Cronbach's $\alpha = 0.83$. The second factor, *Between concern and interest*, relates to disturbing behaviors regarding the athlete's professional or private life (such as the coach inviting her to his home for coffee or expressing an interest in her plans for the weekend.) In this study, the internal reliability of this factor was Cronbach's $\alpha = 0.85$. The third factor, *Sexist behavior*, relates to inappropriate verbal behavior (such as complimenting the athlete on her appearance or telling rude jokes.) In this study, the internal reliability of this factor was Cronbach's $\alpha = 0.84$. The fourth and final factor, *Professional contact*, relates to certain aspects of the coach's training (such as physical contact while demonstrating or teaching or when expressing joy following the athlete's victory.) In this study, the internal reliability of this factor was Cronbach's $\alpha = 0.80$.

Procedure

The pre-service PE teachers were contacted via the mailing lists of the authors' affiliated academic institution; the Olympic athletes were contacted via the Olympic Committee of Israel. The study was approved by the Institutional Review Board at the authors' affiliated academic institution (No. 257, 2020). After submitting a signed written consent form, the participants received the study questionnaire via email. Anonymity was ensured throughout the study.

Data analysis

First, we present descriptive statistics. Then, to test main effects and combined effects of gender and athletic level of performance, two-way analysis of variance (ANOVA) was conducted for each of the four factors addressed in the questionnaire.

Results

First, mean scores (M) and SD were calculated for the rating of each of the 27 man coach–woman athlete behaviors, on a scale of 1–4. For each item, we also examined the percentage of man participants and of women participants who rated an item as 4, indicating that the specific man coach–woman athlete behavior constitutes sexual harassment to an extreme degree (Table 1).

The factor that was most perceived as constituting sexual harassment was *Severe harassment and exploitation*, with the highest mean score (M = 3.75) and the smallest SD (SD = 0.23), thereby indicating a high level of agreement among the participants regarding the seriousness of the items that were presented in this factor. In general, women participants tended to perceive these behaviors as more disturbing than man ones. This difference between genders was especially prominent in the group of non-competitive athletes and was much smaller in the group of Olympic athletes. The most noticeable differences between the three groups of participants were in relation to item 5, i.e., *The coach gives the athlete a back or shoulder massage just for fun*, whereby 60% of the competitive athletes and 52% of the non-competitive athletes rated this item as 4 (i.e., extreme sexual harassment), while only 28% of the Olympic athletes did so. Considerable differences were also seen regarding item 10, *Caresses the athlete*, whereby 73% of the non-competitive athletes and 62% of the competitive athletes rated this behavior as extremely disturbing (4 on the rating scale), compared to only 35% of the Olympic athletes.

The next factor that was most perceived as constituting sexual harassment was *Sexist behavior*, with an average score of 2.57 (SD ± 0.42). In the group of Olympic athletes, no differences were seen between genders in their scores, except for item 20, *Complimenting the athlete on her appearance*, which was perceived by man participants as more disturbing than by woman ones; however, in the group of non-competitive athletes, women participants perceived this item as more disturbing than their man counterparts. Moreover, participants from the non-competitive group perceived the behaviors in this factor as very disturbing, while those from the Olympic group perceived them as least disturbing. The largest gap between the three groups was seen in item 20, *Complimenting the athlete on her appearance*, with 44% of the participants in the non-competitive group rating this as 4 (constitutes sexual harassment to a great extent), compared to 32% in the competitive group, and only 5% in the Olympic group.

The mean score for the *Between concern and interest* factor was $M = 2.41$ (SD ± 0.36), indicating that the behaviors presented in this factor are perceived as less disturbing than those presented in the previous two. In this factor, both genders rated these behaviors fairly similarly. However, for four statements, man participants perceived these behaviors as more disturbing than woman ones, while for three behaviors, women participants in the group of non-competitive athletes perceived these as more harassing than their man counterparts. In general, participants from the non-competitive group rated the behaviors in this factor as most disturbing while those from the Olympic athletes group rated them as least disturbing. The largest difference

TABLE 1 Participants' perceptions of the factors and items as constituting sexual harassment ($N = 183$).

			Olympic Athletes *n*-53		Pre-service PA teacher athletes *n* = 83		Pre-service PA teacher non-athletes *n* = 47	
			Rated the item as 4 (to a great extent)					
	M	SD	Ma% *n* = 14	Fe% *n* = 39	Ma% *n* = 42	Fe% *n* = 41	Ma% *n* = 8	Fe% *n* = 39
Severe harassment and exploitation	**3.75**	**0.23**						
1. Shows sexual interest in the athlete	3.85	0.44	84.62	94.59	80.49	85.44	75.00	89.74
2. Proposes sexual encounters without reward for agreement/threat for rejection	3.83	0.49	83.33	89.19	85.37	86.67	87.50	89.74
3. Tells the athlete about his sex life	3.78	0.52	71.43	86.49	78.05	80.24	75.00	89.74
4. Stares at the athlete's breasts	3.79	0.46	64.39	81.08	82.93	82.93	62.50	87.18
5. Gives the athlete a back/shoulder massage for fun	3.23	0.88	28.67	22.86	55.26	60.34	50.00	52.63
6. Pinches the athlete on her behind	3.9	0.34	85.71	91.89	92.68	90.24	75.00	97.37
7. Asks the athlete about her sex life	3.83	0.4	57.14	89.19	80.00	81.55	75.00	97.30
8. Proposes sexual encounters, with reward for agreement/threat for rejection	3.93	0.25	92.91	94.59	92.68	91.56	100.00	94.74
9. Kisses the athlete on the mouth	3.92	0.29	92.91	94.59	92.68	91.56	75.00	97.30
10. Caresses the athlete	3.5	0.71	35.71	48.65	65.00	61.73	62.50	73.00
Between being concern and showing an interest	**2.41**	**0.36**						
11. Invites the athlete to train at his home	2.14	1.10	7.14	3.03	21.62	19.73	25.00	28.57
12. Invites the athlete to his home for coffee	2.18	1.01	7.70	5.41	7.50	11.34	0.00	33.33
13. Asks the athlete what she does in her spare time	2.08	0.94	0.00	2.78	12.82	8.87	0.00	15.79
14. Invites the athlete out for dinner	3.04	1.07	21.43	25.71	46.34	50.00	50.00	68.42
15. Asks the athlete about her plans for the weekend	2.55	1.09	14.30	13.51	31.71	28.06	37.50	30.77
16. Invites the athlete to a nearby café for lunch	2.44	1.00	7.14	5.56	20.00	22.54	25.00	18.42
Sexist behavior	**2.57**	**0.42**						
17. Talks about what he likes to do in his spare time	2.02	0.93	0.00	2.78	5.00	8.97	12.50	15.79
18. Calls the athlete by a pet name (such as "sweetie" or "honey")	2.6	0.96	14.3	19.44	17.07	17.07	37.50	28.95
19. Tells the athlete about his plans for the weekend	2.27	0.99	0.00	5.71	19.51	17.07	37.50	15.79
20. Compliments the athlete on her looks	2.96	0.82	21.43	5.56	30.00	32.13	25.00	44.74
21. Makes derogatory remarks about women	2.98	0.90	28.61	27.78	29.27	24.74	37.50	51.35
Professional physical contact	**2.31**	**0.84**						
22. Touches the athlete on her shoulder or arm while giving explanations	1.69	0.88	0.00	2.78	5.35	6.35	0.00	13.21
23. Sits or stands close to the athlete when talking in the office	2.21	0.97	0.00	5.56	7.32	11.04	12.50	20.51
24. Closes the door when talking in the office	2.33	1.02	0.00	2.78	20.00	18.85	25.00	23.68
25. Places his hand on the athlete's shoulder or arm when greeting her	2.17	1.00	14.30	2.78	14.67	14.87	37.50	15.4
26. Kisses the athlete on her cheek	3.92	0.29	57.14	22.22	58.5	67.16	62.50	64.1
27. Hugs the athlete after winning a competition	1.56	0.85	0.00	0.00	5.00	5.00	12.50	10.5

M = mean scores; SD = standard deviation; Ma = Males; Fe = Females.% Rated the item as 4 (to a great extent).
Bold numbers represent Means and SDs of the questionnaire' factors.

between participants was seen in statement number 14 *Invites the athlete out for dinner*, with 68% of participants from the non-competitive group rating this as extremely disturbing (score 4), followed by 50% of participants from the competitive group, and finally, only 25% of the Olympic athletes perceived this behavior as disturbing.

The factor that was least perceived as constituting sexual harassment in the sports arena was *Professional contact* ($M = 2.31$; SD ± 0.84). Interestingly, four of the six items in this factor were not rated as 4 (to a great extent) by any of the man participants in the Olympic group. In fact, some of these six items were rated as 1 (not at all disturbing), including item 27, *hugs the athlete after winning a competition*, and item 22, *touches the athlete on her shoulder or arm while giving explanations.* On the other hand, a high rate of participants perceived item 26, *Kisses the athlete on her cheek*, as highly disturbing. In the group of Olympic athletes, the following two items were perceived by men participants as more disturbing than by women participants: item 25, *Places his hand on the athlete's shoulder or arm when greeting her*, and item 26, *Kisses the athlete on her cheek*. In the two non-Olympic groups, differences between genders were relatively small; moreover, 32% of the Olympic athletes perceived this factor as not disturbing, except for the above-mentioned item 26.

Gender and sports

To test main effects and combined effects of gender and athletic level of performance, two-way analysis of variance (ANOVA) was conducted for each of the four factors addressed in the questionnaire. Regarding the factor, *Severe harassment and exploitation*, a main effect was seen for participants' athletic level of performance [$F_{(2,174)} = 3.67$, $p = .03$, $\eta 2 = .04$], with pairwise comparison analysis showing that participants in the competitive group perceived these items as constituting sexual harassment to a greater extent than those in the Olympic group. However, no differences were found between the non-competitive group and the Olympic group. As seen in Figure 1, a main effect was also found for gender in this factor [$F_{(1,174)} = 6.02$, $p = .01$, $\eta 2 = .03$], whereby women participants perceived these behaviors as more disturbing than man ones. No interaction was seen between gender and athletic level ($p = .21$).

Regarding the second factor, *Between concern and interest*, a main effect was seen for participants' athletic level of performance [$F_{(2,174)} = 12.44$, $p < .001$, $\eta 2 = .12$], whereby both groups of non-Olympic participants perceived these behaviors as more disturbing than the Olympic athletes. As seen in Figure 2, a main effect was also found for gender [$F_{(1,174)} = 4.53$, $p = .03$, $\eta 2 = .02$], whereby women participants perceived these behaviors as more disturbing than man ones. No interaction was seen between gender and athletic level ($p = .39$).

Regarding the third factor, *Sexist behavior*, a main effect was seen for participants' athletic level of performance [$F_{(2,173)} = 6.69$, $p = .002$, $\eta 2 = .07$], whereby both non-Olympic groups perceived these behaviors as more disturbing than Olympian athletes. As seen in Figure 3, no main effect was seen for gender ($p = .43$) and no interaction was seen between gender and athletic level ($p = .86$).

Regarding the fourth and final factor, *Professional contact*, a main effect was seen for participants' athletic level of performance [$F_{(2,174)} = 13.47$, $p < .001$, $\eta 2 = .13$], whereby both groups of non-Olympic participants perceived these behaviors as more disturbing than Olympic athletes. As seen in Figure 4, no main effect was seen for gender ($p = .79$) and no interaction was seen between gender and athletic level of performance ($p = .13$).

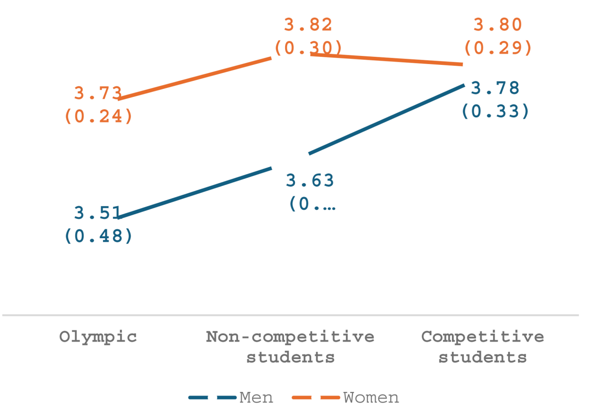

FIGURE 1
Severe harassment and exploitation.

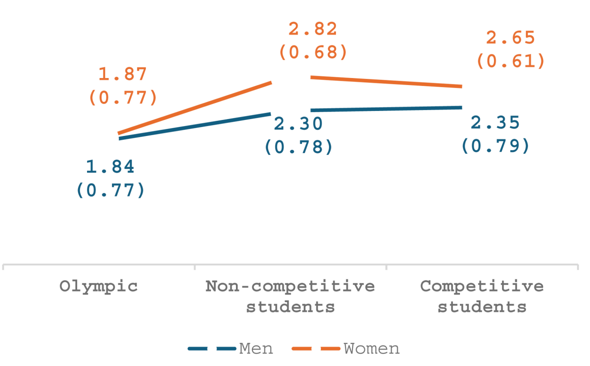

FIGURE 2
Between being concern and showing interest.

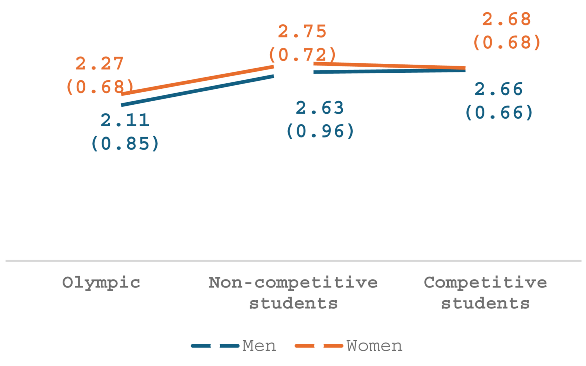

FIGURE 3
Sexist behavior.

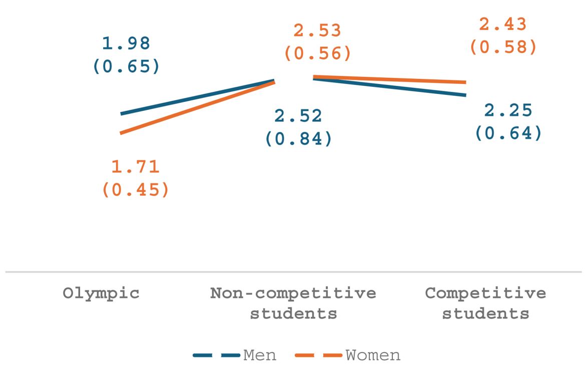

FIGURE 4
Professional physical contact.

Discussion

This study examined how Olympic athletes and pre-service PE teachers perceive behaviors of men coaches towards women athletes, within the broad umbrella of the term *sexual harassment*. Such analysis is especially important in light of the lack of consensus regarding what constitutes sexual harassment in general and in the field of sports in particular. In this research, an emphasis was placed on differences in perceptions between competitive athletes, non-competitive athletes, and

Olympic athletes, and on differences between genders within and between these groups. The results of the current study reinforce earlier findings regarding differentiated attitudes towards sexual harassment [e.g., (36, 47)]. For example, the *Severe harassment and exploitation* factor and the *Sexist behavior* were rated as more disturbing than the *Between concern and interest* factor and the *Professional contact* one. This indicates that participants do not perceive all behaviors as constituting sexual harassment to the same degree. Brackenridge (47) explains that the terms *sexual exploitation*, *sexual harassment*, *sexual violence*, and *sexual assault* are often perceived as a continuum, which could explain why not all behaviors elicit the same response. Yet while all groups of participants and both genders perceived items in the *Severe harassment and exploitation* factor as the most disturbing, followed by those in the *Sexist behavior* factor, differences were seen between men and women, and between the three groups of participants according to their level of sports performance.

Indeed, our findings highlight the lack of consensus regarding what is considered sexual harassment and/or its severity. This could be explained in part using the Institutional Theory, whereby the sport as an organization provides a set of rules that define how its members should behave, as a means of control and for establishing basic legitimacy and recognition (29). Moreover, competitive sports tend to institutionalize behaviors such as grooming, as part of a legitimate development process for athletes (38), which could explain why certain behaviors were perceived by the Olympic athletes as legitimate, yet were perceived as disturbing by the pre-service PE teachers who are not part of a sport institutions, but rather are part of a college institution that emphasizes different values (48).

Interestingly, the behaviors that are described in the *Between concern and interest* factor were rated as less disturbing than those in the *Severe harassment and exploitation* one. Moreover, both man and women participants perceived these behaviors at a fairly similar rate. However, the Olympic athletes perceived the behaviors in the *between concern and interest* factor as least disturbing, while the non-competitive participants perceived them as most disturbing. The name of the factor points at a lack of distinction, indicating a type of continuum. Hassall et al. (49) claims that some coach-athlete behaviors can be perceived as ambiguous, meaning that they may or may not be construed as sexual harassment. It is evident from the current findings that athletes from different levels of sports do not share the same attitudes towards different coach-athlete behaviors, perhaps reflecting this ambiguity. For example, the item, *Invites the athlete out for dinner* was perceived as three times more severe and disturbing by the non-competitive group than by Olympic athletes – two populations that do not share the same organizational culture. However, when it is not clear what is an accepted or unaccepted behavior, and the line between support/closeness/contact becomes blurred, interpretations may vary. Carstensen (50) therefore claims that sexual harassment should not be defined solely by the victim's interpretation, but should also be addressed in relation to the grey area, the context of the behavior, and the continuum of behaviors. The researcher also emphasizes the need to concentrate on structural dimensions as a means for increasing gender equality in organizations and other work domains.

As stated, the *Professional contact* factor was perceived as the least disturbing, and women participants perceived the behaviors in this factor as *less* disturbing than man ones, especially within the group of Olympic athletes. As such, it seems that women may not perceive intimate body gestures, such as hugs and kisses on the cheek, as disturbing, whereas men do. These findings have several possible explanations. First, as suggested by Taylor et al. (3), the culture of silencing and nurturing that exists in sports organizations encourages athletes to accept and even defend sexual abuse as a normal occurrence. As such, such behaviors are less likely to be reported and/or to be perceived as disturbing by athletes from competitive sports organizations. Moreover, different participants from different backgrounds may perceive certain behaviors to be in the grey zone along the continuum of harassment or find ambiguity in relation to what is considered harassment.

It is possible that differences exist between men and women regarding the perception of what constitutes a "red line." That is, when the issue of sexual harassment was first raised as a widespread phenomenon in all its layers, it was initially directed towards men harassing women. The process of conceptual change and the internalization of its implications took years, and once it was internalized, it became apparent that men, at least at a perceptual level, are aware of the problematic nature of this phenomenon. In contrast, women, who were traditionally on the receiving end of such harm, find themselves in a position where their ability to discern when and how they are threatened includes a certain level of tolerance. Moreover, it is important to remember that there are also cultural differences regarding what is perceived as intimate proximity and which statements are considered compliments or harassment. Lastly, there is the expression, "Once burned, twice shy," meaning that when striving for change, the full range of behaviours is addressed.

This study offers important insights regarding how people from different levels of athletic performance, and how people from the different genders, perceive sexual harassment. Yet despite its contribution, some research limitations should be addressed. First, both the pre-service PE teachers and the Olympic athletes who participated in the study volunteered to do so, and as such, may be more aware of the research subject matter than those who chose not to take part in the study. In addition, the questions were regarding the behavior of men coaches toward women athletes whereas both genders could be included in all questions. Therefore, generalization of the results should be performed with caution. It should be noted that for both women and men athletes, some research suggests that those with men coaches are more tolerant of sexually harassing behaviours while those with women coaches are less tolerant of these same behaviours (51). Also, the research participants represent a narrow segment of the athlete population, particularly absent are those from high stakes, hypermasculinized and physical sports for the most part.

Following the findings of the current study, whereby less severe behaviors may be excused, while more extreme behaviors may be condemned, we join Carstensen' (50) suggestions regarding the importance of eliminating ambiguity and grey areas in order to increase the important aim of achieving gender equity in sport organizations (and in other workplaces.) Therefore, all harassing behaviors should be treated in the same manner, i.e., with zero tolerance (although punishment for such behaviors can vary.) Still, we should keep in mind that although some behaviors are consensual and mutually fulfilling, if "no" means no, does "yes" mean yes? (52). Indeed, such behaviors must be addressed and dealt with in the literature, rather than remaining within the grey area.

Despite the expectation that with current efforts to education and heighten awareness through social media and women speaking out, sexual hassment have become institutionalized in the sports arena, and its prevalence is likely to continue to increase (53, 54). One possible explanation for the increase in sexual harassment in sports is the pervasive culture that has long been entrenched in many athletic organizations. Despite efforts to promote awareness and provide education, these initiatives often face resistance due to deeply ingrained attitudes and beliefs. Moreover, the lack of a universally accepted definition of sexual harassment complicates efforts to address and combat it. This ambiguity can lead to inconsistent reporting and enforcement, making it difficult to hold perpetrators accountable (53, 55). Additionally, while social media and public discourse have empowered more victims to come forward, they have also highlighted the extensive nature of the problem, revealing cases that might have previously gone unnoticed. This increased visibility may give the impression that sexual harassment is on the rise, even as awareness and intolerance of such behavior grow. Furthermore, the efficacy of regulations and their enforcement is fundamental to creating a safer environment in sports. Without stringent policies and consistent enforcement, attempts to curb sexual harassment may fall short. Effective regulations need to be clearly defined, universally applied, and backed by serious consequences for violations to foster a genuine shift in the sports culture. In summary, while there are ongoing efforts to address sexual harassment in sports through education and awareness, the issue remains prevalent due to cultural entrenchment, ambiguous definitions, and inconsistent enforcement of regulations. Addressing these underlying challenges is essential for any substantive progress in reducing sexual harassment in the sports arena.

Disagreement over the definition of sexual harassment creates a context where different interpretations are applied to behaviours by individuals in different positions. Such a context prevents the establishment of rules and regulations that would apply to everyone in order to reduce or prevent such behaviours. Furthermore, in terms of punishment, if there is no consensus regarding the severity of the actions, it becomes impossible to reach agreement on appropriate penalties, resulting in behaviours for which there are no deterrents.

The conclusions drawn from the current study highlight the lack of consensus regarding what should be defined as sexual harassment in sports. Despite similar perceptions among man and women participants, context was found to play a significant role in how sexual harassment is perceived and interpreted. The findings suggest that behaviors considered less severe may be excused, while more extreme behaviors may be condemned. This ambiguity in defining and addressing sexual harassment in sports can hinder efforts to achieve gender equity within sport organizations and other workplaces.

From conducting this research, it is evident that there is a need to eliminate ambiguity and grey areas in defining and addressing sexual harassment in sports. All harassing behaviors should be treated with zero tolerance, although the appropriate punishment may vary. It is crucial to address consensual behaviors that may still be harmful and ensure that boundaries are respected. This research can inform sport organizations and educational programming by emphasizing the importance of clear policies and training on sexual harassment prevention and response.

It is important to note that this study exclusively focuses on the experiences of adults, and that the experience of harassment may manifest differently and have distinct effects on child athletes. We also emphasize that future research should examine this issue further, potentially comparing the experiences of abuse in sports between adults and youth.

This study's findings have the potential to inform and improve sexual harassment prevention strategies across the sports sector. By identifying differences in perceptions based on gender and level of sports involvement, the research can guide the development of more targeted and effective educational programs and policies. This is particularly crucial given the ongoing challenges in addressing sexual harassment in sports and the need for evidence-based approaches to create safer environments for all participants. Ultimately, this research not only advances our academic understanding of sexual harassment perceptions in sports but also contributes to the broader societal goal of ensuring that sports remain a positive and empowering experience for all individuals, regardless of their gender or level of participation.

For future recommendations, it is essential to continue raising awareness about sexual harassment in sports and promoting a culture of respect and safety for all athletes, coaches, and staff. Sport organizations should implement comprehensive policies and procedures for addressing sexual harassment, provide training for all members, and establish mechanisms for reporting and investigating incidents. Educational programs should focus on promoting healthy relationships, consent, and bystander intervention. Additionally, ongoing research and evaluation of these initiatives are necessary to ensure their effectiveness in creating safe and inclusive sporting environments.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Levinsky-Wingate Academic College, School of Graduate Studies. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

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Conflict of interest

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.

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Longitudinal performance trajectories of young female sprint runners: a new tool to predict performance progression

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Background: Longitudinal performance tracking in sports science is crucial for accurate talent identification and prognostic prediction of future performance. However, traditional methods often struggle with the complexities of unbalanced datasets and inconsistent repeated measures.
Purpose: This study aimed to analyze the longitudinal performance development of female 60 m sprint runners using linear mixed effects models (LMM). We sought to generate a practical tool for coaches and researchers to establish benchmarks and predict performance development.
Methods: We analyzed 41,123 race results from 8,732 female 60 m track sprinters aged 6–15 years, collected from the Swiss Athletics online database between 2006 and 2021. Only season-best times per athlete and only athletes with at least 3 season-best times in their career were included. LMM was used to generate performance trajectories, benchmarks, and individual predictions. A practical software tool was developed and made available to allow individual performance prediction based on race times from previous seasons. In addition, classic empirical percentile curves were constructed using the Lambda-Mu-Sigma (LMS) method.
Results: LMM handled the dataset's complexities, producing robust longitudinal performance trajectories. Compared to empirical percentiles generated using the LMS method, which provided a retrospective view of performance development, the mixed model approach identified individualized longitudinal performance developments and estimated predictions of future performance. The best-fitting model included log-transformed chronological age (CA) as a fixed effect and random intercepts and slopes for each athlete. This model explained 59% of the variance through fixed effects (marginal R^2) and 93% through combined fixed and random effects (conditional R^2).
Conclusion: LMM provided longitudinal sport performance data, enabling the establishment of performance benchmarking and prediction of future performance. The software tool can assist coaches in setting realistic training goals and identifying promising athletes.

KEYWORDS

talent identification & development, benchmarking, performance prediction, female athlete, sprinting

Introduction

Understanding the individual athlete's journey from initiation to peak performance is of fundamental interest to athlete development researchers and sport practitioners. The trajectory of an athlete's performance is influenced by a multitude of contextual, environmental, and individual factors, as highlighted in recent studies on talent identification and talent development in various sports. Understanding these factors is critical for designing effective athlete development frameworks and tailoring interventions to optimize long-term performance outcomes (1, 2). A recent and growing body of research highlights the importance of assessing performance development, rather than relying solely on current competitive performance, as a critical criterion for sustainable and long-term talent development. To understand development, longitudinal data assessments are required rather than a single performance test (1, 3, 4). At an individual level, performance development is influenced by contextual, environmental, and training conditions, anthropometric and physiological development, as well as biomechanical and technical skill development. This complexity complicates athlete assessment and makes predictions at a young age difficult (5). Multi-factorial and regular assessments, as provided by longitudinal data collection, are required to establish a comprehensive understanding of performance development, i.e., baseline starting points, relative progress and change, rates of development relative to other athletes, and the likely underlying factors contributing (or not contributing) to progression (or sub-optimal progression) (6). As such, there is a growing interest in determining practical developmental benchmarks (7) and performance forecasting based on longitudinal data, as these methods optimise the use of existing resources to improve athlete development and gain a competitive advantage (8–10).

Benchmark percentiles can serve several purposes in athlete development: talent selection, identification of progressing latent talent, organizational/coaching interventions and programme targeting (11). Performance trajectories can also be used to construct percentile curves, which determine an individual's relative progress at a given point in development (or over a period of time) compared to a specific reference population. There are two main methods for constructing percentile curves: empirical percentiles—calculated directly from observed data using the Lambda-Mu-Sigma (LMS) method—and mixed models. The LMS method models the changing distribution of measurements over time and includes three parameters: Lambda (L), Mu (M), and Sigma (S), which represent the skewness, the median, and the coefficient of variation, respectively. These parameters are fitted with a maximum penalized likelihood, to smooth the percentile curves, which is particularly useful when assessing individual trajectories relative to a specific reference population (12–14). However, the accurate estimation of percentiles from the LMS method relies on the assumption that the variables of interest are normally distributed after the transformation and smoothing. Although this method has been widely used in fields such as health and sport science to produce reference growth charts and to monitor physical fitness (15), the LMS method primarily provides a retrospective view of past performance development and may not adequately account for individual variability over time in a longitudinal dataset. As such, when analyzing longitudinal performance the mixed model approach is superior to the LMS, due to its flexibility when dealing with unbalanced data, its ability to provide individualized trajectories and predictions, its statistical robustness, and its greater explanatory power (16).

Linear mixed models (LMMs) are particularly well suited to dealing with the complexities inherent to longitudinal sports data, such as multiple dependent observations and unbalanced data. These models account for the heterogeneity in the frequency of observations due to factors such as injuries, team selection and changes in competition schedules, making them ideal for longitudinal sports science research (16–18). This flexible statistical approach incorporates both fixed and random effects allowing a comprehensive analysis of performance trajectories and allows researchers to include multiple predictors and account for individual differences while improving the accuracy of longitudinal trends and allowing for benchmarking. An additional advantage of the LMM is the ability to predict and forecast future trajectories (e.g., performance development) based on a combination of current and past information (10, 16, 19). LMM-predictions are calculated by combining the best linear predictor of random effects with the best linear estimate of fixed effects. Typically, predictions are made for a subset of explanatory variables at given values, while the remaining variables are either averaged or set to specific values. The prediction process involves selecting explanatory variables and relevant model terms, determining averaging variables, and deciding on appropriate weightings for the averaging across dimensions in the prediction model (10, 19). If accurate, such predictive capabilities could beneficially inform the decision-making and programming of sports scientists and practitioners. For example, Born et al. (11) demonstrated the utility of LMM in the development of normative data and percentile curves for long-term athlete development in swimming, demonstrating their effectiveness in establishing cohort-based performance benchmarks and individualized predictions. In addition, Antink et al. (20) highlighted the value of longitudinal data in formulating more accurate predictions of future athlete performance decline in Swedish veteran track and field athletes.

Taken together, performance trajectories and predictions of future performance can improve athlete and talent development. This study addresses the challenge of providing individualized performance predictions in youth athletics by leveraging advanced longitudinal modeling techniques. Unlike traditional percentile-based methods, this research integrates individual performance developments through linear mixed-effects models to establish benchmarks and forecast future performance, offering a novel tool for coaches and practitioners to support talent development. By generating a practical tool for practitioners, athlete assessment, individual athlete development programming, coaching intervention, and talent selection could be improved.

The primary aims of the study were: (1) to establish age-specific reference values using classical empirical percentile curves and progressive mixed model approaches, and (2) to develop a prediction model and a practical software tool to predict future performance development.

Methods

Subjects

To analyze race results from female 60 m sprint runners from competitions held in Switzerland between 2006 and 2021, a total of 160,852 observations were provided by the online and public database of the Swiss Athletics Federation. Only results from officially licensed outdoor competitions were selected for this study. In addition, only results for athletes aged between 6 and 15 (11.3 ± 2.1 years) have been retained in the database (observations $n = 160{,}667$). This was justified because the 60 m sprint is an official distance in Switzerland only up to U16. After that, the official distance is 80 m. All data were analyzed anonymously. The study was approved by the institutional review board of the Swiss Federal Institute of Sport Magglingen (Reg.-Nr. 227-2024) and by the ethical standards of the World Medical Association (Declaration of Helsinki). No written informed consent from the subjects was required, as the present study utilized only publicly available data that were analyzed anonymously.

Procedure and data analysis

To ensure a high quality of the data, results that deviated by more than 3 standard deviations from the average performance within each age category were identified as outliers and removed from further analysis. To be included in the data set for the longitudinal data analysis, only athletes with at least three seasons of participation (minimum for longitudinal analysis) were further considered (21). The season's best times were used to identify trends and development patterns over time. According to the later described statistical model, the three race results did not have to originate from three consecutive seasons. The final data set contains 41,123 observations from 8,732 different female athletes. All data analyses were completed using R statistical software (R Core Team) version 2024.04.2 + 764.

Empirical percentile curves vs. linear mixed model approach

Empirical percentile curves

To achieve the first aim of this study, which is to establish age-related reference values, two methods were analyzed. The first method, already used in sports science for modeling smoothed percentile curves, is the LMS method (11, 15). The LMS method is particularly effective for modeling growth and performance data as it accounts for skewness and kurtosis in the distribution (13). The GAMLSS (Generalized Additive Models for Location, Scale, and Shape) method was used to fit the LMS models, utilizing the gamlss function from the R package of the same name (22). This method provides a high flexibility, which is crucial for capturing complex variations in athletic performance across different ages. Only the 3rd, 10th, 25th, 50th, 75th, 90th and 97th percentile curves were then plotted for visual representation.

Mixed model approach

As a second method, linear mixed effects model (LMM) was used. LMM enables the analysis of longitudinal measures with a variable number of observations per subject without excluding data, in contrast to more traditional methods such as ANOVA. Furthermore, LMM is particularly well suited to explaining the development over time (16). To generate the reference values with the LMM, several steps were undertaken. First the predictive model explaining the relationship between sprint performance and chronological age (CA) was created. For that, a new variable CA_mindiff' (later called CAdiff) was calculated CAdiff = CA-min (CA) + 1, resulting in an x-axis intersection at one.

Then normal distribution of the data was investigated with a Q-Q plot and Kolmogorov tests. Both tests indicated non-normally distributed data ($p < 0.05$). The data were log-transformed to compensate for the non-normal distribution and to linearize the relationship between performance and CA.

In the next step of the LMM analysis, the best fitting mixed effects model was identified. Models were formulated using the LMER (linear mixed effects regression model) function from the lme4 (v1.1-31) package in R Studio (23). The initial model, with logarithmic sprint performance as the dependent variable, includes one overall fixed intercept and random intercepts for each athlete (represented by id). This model accounts for the variability in results across athletes who appear multiple times in the data frame and serves as the base model. Then stepwise forward variable selection was done to define successive models. The second model additionally introduces logarithmic age as a fixed effect, while the third model further includes logarithmic age as an additional random slope (see Table 2 for details).

To identify the best-fitting model for the present data, the analyses of the following parameters were undertaken: likelihood ratio test (higher is the value, the better the model), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) (with lower values indicating a better fit), assessed through the ANOVA function (24). After the identification step, model quality was further checked by controlling the linearity and normality assumptions. Linearity was assessed using a Tukey-Anscombe plot, while the normal distribution of random effects and residuals was evaluated using Q-Q plots. The Q-Q plot showed that the residuals were normally distributed, as evidenced by the predicted values aligning closely along a diagonal straight line across the standardized residuals (25).

The next step consisted in creating general reference values based on the best-fitted linear mixed model. For easier and practical interpretation of theses references, data were back-transformed to the original scale. Using the model estimation parameters, typical development patterns (mean trajectory, ±1 and ±2 standard deviations from the intercept) were plotted to visually assess the relationship between CA and performance. This relationship was expressed for the mean trajectory using the following equation:

$$sprint\ performance = e^{est\ intercept} * CA^{est\ slope}$$

With: est intercept: estimate of the fixed intercept

est slope: estimate of the fixed slope

To complete the reference values, the following typical development patterns ±1 and ±2 *standard deviations from the intercept* were defined adding ±1 respective ± 2 standard deviations of the random intercept of the grouping factor id to the estimate of the fixed intercept.

Individual forecasting model

In a subsequent analysis, the individual sprint performance results were plotted against the established reference values to visually depict each athlete's development trajectory. Forecasting models for each athlete were then derived by extracting the individual coefficients (intercept and slope) from the optimal mixed effects model. These coefficients were incorporated into the predictive equation, generating a tailored model that includes both fixed and random effects, thereby enabling the prediction of the athlete's future performance trajectory.

To assess the athlete's performance development relative to the overall group, percentile ranks were determined. Initially, the percentile rank of the individual intercept, which indicates the athlete's initial performance level, was calculated using the LMM. The same approach was applied to calculate the percentile rank for the individual slope, representing the athlete's performance progression over time. This method, inherent to the LMM, allows for the assessment of performance development across time rather than a singular performance point, as is typical with the LMS method.

Bootstrapping for prediction uncertainty

The accuracy of the predicting performance development is highly dependent on both the complexity of the model and the number of data points available for each athlete. To provide a robust assessment of this prediction, we used a bootstrapping approach to quantify the uncertainty surrounding individual performance predictions (26). Specifically, 1,000 bootstrap samples were drawn from the original data set. For each bootstrap sample, the mixed-effects model was re-estimated, allowing for the recalibration of individual-specific intercepts and slopes. These recalibrated estimates were then used to generate predicted performance scores across the CA range. The resulting distribution of predictions at each CA allows to calculate 95% confidence intervals, providing a detailed measure of uncertainty. These confidence intervals were then overlaid on the individual prediction curves, providing a clear visualization of the potential variability in future performance predictions.

Results

Dataset overview

This study analyzed 41'123 race results from 8,732 female 60 m sprint runners aged between 6 and 15 years in Switzerland, covering competitions held between 2006 and 2021.

Comparison: empirical percentile curves vs. mixed model approach

Empirical percentile curves

Using the LMS method with the GAMLSS function in R Studio, empirical percentile curves were generated for the dataset. These curves represent the 3th, 10th, 25th, 50th, 75th, 90th and 97th percentiles of performance over 60 m sprint across the different age groups (see Figure 1).

The analysis showed a clear trend of improving performance (faster times) with age for all the percentiles. For example, the median performance time (50th percentile—P50) decreased from 11.35 s at age 7 to 8.75 s at age 15. The percentage improvement is greater in the younger age categories [from 6 years to 7 years −0.60 s (−5.0%)] than in the older ones [from 14 years to 15 years −0.12 s (− 1.3%)]. The percentile curves provided reference values for evaluating individual athlete performance. Athletes performing at predefined percentiles (e.g., the 97th percentile) can be identified as exceptional performers compared to their peers.

Mixed model approach

Model comparison

According to the linear mixed effect model comparison analysis, the results indicated that Model 3 (CA_SLOPE) (Table 1) provided the best fit for the data [lowest AIC value (−152,493), $\chi^2 = 3{,}357{,}4$, $p < 0.01$]. Assumptions for model quality (linearity and normal distribution) were met, supporting the validity of our linear mixed model (For details of the model comparison analysis, see appendix). The development of the sprint performance over 60 m is best explained by the chronological age, including a subject-specific deviation from the overall relationship allowing the slope to vary by subject (Table 2). The addition of log(CAdiff) as random slope induces a supplementary significant and negative effect (beta = −0.18, 95% CI [−0.18, −0.18], t(41,117) = −255.44, $p < .001$; Std. beta = −0.63, 95% CI [−0.64, −0.63]) compared with the two other models. By specifying a random intercept for each individual, the fact that everyone's results may be correlated (for example, a fast individual today is probably fast tomorrow) is considered, which is highly probable in this context.

Benchmarks

In Figure 2, the plot shows typical development patterns for 60 m sprint performance from the best fitted LMM. The black solid line symbolizes the mean performance development (50th percentile). The dashed lines represent the deviations (± 1 SD and ±2 SD) to the mean performance development (i.e., the 2.3th, 15.9th,

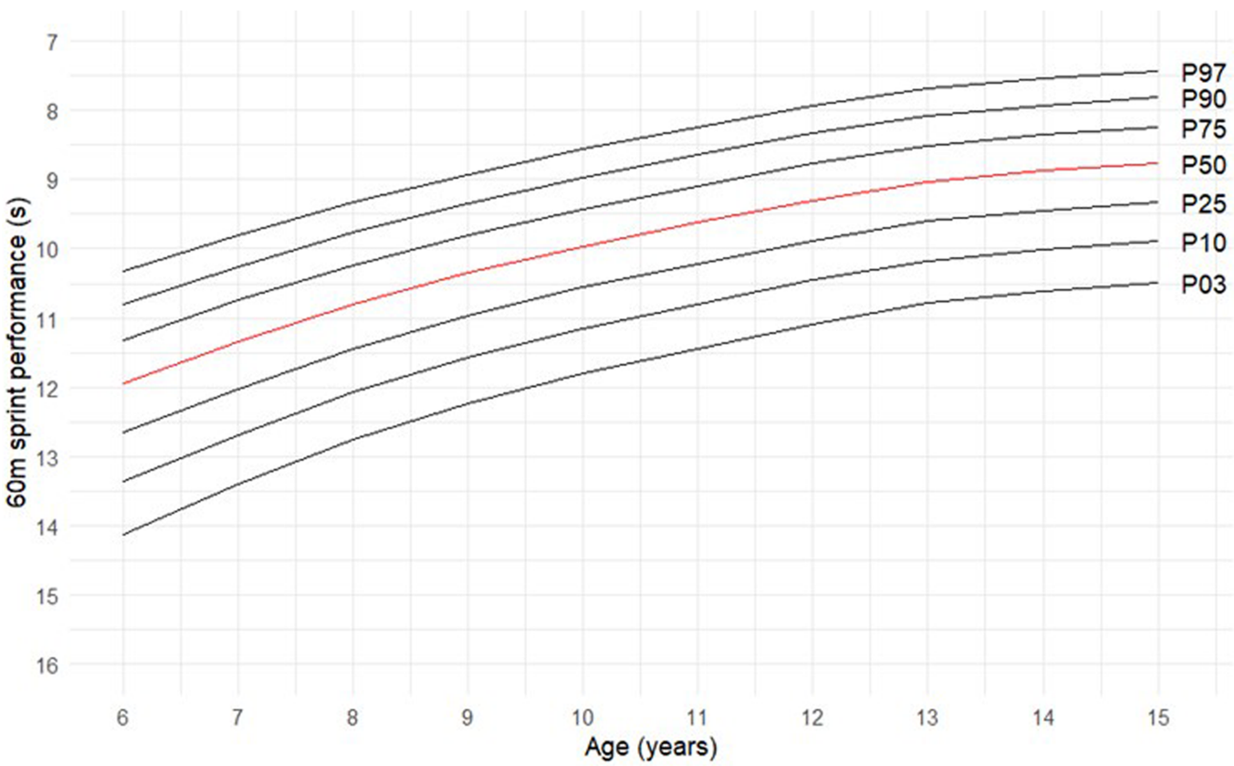

FIGURE 1
Empirical percentile curves elaborated with the LMS method for the 60 m sprint.

TABLE 1 Description of the mixed models.

Number	Name	Equation
Model 1	SPRINT_0	LMER (log(performance_sek)~1 + (1 | id)
Model 2	CA	LMER (log(performance_sek)~log(CAdiff) + (1 | id)
Model 3	CA_SLOPE	LMER (log(performance_sek)~log(CAdiff) + [log (CAdiff) | id]
Model 1	SPRINT_0	$\log(\text{performance\_sek}_{ij}) = \beta 0 + b0_j + \varepsilon_{ij}$
Model 2	CA	$\log(\text{performance\_ sek}_{ij}) = \beta 0 + \beta 1 \log(\text{CAdiff}_{ij}) + b0j + \varepsilon_{ij}$
Model 3	CA_SLOPE	$\log(\text{performance\_ sek}_{ij}) = (\beta 0 + b0_j) + (\beta 1 + b1_j) \log(\text{CAdiff}) + \varepsilon_{ij}$

TABLE 2 Details of the best fitting model.

Predictors	log(performance sek)		
	Estimates	CI	*p*
(Intercept)	2.5899	2.5873–2.5926	<0.001
CAdiff [log]	−0.1775	−0.1789 – −0.1761	<0.001
Random effects			
σ^2	0.0007		
$\tau_{00\ \text{id}}$	0.0090		
$\tau_{11\ \text{id.log(CAdiff)}}$	0.0019		
$\rho_{01\ \text{id}}$	−0.84		
ICC	0.8204		
N_{id}	8,732		
Observations	41,123		
Marginal R^2/conditional R^2	0.5902/0.9264		

σ^2, Residual variance; $\tau_{00\ \text{id}}$, variance of the random intercepts across individuals; $\tau_{11\ \text{id.log(CAdiff)}}$, variance of the random slopes for log(CAdiff) across individuals (id); $\rho_{01\ \text{id}}$, correlation between the random intercepts and random slopes; ICC, Intraclass Correlation Coefficient; N_{id}, Number of id.

84,1th, 97,9th percentiles). The gray lines represent each individual model. For a more practical interpretation, the plot is represented back-transformed to the normal scale.

Performance prediction

The mixed model's ability to predict future performance was evaluated using the longitudinal data. Individual performance trajectories were plotted, and future performance was forecasted based on the model. As the prediction is dependent on model's complexity and the number of existing datapoints for the considered athlete, an accuracy of the prediction was calculated with a bootstrapping approach. The accuracy is shown in Figure 3 for an example case of an athlete, with the light blue area.

Interpretation of individual trajectories

Individual performance trajectories revealed that athletes with higher initial performance levels showed less improvement over time compared to those with lower initial performance levels. This was evidenced by a negative correlation between random intercepts and slopes (r = −0.84).

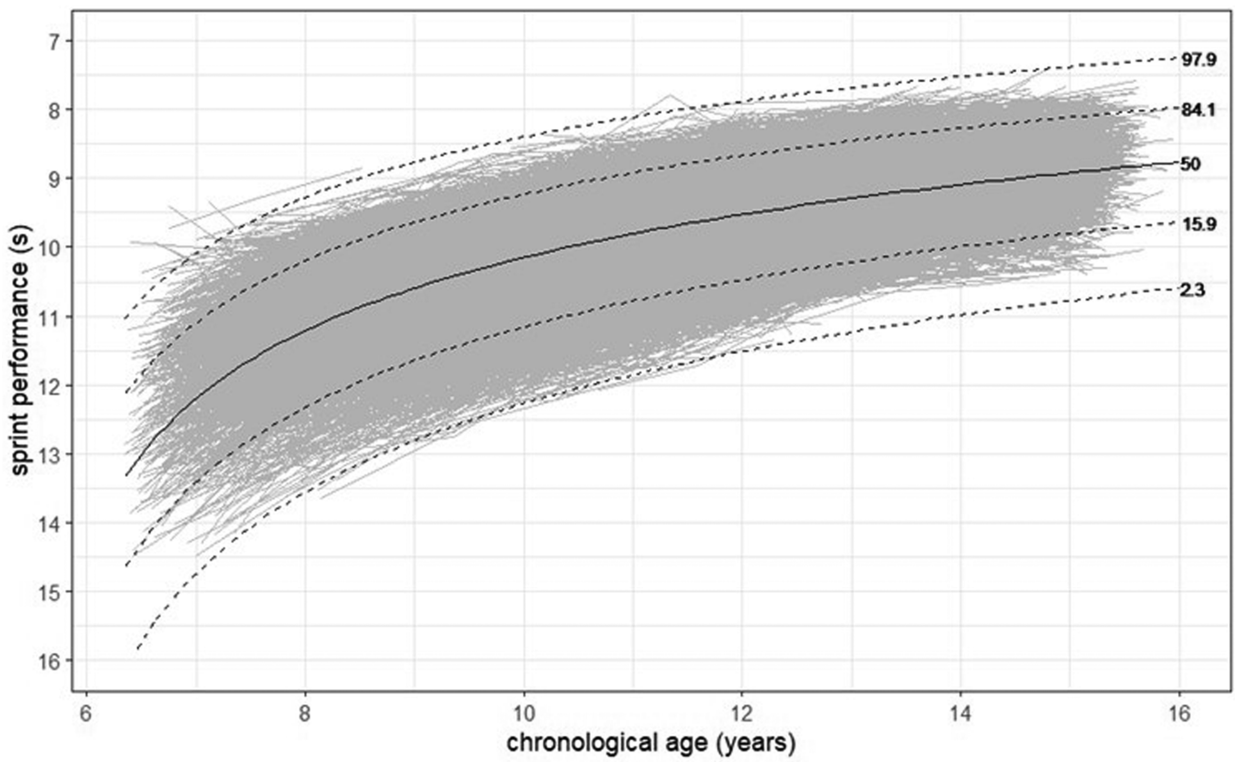

FIGURE 2
Back transformed data to normal scale with individual models.

In Figure 3, the individual model of a case athlete example (dashed blue line) and her actual performance results (solid blue line) are depicted. By considering the individual athlete's data, both the intercept, which describes the initial performance level, and the slope, which represents the development trajectory, were extracted and percentile ranks were calculated. This approach allows the athlete to be positioned relative to the overall group and is of great interest for long term athlete's development. For example, the analysis indicated that the athlete example depicted in blue had an initial performance level situated at the 14,6th percentile. In comparison to the overall group, this athlete exhibited a very good progression in performance improvement, as reflected by a result at the 97,9th percentile. This comparison highlights the variability in both starting performance levels and developmental trajectories among athletes.

Practical tool

A shiny app (https://baspo-ehsm-tw.shinyapps.io/sprint_60m_w/) was developed to assist coaches and athletes in predicting future performance (Figure 4). Based on the least three season's best times, the tool predicts performances for the next seasons. As reference values, typical development patterns of the population obtained from the LMM are represented in the background.

Discussion

The primary objective of this study was to provide age-specific reference values using percentile curves for 60 m sprint performance and to develop a prediction model and a practical software tool for predicting future performance development. Mixed models were able to deal with the complexities of such longitudinal sports data, such as multiple dependent observations and unbalanced data sets. Compared to traditional ANOVA, this approach can provide comprehensive benchmarks and predictive models for performance development.

The results indicated that the best-fitting model included log-transformed chronological age as a fixed effect and both a random intercept and slope for each athlete, demonstrating that these variables significantly impact performance development. This finding is supported by existing literature, which suggests that individual growth patterns and the ability to handle multiple performance observations are crucial for accurate performance prediction (27, 28). This aligns with the findings by Newans et al. (16), who highlighted that traditional repeated measures ANOVA would exclude a significant portion of data, thus limiting the analysis. In this study, mixed models allowed us to include all available data points, regardless of missing data, which is a common occurrence in sports due to factors such as injuries and team selection. The mixed model analysis provided detailed individual performance trajectories, allowing for precise

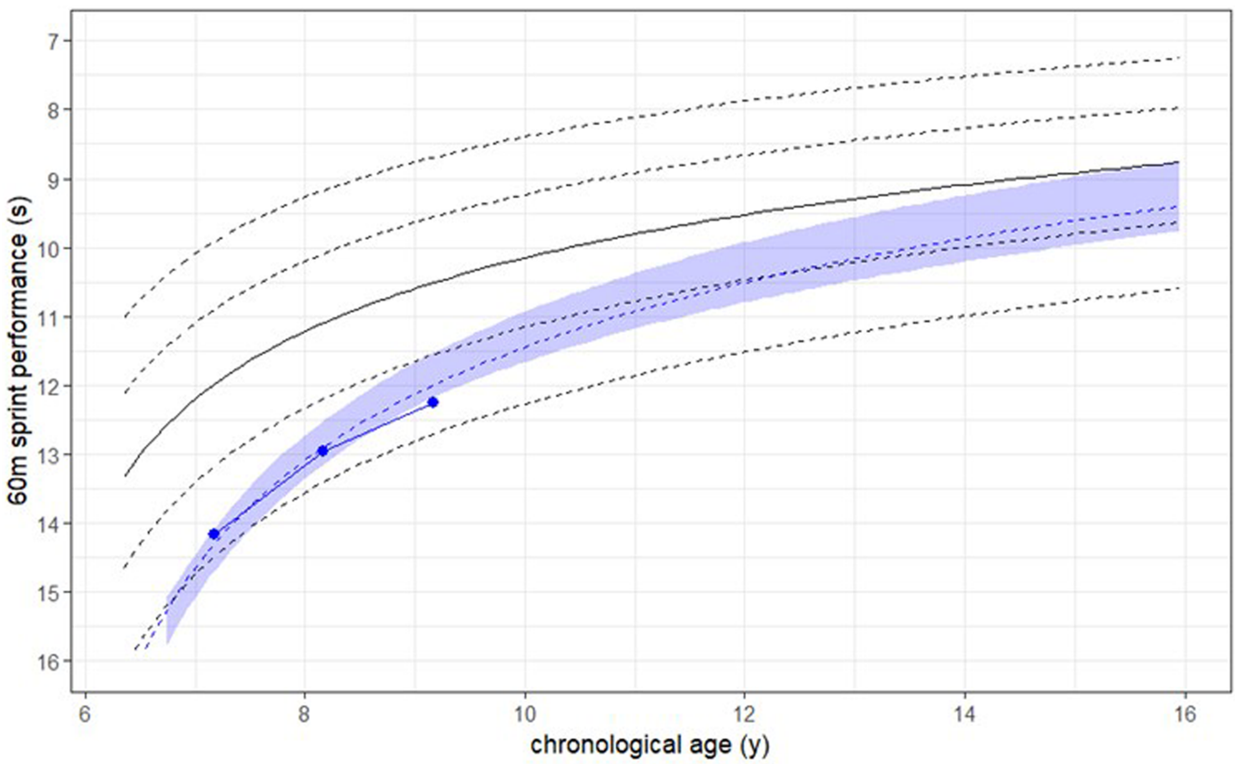

FIGURE 3
Representation of competitions' performances of a case athlete example (blue dots) with her performance prediction (dashed blue line) and the respective prediction's accuracy (light blue). Black lines represent the global performance development from the overall population.

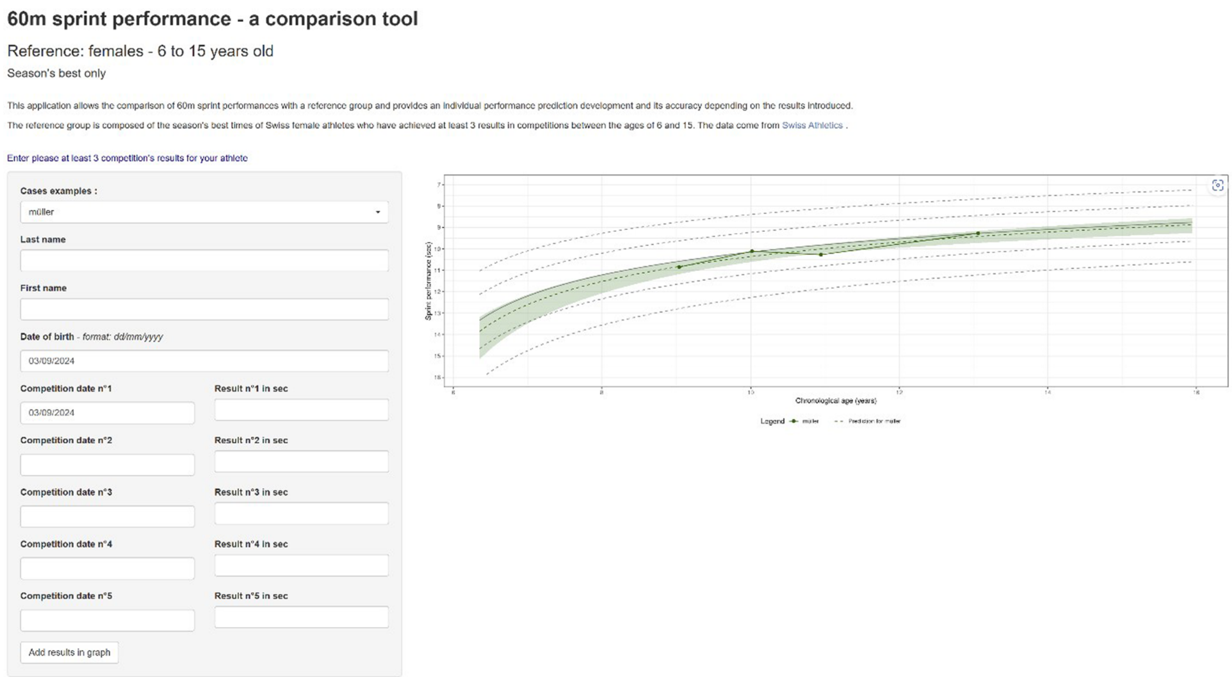

FIGURE 4
Practical tool for performance prediction.

benchmarking and a realistic performance prediction. Athletes with higher initial performance levels (higher positive intercept) exhibited lower positive slopes, indicating less room for improvement. This inverse relationship between initial performance and improvement potential aligns with previous studies in sports science (17). The ability to predict future performance based on individual trajectories is a significant advancement, offering practical tools for coaches and sports scientists to set realistic training goals and can help to identify promising young athletes.

International comparison: article de Tonnessen et al. 2015: only the 100 best athletes from 11 to 18 years old over 60 m (similar progression in performance).

Methodological considerations

Mixed models offer several advantages over traditional ANOVA, particularly in the context of longitudinal data analysis. They provide greater flexibility in handling missing data, incorporate both fixed and random effects, and allow for the inclusion of multiple predictors. This makes them particularly suited for sports science research, where data heterogeneity and non-standardized measurement intervals are common challenges (29). Furthermore, in our case, the linear relationship between the dependent variable and the explanatory variable obtained through logarithmic transformation makes data analysis more accessible. It may be that, by analyzing other relationships and/or integrating more parameters into the model, the relationship is no longer linear, necessitating the application of more complex mixed models. Making practical application less affordable.

The application of mixed models in our study allowed for a more nuanced understanding of performance development. By explicitly modeling time and accommodating individual variability, mixed models provided insights that would not be possible with traditional methods. For instance, the ability to model individual trajectories and predict future performance offers a significant practical advantage for talent identification and development programs.

Practical implications

The model provides a robust framework for benchmarking athletes' performance development relative to their peers, enabling coaches to identify talent and athletes with exceptional potential. Furthermore, the predictive tool facilitates the assessment of individual performance trajectories and the establishment of realistic, data-driven performance goals. By leveraging this tool, coaches can evaluate training effectiveness and detect critical periods that require attention, such as declines in performance, stagnation, or significant improvements. Identifying these patterns creates opportunities for meaningful dialogue with athletes to uncover and address the underlying causes of deviations from expected trajectories. By incorporating a limited yet impactful set of explanatory variables, the current model offers a streamlined and practical approach to understanding factors influencing performance development. For example, a declining trajectory might signal the need for modifications to training loads or recovery practices, while surpassing age-specific benchmarks could indicate readiness for more advanced challenges. These practical applications highlight the value of integrating advanced statistical models and longitudinal data into athlete development, bridging the gap between research insights and actionable coaching practices. Our findings emphasize the importance of continuous monitoring and assessment of athletes' performance over time. By utilizing longitudinal data and advanced statistical methodologies, coaches and sports scientists can make evidence-based decisions that enhance athlete development, improve training outcomes, and optimize resource allocation.

Limitations and future directions

Despite the strengths of our study, some limitations warrant consideration. The reliance on existing competition performances introduces potential biases related to competition level, age groups, and specific timeframes. Additionally, the retrospective nature of the analysis and the treatment of outliers could influence the observed performance trajectories. Future research should aim to combine retrospective and prospective data collection with standardized protocols and databases to provide a more comprehensive understanding of athlete development. While the principles of longitudinal performance tracking are broadly applicable and unspecific to sex, physiological and developmental differences between females and males influence performance trajectories. Future studies should therefore establish percentiles and provide the predictive tool for young male athletes. Additionally, sex comparisons may reveal interesting insights into performance development, hence may identify possible specific or generalizable trends. As shown in this study the LMM provides improved prediction of athletes' performance. Future research should expand this approach to include additional key performance parameters and biological age, which were not considered in the current study. In addition, mixed models should be applied in different sports, age groups, and both genders to validate and extend the results of this research.

Conclusion

Our study provides performance trajectories and benchmarks using classic LMS percentiles and mixed models, which help to overcome multiple dependent observations and unbalanced datasets in longitudinal performance data and provide a predictive model for future performance. The results provide valuable insights into the complexities of talent development and highlight the importance of using appropriate statistical methods for continuous assessment and benchmarking. The benchmarks and predictive models generated by this research provide practical tools for sports practitioners. The tool can help predict future performance based on individual trajectories, which is a significant advance for coaches and sports scientists. Further research building on this foundation can enhance our understanding of athlete development across different sports and will improve evidence-based practice in sport.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

MR: Writing – original draft, Writing – review & editing. MJ: Writing – original draft, Writing – review & editing. JH: Writing – original draft, Writing – review & editing. LH: Writing – original draft, Writing – review & editing. ST: Writing – original draft, Writing – review & editing. SC: Writing – original draft, Writing – review & editing. D-PB: Writing – original draft, Writing – review & editing.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2024.1491064/full#supplementary-material

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Insights into coaching a women's national futsal team

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Introduction: Tournament coaching is known to provide different challenges to coaching a team across a regular season. There is limited time to prepare, meaning that team roles and objectives need to be established quickly, and communication must be effective.
Method: This interpretive ethnographic case study explored how the coach of a women's national futsal team approached this, while competing at a week-long tournament in preparation for a World Cup qualification event.
Results: Following the completion of five interviews (one prior to, three during, and one post tournament), thematic coding produced three main themes: (1) Keeping consistency in development and focus, (2) Communicating openly, and (3) Individualizing approaches.
Discussion: The coach established a clear goal for the tournament, with the focus on the team's game plan and ability to implement the tactics they want at the World Cup, which helped create performance targets that were independent of the results to help maintain consistency. A transformative leadership style, underpinned by free communication empowered the players to buy into the system and enhanced motivation and commitment. The coach, with her staff, made a deliberate effort to spend time individually with players, as this allowed players to create autonomy, which enhanced commitment. The findings provide insights for coaching women's teams in general and add further information about coaching in an idiosyncratic tournament environment.

KEYWORDS
high-performance sport, international tournament coaching, team cohesion, team development, coaching behaviors, coach communication

1 Introduction

Numerous models (e.g., cognitive mediational, athlete-coach relationship) have been developed to assess coaching and leadership effectiveness (1–4). While differences in these can be identified based on contextual factors and specific foci of each model, a general consensus is that successful outcomes for athletes and teams are influenced by the coaching style, athlete characteristics and the coach-athlete relationship (5). However, these assume time is available for the coach to build effective relations and to develop a long-term plan to help athletes grow and meet the desired goals. In tournament environments, where selected athletes are brought together to form a national team, this may not always be the case, making tournament coaching a unique environment with unique stressors (e.g., limited time, role clarity) for the coach and the team (6).

Salcinovic et al. (7), identified four key factors to successful team performance (1) leadership style—where better performance was found with open communication and transformative leadership, (2) performance feedback—where learning, reflection and positive reinforcement enhance performance, (3) supportive team behaviour—with clear team structure and strong group identity preferred, and (4) team orientation—with improved performance attributed to knowledge sharing, functional diversity and team cohesion. Underpinning all four factors is the need for effective communication.

Of the little research related to tournament coaching, Donoso-Morales, Bloom and Caron (8) found that planning and communicating expectations to be key coaching components necessary for success. At tournaments the time for preparation is significantly shorter than in regular season coaching, which increases the pressure on both coach and athlete (9). In many sports, particular futsal, tournaments are not common and major events only occur every two years. Therefore, there is a need to ensure that clear goals are created that allow each individual in the team to understand their role, focus on their objective and prioritise team development. Alongside planning, the coach needs strong communication skills, to ensure each athlete knows their role and the expectations of them (10). Within the time constraints that tournaments instill, the ability to build trust and team unity quickly is critical for success (6). It is also important for the coaching staff to manage their own emotions (i.e., using mindfulness) and keep their body language positive, as this will keep the athletes focused (8).

The limited research that has investigated women's sport teams has highlighted the need for empowerment coaching approaches to be crucial for successful performance (11). By allowing the team input into decisions and utilising a transformative leadership approach members become more motivated and can perform above expectation (7). Donoso-Morales et al. (8), noted that because the stakes are higher at a national championship more stress is perceived. For these coaches, implementing effective emotional management techniques was crucial for their team's success, with coaches specifically planning relaxation activities into the program (8). Management of emotions during the tournament was helped by setting performance goals that were within the athletes' control.

Due to the minimal research available focusing on coaching at a tournament and coaching women at a sport tournament, the aim of this case study was to identify the actions and approaches a national women's team futsal coach employed during a week-long tournament. Of specific interest was how the coach managed the players, built team cohesion, and communicated with the playing group, and how these actions and approaches developed as the tournament progressed. Further, with the continual growth in women's futsal at international level, and the inaugural FIFA world cup in 2025, this knowledge can help other coach's and team to be better prepared for major events.

2 Methodology

2.1 Participant

The participant was appointed the head coach of a women's national futsal team a few months prior to taking the team to the Futsal Women's June Cup, a preparation tournament for the 2025 World Cup qualifying event to be held later in the year. She was a former professional player and member of the national team in both football and futsal. She had previous coaching experience in both women's and men's football and futsal but not at international tournaments, and as a physical education teacher. She was supported at the tournament by an assistant coach, physical conditioning coach, physiotherapist, and doctor (all women) and a goalkeeping coach (man). The tournament was played across a one-week period, with the team spending nine days living together in hotel accommodation. No further details are provided, to maintain some confidentiality for the participant and team.

2.2 Research design

An interpretive ethnographic case study design was utilized with the coach interview on separate occasions in the buildup to the tournament, during the tournament and after the tournament had finished. An interpretive paradigm aims to provide and understanding of the human experience (12), while ethnography allows for the phenomenon to be examine in its natural environment (13). The benefit of ethnography is allowing a holistic and immersive approach to research (14), and encourages continued engagement over time (15). The unique nature of tournament coaching makes this a valued methodological approach to gain the insights into processes and procedures that can fluctuate rapidly due to competition results and/or other coaching and non-coaching factors.

2.3 Research procedure

Semi-structured interviews were conducted by the first author with the coach on five separate occasions. An initial interview was completed before the tournament commenced, followed by three interviews during the course of the tournament, and finally a reflective interview was completed three days after the tournament finished. Guided by the contemporary literature, interview questions focused on the coach's approach to developing cohesion within the team, her approach to building relationships with each player, the process of working with other coaches and support staff, how coaching strategies were adapted between games, and reflections on challenges that occurred. Prior to the interviews an external subject specialist and research provided feedback on the interview guide to enhance quality. The aim of each interview was to capture how the coach worked with these athletes and managed the known time pressure, and how she adapted her coaching to meet the needs. Each interview was recorded and transcribed to produce 77 pages of single-line text that produced a detailed record of the lived experience.

2.4 Data analysis

Inductive, thematic coding, as suggested by Rivas (16), was employed by the first author on the interview transcripts, using Nvivo 13 software (Lumivero). Firstly, the transcripts were read and re-read to obtain familiarity with the content. During this process memos were created to identify information deemed important to the phenomenon being investigated. Next, a zigzagging strategy was implemented to identify initial codes, that guided subsequent data coding to refine the thematic codes. The transcripts and codes continued to be analysed until no new data emerged. *in vivo* codes, which keep the lived experience, using gerunds (17) were applied on a sentence-by-sentence basis, which helps to avoid misinterpretation. Next these codes were grouped into categories that were reviewed to form lower-order themes. These lower-themes were then grouped into distinct higher-order themes of the greatest generalisability. At each stage the other members of the research team reviewed and reflected on the emerging codes and themes.

3 Results

Three higher-order themes were identified during the thematic coding: (1) Keeping consistency in development and focus, (2) Communicating openly, and (3) Individualizing approaches. These were developed from eight lower-order themes that pertained directly to coaching this women's team. See Figure 1.

3.1 Keeping consistency in development and focus

A crucial component to the development of the team was to be consistent in what they were doing and focusing on. As a preparation event for the World Cup qualifiers later in the year, this tournament was focusing on the team's tactics and strategies, ability to work together, and how they could react to different game scenarios. The coach explained:

> We are using this as an opportunity for all the players and we just we learn from the mistakes. I don't have problems with making mistakes. You need to continue trying what we are doing and telling you to do and that's it.

This meant that the team tactics for each game stayed the same for each match, as the coach tried to implement her system to the playing group. As the tournament continued, the coach aimed to empower the senior players to provide input. "[older players, specifically player #1] is taking the responsibility. She is responding well. She is there for them. She's a good leader, along with maybe two or three other girls that are asking questions and are very intelligent in their communication".

There were some specific strategies used to keep this consistency. Primarily a positive approach was taken in all areas, with the team focused on what had gone well and not dwelling on performance errors. This positivity allowed the players to concentrate on development and not worry about being called out for mistakes, as many of them had sometimes experienced in the past. The coach elaborated, "we are taking a much more focused, positive kind of thing and there doesn't need to be the more aggressive kind of style within what we're doing". This encouraged the players to be more proactive and less anxious. As a result, the players appeared to become more empowered and would contribute further to the team development. It also allowed some of the younger players to become more integrated into the team, which was a crucial part of planning for the future. Similarly, the players were also more willing to accept decisions made by the coaching staff. For example, the decision to allocate players to rooms based on position was understood. The coach explained,

> I was thinking a lot because I was doing the plan and the schedule for their rooms, together with the staff. And that's something that we also did good because we changed a little bit. So, they can know each other and for example, the goalkeeper, who is a little bit older, she normally was in with her friend, but now we've put the goalkeepers together. The three goalkeepers together and on the first day it was "*Oh*

FIGURE 1
Higher-order and lower-order themes.

> *my God, I have to go with another goalkeeper*" … But yesterday at the individual meeting, she said that she is very positively surprised because they started to talk. They are building relationships.

Following the tournament, the coach reinforced this positive approach by "talking to the girls and I asking each of them to say what was the most valuable moment for each of them". This reflection will form the base of the future team development activities.

3.2 Communicating openly

After playing under more autocratic male coaches in her playing career, the coach was aware that a more open and free communication style was required to engage the players and encourage them to play to their potential. She made time for players to speak in team meetings, which helped create a positive energy and calmness within the playing group, and increase cohesiveness. She explained, "their energy is very good. They are very calm. They feel like they can express themselves. They feel like they can ask question". They continued to explain that it was important that, "I'm not here to forbid anything. I want them to choose what they want to do". This open communication encouraged team development and autonomy. While it was difficult for the players who were not used to such an approach, to engage initially, they soon opened to the process and used this to develop the team culture and cohesiveness. This was enhanced after the tournament when the coach, "had a final meeting with them before leaving for home. You know before everybody goes on their way, to give them some goals for the future; What we expect from them or what is the idea of the national team". This ensured that this tournament was not seen as just an individual occasion but rather part of a bigger picture and development towards the World Cup qualification.

The head coach was also responsible for the wider coaching and sport science team. Within this, she needed to ensure that these staff adopted her philosophical approach to the team. Key was "good communication" between them. She explained,

> I would say the energy of my staff is very professional when we are working and very relaxed when we are off the pitch, and they are also in good communication with the girls. So, I think we are kind of transferring the good energy and the normal behavior towards them.

In particular she worked closely with her assistant coach and used this opportunity to help develop her [the assistant] coaching skills. "My assistant coach also is growing… She doesn't have a lot of coaching experience, so it is normal that sometimes she misses small things in communication and the coaching elements. But then when the timing is right, we talk to each other about what is important". This was also a deliberate ploy to ensure the assistant's role at future tournaments could be enhanced.

3.3 Individualizing approaches

A deliberate effort was made by the coach to individualize plans for players. This included physical training, video feedback and personal planning sessions with each player. By doing so, the coach was able to further develop player autonomy and ownership and provide clear objectives for each player that was role specific. "I had individual meetings with them just to hear their feedback and how they feel", the coach explained. She focused on this specifically because she thinks it was essential when working with women.

> I think it is different in the way that when girls feel that they have support and they have trust in their coach, they give you more and they open even more, you know. Boys are like, they just want to play football. But girls need time to feel that they can express themselves and that's what is happening when you are communicating fairly with them.

The positive results of this approach were easily observed by the coach, particularly in the younger players. She explained, "I had individual training sessions with six younger players. And when we isolated from the [older players], they were blossoming. Like they, they received the tactical information easily and they managed to do that in the game".

The willingness of the coaching staff to be open to individual player needs, was helpful in building positive relations between the staff and players. The players were able to respect that the coaches understood their situation and that the coaching team was there to support the players. To develop the team culture further, the coaching team used the senior players to help set standards and behavioural norms.

4 Discussion

Within the refinements of a regular season, coaches have recognised the need to implement activities that are designed to better prepare their athletes for end of season championship tournaments (10). A similar approach was taken by the coach in the current study, as she aimed for consistency in development and focus with an eye on the more important World Cup qualifying tournament later in the year. While no research has assessed the effectiveness of this approach, anecdotal reports note that this is common for coaches in tournament settings. Keeping the focus on development and reducing the emphasis on the end result is highly valued by female athletes (18), and this helped the coach to develop a strong coach-athlete relationship. To achieve this the coach provided clear goals, expectations and behaviours for the players. Donoso-Morales et al. (10) have previously identified that this becomes even more critical in the tournament setting, especially as emotions can be heightened by the increases in stakes. During a tournament, supportive coaching behaviours can also enhance performance (19), with female athletes also valuing the development of transferrable skills and personal support (20).

For female athletes, coaches need to adapt their coaching to meet the athletes' needs (21), with transformative coaching approaches appearing more beneficial in tournament settings (8). The coach in the current study made a conscious effort to do this by implementing an open approach to communicating with her players and other staff. Further research is required, but this could also be a method to ensure better athlete wellbeing (22) Stewart (18) noted that a positive coach-athlete relationship allows for more open communication, and despite the intensity of being a tournament the coach concentrated on positive outcomes and provided feedback that encouraged athlete autonomy. The open communication also ensured that each player and staff member understood their role and responsibility, which is essential to succeed in a tournament (6). The coach in the current study reflected on the importance of this approach to building cohesiveness within the staff.

An empowerment approach is beneficial for coaches to build team cohesion and encourage a quick acceptance of the team goals and culture (7). A key focus for the coach in the current study was to work with each player individually, building their capacity to perform at this level and create individualised development plans. Like Vallée and Bloom (11), this included both on and off court components. Individualising plans for female athletes is an important component of building coach-athlete relations (21). Within the tournament environment this is more challenging, as the head coach is also responsible for the planning and management of all activities at the tournament (6) and therefore, can be time challenged by other demands. However, coaches who are more structured and unwilling to adapt reduce female athletes' willingness to participate (18). Similar ideas have been suggested for female athletes management of injury (23), and how to address gender environmental challenges faced by female athletes. As such, coaches need to be aware of the emotional climate of a tournament and adjust accordingly. One strategy employed by the coach in the current study was to use more experienced players to help reinforce standards and expected behaviours. While the effectiveness was not specifically measured, the coach recognised this to been well received by the players and important for development. Donoso-Morales et al. (8) noted that the use of other players to provide leadership is helpful in tournament environments. By doing so, the coach can create others to be role models for less experienced members of the team, which many female athletes desire (20).

5 Conclusion

There are significant challenges to coaching in a tournament that are not present in general coaching settings. The time constraints require coaches to plan in detail and clearly communicate with athletes and support staff. The current study adds to the developing knowledge of how coaches manage this, identifying three key strategies: keeping consistency in development and focus; communicating openly; and individualising approaches. The development of positive coach-athlete relations, where the dyad has mutual trust, aids the process. This appears especially true for female athletes. The coach needs to adapt to what is happening during the tournament and understand how this may influence the emotional climate for the athletes. For the coach in the current study, staying positive and empowering her players to develop autonomy allowed for success. While this can be more difficult at a tournament, it is essential that the coach understands this and adapt their behaviour to meet the athlete needs.

Data availability statement

The datasets presented in this article are not readily available because there is a limited population that the data could come from and in order to keep some confidentiality for the participants the data is restricted, but an edited version can be requested. Requests to access the datasets should be directed to fcarson@lunex.lu.

Ethics statement

The studies involving humans were approved by LUNEX Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

FC: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Visualization, Writing – review & editing. TN: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Visualization, Writing – review & editing. KB: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – review & editing.

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