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40 years of relative age effects in sport: lessons from the past and directions for the future

Edited by
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40 years of relative age effects in sport: lessons from the past and directions for the future

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Editorial: 40 years of relative age effects in sport: lessons from the past and directions for the future

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Editorial on the Research Topic
40 years of relative age effects in sport: lessons from the past and directions for the future

Introduction

2024 marked 40 years since Grondin, Deshaies, and Nault's (1) seminal work on relative age effects in sport. In their article, *Trimestres de Naissance et Participation au Hockey et au Volleyball* [Birth Trimesters and Participation in Hockey and Volleyball], they analysed the birthdate distribution of competitive youth and professional ice hockey and volleyball cohorts from North America. They revealed that players born in the early months of the selection year were overrepresented, whereas those born later in the year were underrepresented in ice hockey, although this pattern was not observed in their volleyball sample. Unaware of this article, Barnsley, Thompson, and Barnsley (2) shortly after reaffirmed these results in North American ice hockey, coining the term "relative age effects" (RAEs) to describe the phenomenon. They argued that the age group structures used to band athletes contributed to the loss of potentially talented individuals, as the abilities of relatively younger athletes were not accurately reflected in their performance due to age-related disadvantages. These foundational studies went on to inspire hundreds of relative age investigations worldwide.

Fast forward to today, and despite these early warnings, RAEs have proven remarkably persistent and difficult to mitigate in high-performance sport systems [see (3–6) for reviews; see (7–9) for editorials]. Notably, RAEs have been shown to be widespread across both boys' and girls' youth sport, significantly influencing the processes of identification, selection, and development of young athletes (10). These effects have, in turn, shaped long-term outcomes related to performance, participation, and personal development in sport (11, 12). Over the years, the relative age literature has reinforced several other key insights. For example, RAEs have tended to be more pronounced in popular sports such as basketball, soccer, ice hockey, and rugby (13), as well as in more competitive contexts as athletes progress into talent development systems (14).

The 40th anniversary of the original relative age studies offered a timely opportunity to reflect on developments in both research and practice. It also served as a prompt to look

ahead and consider how athlete development systems can be improved to better serve all individuals, regardless of birth month. To help achieve this, we created this research topic as a platform for researchers and practitioners to reflect on RAEs and consider how we can move this area forward. As part of the call for articles, we felt it was critical for the field to adopt methodologies that not only reviewed the extensive body of literature across different sport settings, but also applied theoretical frameworks to deepen our understanding of how RAEs occur. Importantly, to influence practice beyond academic discussion, we believed it was essential to also capture studies that designed, implemented, and evaluated a range of relative age solutions across sporting environments. It was hoped this would encourage the development of targeted, evidence-informed interventions capable of addressing relative age disparities in meaningful, context-sensitive, and sustainable ways. Given that different sports are likely to require bespoke strategies [e.g., age- and size-based banding, birthday-banding, corrective adjustments, and competency-based banding for team, racket, timed, and combat sports, respectively (15)], further investigations into the mechanisms behind RAEs from multi-, inter-, and trans-disciplinary perspectives were also welcomed.

The purpose of this editorial is to summarise our research topic: *40 Years of Relative Age Effects in Sport: Lessons from the Past and Directions for the Future*. Based on the articles included, we have focussed on five key areas that emerged: (a) methodological reflections, (b) developmental pathways and career trajectories, (c) relative age and biological age, (d) relative age solutions, and (e) lessons from the past and directions for the future.

Methodological reflections

In total, 85 authors from 14 countries contributed to the 23 articles included in this research topic. Studies were a mixture of quantitative ($n = 16$), qualitative ($n = 2$), and mixed method ($n = 1$) approaches. The majority of submissions were empirical studies ($n = 20$), with perspectives ($n = 2$; Grondin; Sweeney et al.) and a reflection ($n = 1$; Barnsley) also included. Of the empirical studies, 14 used analyses of large datasets to examine the prevalence of RAEs over at least one season, and of those articles, eight tracked RAEs over two seasons or more to examine historical trends. The remaining empirical studies used a mixture of measurement data ($n = 2$), questionnaire data ($n = 1$), interview data ($n = 1$), and some combinations of these approaches ($n = 2$). These empirical studies included a total of 213,789 participants (or individuals within the sample under investigation if secondary analysis was used), with 91,802 of those being women and girls, and 118,288 being men and boys. The individuals at the focus of the research came primarily from Europe and North America, with the two most represented countries being Germany ($n = 4$) and Spain ($n = 3$).

Within the articles, 16 focused on athletes and RAEs, two focused on the perceptions of interest holders on RAEs and potential solutions, one focused on the relative age of coaches, and one focused on the perspective of coaches. The most popular sport researched was, unsurprisingly, soccer ($n = 11$), followed by ice-hockey ($n = 3$), and handball ($n = 2$), while under researched sports such as fencing (Bonito et al.), orienteering (Ferriz-Valero et al.), squash (Kelly et al.), and swimming (Difernand et al.) were also examined. Women and girls were the sole focus of four studies, men and boys were the sole focus in eight studies, while another five studies included mixed genders, with the remaining two empirical studies not reporting the gender of participants.

With regard to procedures and analyses, some new and novel approaches were used. For example, Schorer et al. employed a retrospective and a longitudinal method. This approach helps to illuminate changes over time in birth quartile distribution, reiterating the need for relative age research to embrace longitudinal designs. It was also encouraging to see two studies (Kelly et al.; Smith et al.) employ interviews to gain the subjective experiences of those who influence and interact with RAEs. As well, one of the few studies that examined RAEs in the coaches themselves was included in this special issue (see Grondin et al.). This variety of samples and approaches presents a more nuanced and dynamic portrait of the impact of RAEs across multiple sport systems (see Table 1 for a summary of the articles included).

Developmental pathways and career trajectories

As expected, there were several studies that examined RAEs across athlete development pathways, particularly in soccer. While some of these used typical approaches to identifying and considering RAEs (e.g., Heilmann et al.; Peña-González et al.), the samples and research questions explored extended our knowledge to new populations. For instance, Pérez-González et al. showed RAEs existed in four of the five top five European women's football leagues, highlighting the knock-on effects of relative age at senior levels. Other studies used untraditional approaches to examine the impact and development of RAEs, such as the use of survival analysis to examine sport dropout in French swimmers by Difernand et al.

Perhaps most notably were the impressive number of studies examining RAEs from longitudinal and developmental perspectives. Many of these (e.g., Brustio et al.; Lemoyne et al.; Morganti et al.; Schorer et al.) emphasised the need to use longitudinal designs to track changes in athlete populations over the extensive time course of athlete development. As an example, Wang et al. used cohort data over 44 years to assess how time impacts RAEs, helping to better understand the career trajectories of professional ice hockey players. Relatedly, Smith et al. emphasised that RAEs can take multiple forms over a long period, reflecting the reality that what appears to be a very simple and straightforward phenomenon is, in fact, multifaceted and complex with varied influences and implications.

Relative age and biological age

Several papers analysed the role of relative age and biological age. This work emphasised that, while they are both vital to

TABLE 1 Summary of the articles included in this research topic.

Author(s)	Submission Type	Method(s)	Number of Participants/ Sample Under Observation	Role of Participant/ Sample	Number of Men/Boys	Number of Women/Girls	Country of Participant/ Sample	Sport	Level of Competition
Kelly et al.	Qualitative	Interviews	15	Coaches	14	1	England	Squash	Developing
Wang et al.	Quantitative	Large Dataset Analyses	10,485	Athletes	10,485	0	Mixed	Ice Hockey	Expert
Bonito et al.	Quantitative	Large Dataset Analyses	2,791	Athletes	1,575	1,216	Mixed	Fencing	Mixed
Smith et al.	Qualitative	Interviews and Questionnaire	15	Athletes	0	15	Canada	Soccer	Developing
Wenger and Csapo	Quantitative	Measurement	98	Athletes	98	0	Austria	Soccer	Developing
Lemoyne et al.	Quantitative	Large Dataset Analyses	4,306	Athletes	4,306	0	Mixed	Ice Hockey	Mixed
Thieschäfer et al.	Quantitative	Large Dataset Analyses	4,599	Athletes	2,340	2,259	Germany	Handball	Developing
Kelly et al.	Mixed Method	Delphi	15	Researchers and Practitioners	Not Reported	Not Reported	Mixed	Soccer	N/A
Ferriz-Valero et al.	Quantitative	Large Dataset Analyses	7,731	Athletes	4,318	3,109	Spain	Orienteering	Mixed
Morganti et al.	Quantitative	Large Dataset Analyses	1,565	Athletes	1,565	0	Mixed	Soccer	Developing
Pérez-González et al.	Quantitative	Large Dataset Analyses	1,634	Athletes	0	1,634	Mixed	Soccer	Expert
Kelly et al.	Qualitative	Questionnaire	134	Interest Holders	Not Reported	Not Reported	Mixed	Soccer	N/A
Schorer et al.	Quantitative	Large Dataset Analyses	1,015	Athletes	542	473	Germany	Handball	Mixed
Peña-González et al.	Quantitative	Large Dataset Analyses	1,120	Athletes	1,120	0	Spain	Soccer	Developing
Barnsley	Opinion	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Difernand et al.	Quantitative	Large Dataset Analyses	160,861	Athletes	79,144	81,717	France	Swimming	Mixed
Grondin et al.	Quantitative	Large Dataset Analyses	3,380	Coaches	Not Reported	Not Reported	Canada	Ice Hockey	Mixed
Peñín-Grandes et al.	Quantitative	Measurement	80	Athletes	80	0	Spain	Soccer	Expert
Sweeney et al.	Perspective	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Smith et al.	Quantitative	Large Dataset Analyses	1,378	Athletes	0	1,378	Germany	Soccer	Developing
Grondin	Perspective	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Heilmann et al.	Quantitative	Large Dataset Analyses	3,174	Athletes	3,174	0	Germany	Soccer	Developing
Brustio et al.	Quantitative	Large Dataset Analyses	9,527	Athletes	9,527	0	Mixed	Soccer	Mixed

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consider during the identification, selection, and development processes in sport (16), they are two separate constructs that operate independently (17). Out of three studies, two focused on soccer, with one comprised of participants in a Spanish professional academy (Peñín-Grandes et al.), and the other the first examination of relative and biological age constructs in an Austrian soccer context (Wenger and Csapo). The third study investigated the association of maturation and relative age with talent selection in German youth handball players, whereby the authors presented evidence that a unique inter-play may exist between the constructs, as it could be crucial for relatively younger players to mature earlier to increase their selection odds (Thieschäfer et al.).

Research on a range of sports including cricket (18), handball (19), rugby (20), and soccer (21) has showed "bio-banding" [i.e., a format that groups athletes based on maturity status rather than chronological age (22)] to be an effective way at mitigating biological age effects. It is important to emphasise, though, that bio-banding is a potential solution for maturation-related biases, and not for RAEs. Thus, integrating bio-banding alongside relative age solutions, or combining solutions together [e.g., (23–26)], may be fruitful areas for future research.

Relative age solutions

A persistent call from relative age researchers, including in this research topic, is identifying potential solutions. Although many authors reiterated these sentiments in their articles, only three empirically explored this area, with only one evaluating the implementation of the solution. Building on previous quantitative work on "birthday-banding" (i.e., each individual athlete competes with those of the same chronological age, moving up to the next birthday-band on their birthday), which corresponded with no RAEs exist in the England Squash Talent Pathway (27), Kelly et al. explored coaches' perspectives of the approach. They noted how birthday-banding produced fairness for athletes who might have been removed due to their birthday, offering a possible relative age solution for other racket sports.

The Royal Netherlands Football Association (KNVB) relative age solutions project also contributed two studies. First, following a call to action for interest holders to propose relative age solutions to KNVB, almost 200 proposals were categorised into 13 independent approaches (Kelly et al.). Interestingly, whilst no new suggestions outside the existing literature were proposed, only two have been empirically tested in soccer (24, 28). Second, Kelly et al. evaluated these 13 proposed solutions, using a two-round adapted e-Delphi study with 15 international experts (i.e., researchers and practitioners). Generally, highly rated solutions perceived to effectively moderate RAEs were expected to be more challenging to implement, whereas those more feasible to implement were considered less effective. Results also showed regular disagreement amongst the international experts, highlighting that achieving consensus on possible relative age solutions may be challenging.

Lessons from the past and directions for the future

As part of this research topic, we were fortunate to include four decades worth of reflections from the inaugural researchers of RAEs—Professor Simon Grondin and Professor Roger Barnsley. In his opinion article, Grondin closed by repeating a key takeaway message from his original 1984 paper, emphasising how even after 40 years, many sport systems have still not comprehended this simple message: "It must be remembered that two children born in the same year do not necessarily have the same age" (1). Barnsley repeated these sentiments in his perspective article, showcasing that the data they published from the 1983 Western (WHL) and Ontario (OHL) Major Junior A Hockey Leagues (2) and from the 1989 FIFA U17 and U20 World Cups (29) remains almost identical, whereby those born in the first three months are overrepresented (cumulative ~40%) and those born in the last three months of the selection year are underrepresented (cumulative ~12.5%).

Overall, it is fair to say that whilst our understanding of RAEs has grown considerably over the last four decades, not a lot has changed in practice. Indeed, both Grondin and Barnsley expressed their disappointment with how the applied field has not utilised the comprehensive research knowledge. We call for researchers and practitioners to work closer together to be solution-focused, helping create more developmentally appropriate learning environments for all young athletes to achieve their potential in sport, irrelevant of their birthdate.

Summary

Although a large body of research has documented the presence of RAEs across various sporting contexts, and despite the ongoing recommendations from researchers and practitioners, efforts to design, implement, and evaluate effective and feasible solutions have been limited. Moreover, while several theoretical explanations have been proposed and greater clarity provided on the differences between biological and relative age, there remains a lack of empirical studies that clearly identify the underlying causes of RAEs in sport. Such studies would be invaluable in guiding the development of context-sensitive interventions (9). In addition to the continuously growing number of relative age studies across a variety of sport environments, an important next step will be to systematically review the literature, using meta-analyses, in widely researched sports. This will aid the development of sport-specific consensus on RAEs and outline next steps.

Finally, we call for researchers and practitioners to focus their efforts not only on replicating relative age research in different contexts, but also ensuring each study meaningfully adds new knowledge to the field. Researchers should use relative age studies as an opportunity to examine multi-, inter-, and trans-disciplinary features that contribute towards RAEs, as well as explore the direct and indirect effects of relative age to help

explain how they occur. Doing so will inform strategies that are effective and feasible for sport-specific contexts, helping to create youth sport environments that foster long-term performance, participation, and personal development outcomes for every young person, regardless of when they are born.

It was a pleasure to assemble this research topic. We hope the reader finds the articles useful in helping to advance their own research and practice. Thanks to the authors, reviewers, and participants for their support—without their efforts, advancing our knowledge of RAEs would not have been possible.

Author contributions

AK: Writing – original draft, Writing – review & editing. KJ: Writing – original draft, Writing – review & editing. AM: Writing – original draft, Writing – review & editing. JB: Writing – original draft, Writing – review & editing.

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To be or not to be born at the right time: lessons from ice hockey

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KEYWORDS

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Perhaps surprisingly, an individual's date of birth has a notable and long-term influence on their development. Any kindergarten or grade 1 teacher will speak of the remarkable difference, physically and/or psychologically, between the younger and older children in their class. While this influence had been documented in schools since the 1960s (1), it was not until the 1980s that the phenomenon was noted in sport, in ice hockey in particular (2, 3). Curiously enough, in sport, this seemingly-important difference has been long disregarded. However, despite over 40 years of research on this issue, the problems it causes remain unresolved.

The effect of an individual's birthdate on sport participation and attainment, eventually referred to as relative age effect (RAE), went from an object of curiosity to a cruel and pervasive reality that is a worldwide and widespread phenomenon (4–6). Consistently, it is a key factor explaining success in sport, and in talent identification selections. It eventually became popular as an example for explaining that success in general, in several spheres of activity, could be related to an arbitrary decision of how and when to group individuals to provide consistency in instruction and training.

The 1984 paper

As a child born at the end of November and playing ice hockey, I suspected that there was something wrong, unfair, with the categorization system. Indeed, I realized it more clearly as a baseball[1] player in Little League: instead of the disadvantage caused by a cutoff date set on January 1st, I experienced some advantage of a system based on chronological age with a cutoff date set on August 1st. I certainly did not know how to translate this curiosity into a scientific question, but I guess the issue was sleeping inside of the teenager I was who eventually undertook university studies to become a physical educator.

The 1984 article on the RAE in ice hockey (Grondin et al.) was based on my Master's thesis, defended in October 1982 in the *Département de kinanthropologie* at *Université de Sherbrooke* (8). The thesis was supervised by Dr. Paul Deshaies. The content of the thesis was first presented at the 51st Annual meeting of the "*Association canadienne-française pour l'avancement des sciences*" (ACFAS) held in Trois-Rivières in May 1983. The abstracts of two talks were published in the proceedings of the meeting. One talk

[1]There is also an effect of the moment of birth in baseball, and this effect is important in Japan where the cutoff date is April 1st (7).

presented the research question and the data showing that there was a real problem (9); and the second talk was dedicated to a suggestion, based on birthdate, to solve the problem (10). It was only in 1993 that I met Roger Barnsley and Gus Thompson, when they organized a symposium on the RAE during the annual meeting of the *Canadian Psychological Association* held that year in Montréal. They were kind enough to invite me to participate in the symposium, lending me the podium to talk about the RAE in ice hockey (11) while they were talking about this effect on academic achievement (12), mental health (13), and sport in general (14).

It was in 1984 that an article based on the thesis was published. The data, which were collected at the *Fédération Québécoise de hockey sur glace* (now Hockey Québec) and *Fédération de volleyball du Québec*, revealed a series of critical messages:

(1) In competitive ice hockey ($n = 3{,}826$), many more players were born in the first quarter of the year than in the fourth. This effect was present and strong in all competitive minor ice hockey categories, beginning with Atom (9- and 10-year-old players) up to Junior ice hockey (under 20). This effect was not as strong but statistically significant in the National Hockey League.

(2) Within each competitive minor ice hockey category, the effect was stronger in higher classes of competition (AA > BB > CC)[2], that is, in cities with a larger population. For example, amongst Pee Wee AA players (11–12 years of age), 47.8% and 8.9% were born in the 1st and 4th trimester, respectively. All this to say that when there are more players competing for a position on a team, the effect of birthdate is stronger.

(3) In general, there was no effect of birthdate in volleyball, for either female and male players, probably because there was less competition for obtaining a position on a team, this sport being less popular than ice hockey in Canada (and maybe because at the time, teams were formed in schools, which was not the case in ice hockey). Nevertheless, there was a birthdate effect for regional volleyball elite teams involving 14- and 15-year-old male players, teams that were built for a provincial competition. In other words, more competition for obtaining a place on the team resulted in an effect; therefore, the effect observed in ice hockey was not due the fact that this sport had physical contact (or some violence) since the effect also seemed to occur in volleyball when certain conditions are met.

(4) The final main message of the paper was a recommendation to improve the categorization system, even based on chronological age. The key point involved recognizing that the problem was caused by the adoption of a "yearly-based system" instead of a "monthly-based system" that would not be a multiple of 12. Two examples were given in the article, with 15- and with 21-month long categories. In the latter case, in a four-category system, the curriculum would last 7 years, each player going through the 7 years would play 2 years in 3 categories, and 1 in another category. This single season in a category would occur at a moment of the curriculum (category 1, 2, 3, or 4) that would depend on the system adopted and the birthdate of a player.

The 1982 thesis, but not the 1984 paper, also contained a non-trivial recommendation: if the problem cannot be solved within a singular sport, we should at least avoid adopting the same cutoff date in all sports. This suggestion went squarely in the opposite direction of a 1980 Québec government report on age categories in sport (15). Since, there have been several other recommendations [see (16)], including one where it is suggested to have two ice hockey seasons (September–December and January–April) per year, each half-season having different cutoff dates, for instance, January 1st and July 1st (17).

Other ice hockey data, since

Since the publication of Grondin et al. (3) and Barnsley et al. (2), there have been several papers on birthdate effects in ice hockey [e.g., (18–25)]. Some recent papers were dedicated to Russian or Czech ice hockey [e.g., (26, 27)], or to women's ice hockey [e.g., (28, 29)]. Other research has established that there is not much difference on anthropometric measures of ice hockey players born in the different trimesters of the year (30, 31). Finally, several papers were dedicated to the case of the NHL, including the fact that the effect is weaker there than in minor ice hockey, a finding referred to as a reversal effect (18, 32–35).

Amongst the multiple articles on birthdate's effect on participation in ice hockey, there is one less cited paper that contains quite precious data (36). The data are interesting because it shows clearly, and how rapidly, the effect is installed. In Québec, the cutoff date was January 1st until the 2002–2003 season. For six ice hockey seasons, from 2002–2003 to 2007–2008, the cutoff date was October 1st, this date being the cutoff for schools in Québec. After the 2007–2008 season, the cutoff date for ice hockey was moved back to January 1st.

According to Table 2 of Lavoie et al. (36), for the highest competitive level of 15- and 16-year-old players (Midget AAA), 44.94% were born in October, November, or December during the 2007–2008 season. The following season, when the cut-off date went back to January 1st, the percentage for this trimester was 19.58%; and, for the 2009–2010 season, went down to 11.74%. In 2007–2008. 23.97% of players were born in January, February, or March, then the second most advantageous trimester. Two years later, 41.30% were born in the first trimester. Not only does this manipulation of the cutoff date show the cause to effect relationship between the birthdate and participation in elite ice hockey, but this effect happens extremely rapidly. Similar effects have been noted by Helsen et al. (37) in elite soccer players.

While the administrative mechanisms driving birthdate effects seem simple, the psychological factors underpinning the effect are complicated. In a recent article about talent identification in ice hockey, Fortin-Guichard et al. (38) showed the importance of self-regulation planning and gaze behaviour

[2]There were AA teams in cities with more than 45,000 people, and BB teams in cities with 20,001–45,000 people.

for identifying talent of 15–16-year-old players. What is interesting in this paper is the uniqueness of the method used: (1) only players selected after the first two rounds of selection ("sleepers") were under investigation and (2) scouts were asked, 3 years after the draft (players now competing at the Junior level) to identify who they would have liked to pick, out of players selected in the first two rounds. Out of the 70 remaining players who were tested as a Midget, 15 were identified by scouts. Only 7 out of the 44 players born from January to June were selected, while 8 out of 26 players were born from July to December. Note that, amongst the players tested and selected in the first two rounds, 21 out of 25 players were born from January to June. In other words, scouts do not compensate for the enormous bias caused by the moment of birth and the categorization system.

Just to make it clear

There is a clear and long history of evidence regarding the heterogeneity of development. An old article by Bouchard and Roy (39) revealed that, amongst participants in the famous Québec Pee Wee tournament (for players 11 and 12 years of age), players' "bone age" (an indicator of skeletal maturity) varied from 7 to 14 years. But because a picture is worth a thousand words, let's use a photo to make the point clear about this potential heterogeneity. The two children in Figure 1 played soccer and went to school together. Their age? About the same. Despite their physical difference, there is only 1-month difference between them in chronological age. The fun fact here is this one: the taller one was born in January, and the other a bit earlier, in December. In other words, the following season, the taller one had to remain in the same category, and the smaller one had to move into a category with older children.

The problem can also be considered another way. To keep it simple, let's consider two children, Player A born on January 1st and Player B born on December 31st of the same year. There is a high risk that a coach not sensitive to the impact of birthdate, at the moment of building a team, will make decisions based on a spontaneous dichotomy, "first year player" vs. "second year player". If the objective of the coach is to win, the older player has a better chance to be part of the team. But if the objective is to detect talent, and eventually contribute to its development, two questions should be asked. (1) A year from now, will Player B be as good as, or better than, Player A is now? (2) Will the difference between current player A and player B in two years be smaller or larger than the current difference between players A and B?

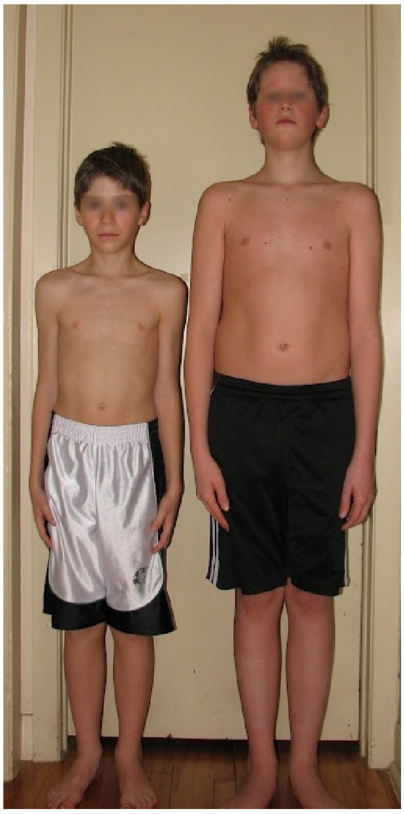


FIGURE 1
The taller boy on the right is 1 month younger that the smaller one on the left, but because one was born in January and the other in December, the taller boy will stay in the same age category the following season and the smaller one will move into a category with older children (photo from (17); with permission of the persons, now adults, on the photo).

A final word

The past 40 years have revealed something remarkable and deplorable: even when a problem is well-known, obvious, and well understood, even when there are potential solutions, it remains extremely difficult to activate changes in a system! It is difficult to know with certainty whether the discrimination caused by birthdate would be reduced, but relatively simple solutions are worth testing, be it the adoption of 15- or 21-month age categories, or at least, with a categorisation avoiding multiples of 12 months; or by forcing to have at least 3 players per trimester in competitive teams.

To close this article, let's use a translation of the last sentence of the 1984 paper, and of the 1982 thesis, that was a message for any coach or educator [see also (40)]: "In brief, it must be remembered that two children born in the same year do not necessarily have the same age." Even after 40 + years, it seems many in the sport system have still not gotten this message.

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Conflict of interest

The author declares 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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Relative age effects in German youth A and B men's soccer teams: survival of the fittest?

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The study investigates relative age effects (RAE) in German youth soccer (Youth Bundesliga A: January 2004 to December 2005 and B: January 2006 to December 2007; highest league in German youth soccer) and its persistence in third-division players. Data from the 2022–2023 season (120 teams, 3,174 players) were analyzed using chi-square tests. Significant RAE was found in the A-series ($p < .001$), B-series ($p < .001$), and third-division professionals ($p < .001$). Notably, RAE was prominent among younger players but less evident in older third-division players ($p = .116$), indicating a diminishing selection effect with age and professional tenure. Coaches and talent managers are advised to consider RAE and additional factors like player maturity in talent selection for more efficient talent management strategies, especially in youth academies.

KEYWORDS

birth quartile, relative age effects, youth soccer, maturation, talent selection

1 Introduction

In a sports context, calendar age, and birthdates are essential for grouping athletes for competitive comparison. In general, there has been a tendency to select athletes for teams born early in the year or a particular selection period (close to the cut-off date of selection). Recent studies have demonstrated that relative age effects (RAE) in sports is a global phenomenon that affects a wide range of competitive sports (1). The impact could be demonstrated for individual sports (2, 3) and team sports such as basketball (4, 5), ice hockey (6, 7) or especially for soccer (8, 9). Children and adolescents born early in the year enjoy considerable advantages over those born later in the year in terms of academic achievements (10, 11), emotional and social life (12, 13). There are various reasons for this effect and its continued existence through the older age groups in the context of sports: the Matthew effect (14), the Pygmalion effect (15), and the Galatea effect (14, 16). For example, a contrary hypothesis is postulated by Kelly et al. (17) and describes the advantages of later-born athletes (the underdog hypothesis). The Matthew effect (14), also known as the "rich get richer" effect, refers to the phenomenon where individuals or groups already successful in a particular field tend to become even more successful over time. This can happen for various reasons, such as access to resources, support, or opportunities unavailable to others. In sports, the Matthew effect can manifest as the RAE. Athletes born early are often physically more mature and developed than those born later in the year (14). As a result, they may be selected for the more advanced teams and programs and receive more coaching and training opportunities (18). Over time, this can create a self-reinforcing cycle where early-born athletes continue to dominate in their sport while late-born athletes may struggle to keep up. This can lead to a skewed distribution of success and opportunities in the

sport, with the "richest" (i.e., early-born) athletes becoming even more successful. In contrast, the "poorest" (i.e., late-born) athletes fall behind (see Figure 1).

The Pygmalion effect (15), also known as the Rosenthal effect, refers to the phenomenon in which higher expectations of individuals lead to increased performance. With the RAE, athletes born early in the year are more likely to be selected for professional teams and programs (i.e., youth academies). This results in higher expectations of the coaches and scouts. As a result, the abovementioned Matthew effect is supported. This can contribute to a self-fulfilling prophecy, as the increased expectations lead to improved performance, leading to even higher expectations. The Galatea effect (14, 16) is a phenomenon where individuals who are given positive feedback and encouragement tend to perform better than those who do not receive such feedback. In the context of RAE, early-born athletes are more likely to receive positive feedback and encouragement from coaches and surroundings due to the abovementioned advantages. This could again lead to a self-fulfilling prophecy, where these athletes continue to receive positive feedback and encouragement, leading to better performance and more opportunities to advance in their sport. As a result of RAE, the late-born players may be labeled as "underdogs" in the context of the underdog hypothesis (17). They may have to work harder to prove themselves and earn opportunities to advance in their soccer careers (see Figure 2). According to review studies and meta-analyses, numerous factors moderate the RAE in sport (19, 20). These include playing position, gender, age, level of competition, and setting of the sport.

In professional soccer, the RAE significantly impacts the talent selection and development process. For example, a multi-country study by (21) found an over-representation of players born in the first birth quartile (BQ) in national and professional youth selections across all age groups. The statements apply primarily to male footballers, because for female players the development stage and the composition of the squad still play a key role. Massa et al. (22) discovered a comparable effect in professional football in Brazil. As evidenced by the strong RAE in youth football that has been found in America, Australia, Brazil, Germany, and Japan, among other places, there may be a consistent worldwide effect at play here that is not influenced by national variations in the dates used to determine the start and end of the sporting year (23). A remarkable reduction in RAE effects (24) has not been achieved in the last decades. Recent research shows that maturation has got a higher impact on performance than RAE (25). Nevertheless, Hill et al. (26) argue that RAE and maturation are independent constructs. Thus, different strategies to prevent RAE and selection bias regarding the maturation of players are needed (20, 27). Coaches and scouts should consider RAE in their decisions. RAE could cause individual differences in up to one year.

In German soccer, the findings of Votteler et al. (28) reveal significant direct and indirect RAEs for physiologically demanding tests and almost no effects for technically demanding tests. The study of Helsen et al. (29) shows that relative age effects exist in German youth soccer. However, no advantage in anthropometric or performance-related characteristics can account for it. A player's chances of becoming a professional later in their career are higher for younger players chosen for national teams (30). Götze et al. (31) could identify the influence of gender and competition level on the RAE in German soccer. Their data indicates a RAE in German adult soccer for both males and females, which may be coupled with a loss of great players who were once highly valued during their childhood years. As a result, fewer skilled players would be available for the adult division. The effect sizes for the RAE are large in the U19

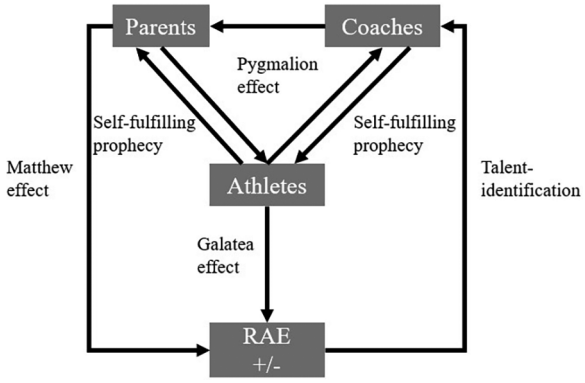


FIGURE 1
A conceptual model showing the influences on athletes' development, highlighting the Pygmalion effect, self-fulfilling prophecy, Galatea effect, Matthew effect, and talent identification. Parents and coaches shape athletes' perceptions and performance, impacting the Relative Age Effect (RAE).

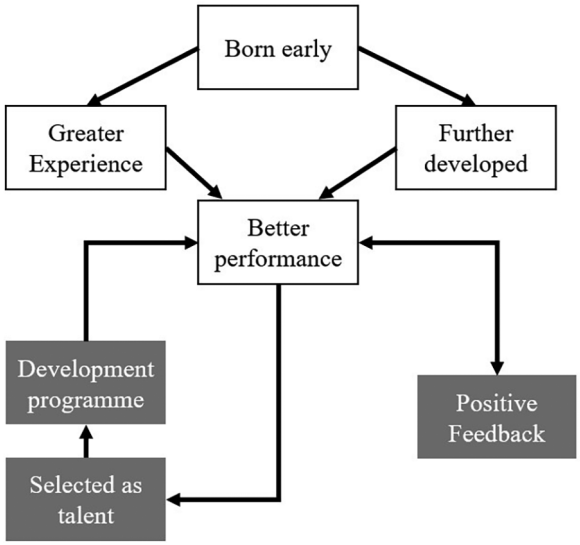


FIGURE 2
A model illustrating how being born early in the selection period can lead to greater experience and further development, resulting in better performance. This improved performance leads to positive feedback and selection into development programs, reinforcing the athlete's recognition as talent.

and small to medium from U20 to the first league (including the national team and first and second Bundesliga). The German youth soccer system (before 2023), particularly through the B-Junioren Bundesliga (U17) and A-Junioren Bundesliga (U19), provides a structured and competitive environment for young talents. These leagues are pivotal in the development of players, many of whom progress to professional careers in Germany's top leagues or internationally. The system is supported by rigorous scouting, professional club academies, and a clear pathway from youth to senior professional soccer. The pressure on the youth soccer players, especially for academy players is very high. There are high expectations, intense competitions and they have to balance education and soccer. In this case, it is important to examine single soccer nations, because they potentially differ from others and it allows to compare the different pathways and contextual factors of RAE.

The position on the field plays an important role when analyzing the RAE in athletes (32–34). For example, Schorer et al. (34) could show no significant RAE for circle players and goalkeepers in handball. Professional U-20 South American soccer players were the subject of an investigation by (35), who noted RAE at all positions played except for goalkeepers. Hurley and colleagues (2019) could not find RAE for forwards and goaltenders. There is evidence that goaltenders generally do not show significant RAE. Schorer et al. (34) explain this with different demands for these playing positions, especially for goaltenders. Further studies have indicated that central defenders and midfielders have indicated greater RAE prevalence compared to other positions on the field (36) (Finnegan et al., 2024).

Doyle et al. (18) analyzed the data of the 1,000 best professional footballers (by market value on transfermarkt.de) and found that these players were born earlier than could be expected by chance. The level of competition seems to be a moderation factor for RAE. Furthermore, admission to youth academies plays an essential role in the occurrence of RAE (37). The study of Grossmann and Lames (37) shows that a strength RAE is even more present in youth academy players than in amateur U17 and U19 players. There is significantly less evidence concerning the longitudinal progression of RAE in youth soccer. The only research that indicates a longitudinal analysis of talent selection processes reveals an increase in RAE for players who are newly selected for higher competition levels and no change in RAE extent for players who are retained at the same competition level across successive age categories is the work by Votteler and Höner (23). According to Cobley et al. (1) and Szwarc et al. (38), it is plausible that the elimination of disparities in physical maturity is a contributing factor, meaning that athletes who are relatively younger no longer face any disadvantages (underdog hypothesis). According to Cobley et al. (1), elder athletes switching to different sports may also contribute. Due to overtraining, burnout, or other issues, older athletes who trained hard to reach a high-performance level in their junior years may also decide not to compete in sports. Evidence suggests that specialized training environments are associated with shorter playing careers and higher adult dropout rates in sports, including ice hockey and soccer (1). Moreover, the studies of Dugdale et al. (39) show that RAE does not always translate into senior or adult level, and Andrew et al. (40) show that it does not always lead to success.

Nevertheless, the current findings regarding the RAE often neglect the effect of the level of competition and the transition between age groups, youth academies, and professional soccer leagues. Furthermore, the research often lacks information on the prevalence of RAE in different regions of the examined countries. These findings could help to find sufficient strategies to prevent RAE selection bias. The present study aimed to describe the prevalence of RAE in German soccer and explain it by different explanatory variables such as age group, playing position, performance in the league (by top clubs) and the region of the country.

2 Methods

2.1 Participants

The players of the German Youth Bundesliga A (January 2004 to December 2005) and B (January 2006 to December 2007; the highest league) and the players in the 3. Liga in Germany (third division) were analyzed in this study. One hundred twenty teams and a total of 3,174 players were included (extracted from valid database transfermarkt.de). The twelve months of the year were divided into four birth quartiles (BQs). January, February, and March were classified as "BQ1", April, May and June were classified as "BQ2", July, August and September were classified as "BQ3", and October, November, and December as "BQ4". Birth quartiles were compared with the general population data from 2010 because there were no detailed birth distribution datasets from other years. The distributions did not significantly differ compared with the 2010 data (statista.de). An overview of the characteristics of the three series (Youth A and B Bundesliga and third division in Germany) is displayed in Table 1. The cut-off date for the German youth soccer leagues is the 1st of January. Furthermore, the region (north/north-east, west, south/south-west), the position on the field [goaltender (1), defender (2–6), midfielder (8), offender (7, 9, 10, 11)], and the top teams (top 5 and last 5) were analyzed as covariates. The database often not identify the exact position on the field but one of the above-mentioned category.

2.2 Statistical analysis

The data were first checked for plausibility. No outliers had to be excluded, but for a total of 36 players, an exact birth date could

TABLE 1 Composition of the sample by leagues (U17/19) in season 2022/2023.

Age group	North/north-east	West	South/south-west	Total (*n*)
U17	394	389	391	1,174
U19	443	424	480	1,347
3. division				571
Total (*n*)				3,092

not be evaluated. Chi-square ($\chi 2$) analysis was used to compare quartile distributions in the sample and against population values, following procedures outlined by Kelly et al. (17). This test does not reveal the magnitude of difference between quartile distributions for significant chi-square outputs, so Cramer's V was used. According to accepted correlation standards, the Cramer's V was read as follows: a value of 0.06 or higher would suggest a small impact size, a value of 0.17 or higher would indicate a medium effect size, and a value of 0.29 or higher would indicate a big effect size (41). Since the results are always undirected due to the squaring in chi-square analyses, a subsequent graphical inspection of the data is necessary to make substantive statements about the RAE in the sample.

3 Results

Table 2 shows that the distribution of the month of birth differed significantly ($p < .05$) from the distribution of births in Germany in 2010 in all scales of the U17. A significant effect size ($V \geq 0.30$) and, thus, a large RAE could be demonstrated in all regions.

The most substantial effect was found in the south/south-west region ($\chi^2 = 144.39$, $p < .001$, $V = 0.35$), in which around 73% of players were born in the first half of the year (BQ1 and BQ2). When investigating the differences between the two age groups in the U17, players born in 2007 ($\chi^2 = 45.92$, $p < .001$, $V = 0.39$) showed a higher effect size for RAE than players born in 2006 ($\chi^2 = 303.71$, $p < .001$, $V = 0.31$). The absolute number of players per quartile decreases significantly with decreasing age. While most players were born in Q1 of 2006 ($n = 461$), Q4 of 2007 had the fewest players in the U17 teams ($n = 13$; see Figure 3). Overall ($n = 1{,}174$), the players in the U17 national league shows a large effect size ($\chi^2 = 344.01$, $p < .001$, $V = 0.31$) concerning the differences in the distribution of birth quartiles to the reference population (RAE). Around 71% of all U17 Bundesliga players were born in the first half of the year (BQ1 and BQ2).

The effect sizes of the chi-square test in the U19 age group were not as large as in the U17 age group. Nevertheless, RAEs were also found in this age group. All squadrons showed a significantly different distribution from the reference population and a medium effect size. The south/south-west region shows the strongest effect size for RAE ($\chi^2 = 118.33$, $p < .001$, $V = 0.29$). In the individual age groups, the 2005 players ($\chi^2 = 175.27$, $p < .001$, $V = 0.29$) had a higher RAE than the 2004 players ($\chi^2 = 114.68$, $p < .001$, $V = 0.24$). In the U19, most players were born in BQ1 and the fewest in BQ4 in both birth years (2004: $n = 649$; 2005: $n = 682$). There is a consistent drop in players from BQ1 to BQ4 (see Figure 4). As a result, from BQ1 to BQ4 of 2004, the number of players decreases steadily, then increases in Q1 of 2005 before declining again until Q4 of 2005. For all U19 national leagues combined, a medium effect size was seen for the RAE ($\chi^2 = 294$, $p < .001$, $V = 0.27$). 69.56% of the players were born in the first half of the year (BQ1 and BQ2). For all U19 national leagues combined, a medium effect size was seen for the RAE ($\chi^2 = 294$, $p < .001$, $V = 0.27$). A significant RAE could also be demonstrated for the professional sector in the 3rd division. However, the effect size was smaller ($\chi^2 = 29.69$, $p < .001$, $V = 0.13$) than for the U17 and U19. Overall, 57.44% of all players in the 3rd division were born in the first half of the year (BQ1 and BQ2), which is closer to the reference population compared to the juniors, in which 71.29% (U17) and 69.56% (U19) were born in the first half of the year. Within the 3rd division, only players born after 1998 showed an RAE ($\chi^2 = 28.05$, $p < .001$, $V = 0.17$). For players born before 1998, the deviation of the birth data from the reference population was insignificant ($p = .116$). The 3rd division group ($n = 571$) also included some young players registered for the U19 junior team of the respective club in the U19 Bundesliga ($n = 14$). These players were included in the data analysis for both the juniors and the 3rd division.

The distribution of birth quartiles, considering the position on the field, shows larger effect sizes for goaltenders and defenders compared with midfielders and offenders (see

TABLE 2 Distribution of birth quartiles (%) in the analyzed age groups in the 2022/2023 season compared to the German birth statistics from 2010 (available, comparable age group).

Age group	Classification	n	BQ1 (%)	BQ2 (%)	BQ3 (%)	BQ4 (%)	χ^2	p	V	Effect
U17	North/north-east	394	42.12	25.89	24.11	7.87	103.20	<.001	0.30	Large
	West	389	42.16	31.11	15.17	11.57	110.22	<.001	0.31	Large
	South/south-west	391	47.57	25.06	18.67	8.70	144.39	<.001	0.35	Large
	Young (2007)	100	52.00	21.00	14.00	13.00	45.93	<.001	0.39	Large
	Old (2006)	1068	43.16	28.00	19.94	8.90	303.71	<.001	0.31	Large
	Total	1,174	43.95	27.34	19.34	9.37	344.01	<.001	0.31	Large
U19	North/noth-east	443	38.37	30.47	16.25	14.90	82.96	<.001	0.25	Interm
	West	424	40.33	29.95	19.34	10.38	99.17	<.001	0.28	Interm
	South/south-west	480	42.92	26.67	17.29	13.13	118.33	<.001	0.29	Interm
	Young (2,005)	682	41.94	29.33	17.60	11.14	175.27	<.001	0.29	Interm
	Old (2004)	649	39.14	28.20	17.87	14.79	114.68	<.001	0.24	Interm
	Total	1,347	40.61	28.95	17.59	12.84	294	<.001	0.27	Interm
third division	Young (born after 1998)	307	32.57	28.01	26.06	13.36	28.05	<.001	0.17	Small
	Old (born before 1998)	264	29.55	24.24	25.76	20.45	5.91	.116	0.09	Small
	Total	571	31.17	26.27	25.92	16.64	29.69	<.001	0.13	Small
German birth statistics (2010)		677,947	23.76	24.43	26.98	24.84				

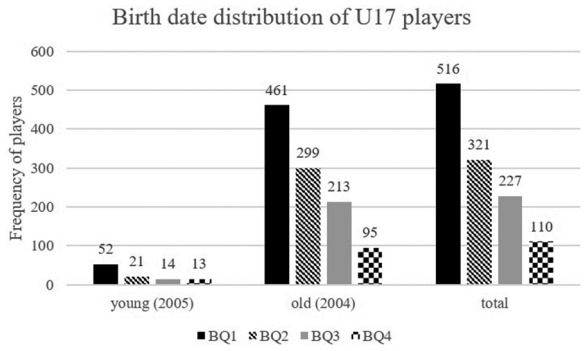


FIGURE 3
Birth date distribution of U17 players (Youth B).

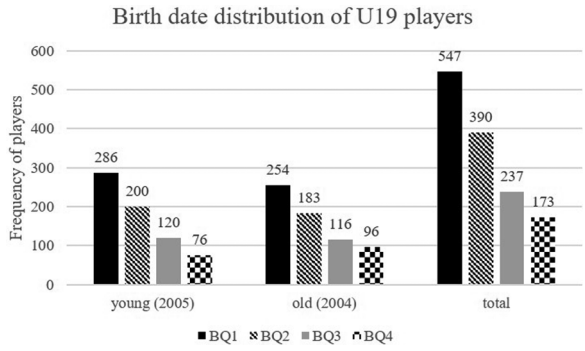


FIGURE 4
Birth date distribution of U19 players (Youth A).

Supplementary Table S3 and Figure 5). In theory, significant RAEs were discovered for every position on the field. Regarding the distribution's deviation, only the third division's goalkeeper position group ($\chi^2 = 2.63$, $p = .45$, $V = 0.12$) shows no significant RAE.

The results of the deviation in the birth distribution based on performance in the respective league are displayed in Supplementary Table S4. Generally speaking, every group shows a modest RAE; however, the last five teams in the third league table show non-significant chi-square tests for RAE ($\chi^2 = 2.81$, $p = .422$, $V = 0.08$). The effect size is always larger for teams ranked among the top teams in the leagues. The effect size decreases with increasing age.

In general, all age groups showed relative age effects. A consistent gradient in the distribution of the quartiles in the birth dates (BQ1 to BQ4) for all age groups is also revealed by the graphical inspection, as shown in Figure 5.

The ratios of BQ2 and BQ3 were nearly identical in the third division. Most players across all age categories were born in Q1, the fewest in Q4, and the third division had the highest percentages in Q3 and Q4. When comparing the age groups, there is a decline in the RAE as age increases. The U17 national leagues exhibited the highest RAE, and the third league displayed a comparatively smaller RAE.

4 Discussion

The study aimed to analyze relative age effects among German juniors A and B as well as the players of the third division (German

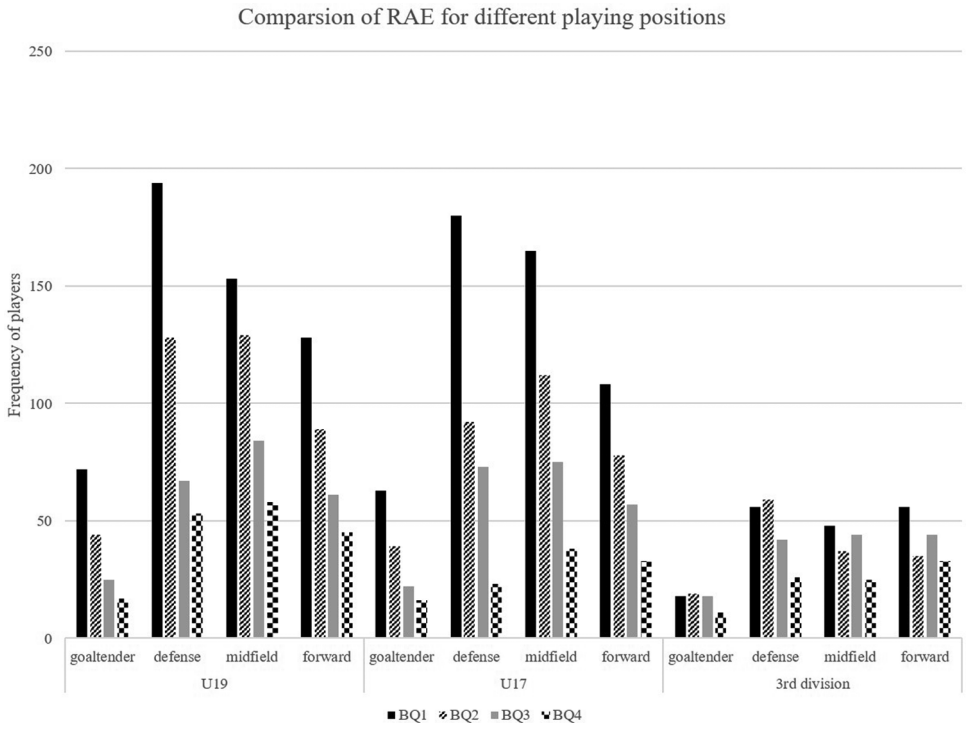


FIGURE 5
Comparison of RAE for different playing positions on the field of U19 (Youth A), U17 (Youth B) and third division.

Bundesliga and 3. Liga) in the 2022/2023 season. Therefore, the 2,521 birth dates of junior players and 571 birthdates of players in the 3rd division were analyzed. The 3,092 birth dates were divided into four quartiles, and the birth date distributions were compared with Germany's birth statistics from 2010. Furthermore, the effects of position on the field and the rank of the associated team in season 2022/23 were calculated. Generally, it could be shown that an RAE exists in every age group despite the older players of the third division.

The findings are in line with the general evidence that players born in the first birth quarter (BQ) are overrepresented in professional youth soccer across different age groups (21–23). Only the older players competing in the third division of the German Bundesliga do not show a significant deviation compared with the average population. This aspect could underpin the "underdog hypothesis". It could be speculated that the players reaching older ages in the professional league had to overcome challenges arising from the initial disadvantages of being born late in the year. The non-translation in senior soccer leagues is in line with the findings, for example, of Andrew et al. (40) and Dugdale et al. (39). The hypothesis would claim that these players worked harder, and because of that, they could stay at this level. Götze and Hoppe (31) also show the influence of the competition level on the RAE in German professional soccer. The current findings show the same phenomenon. The RAE decreases with the age group and the competition level [i.e., U19 > U21 > first division; (31)]. The results of Doyle and Bottomley (18), which state that players with a higher value were born earlier than could be expected by chance, could not be confirmed or disproven because the younger players in our study do not have a value on the market and it was not the aim of the current study. The results of Votteler and Höner (23) longitudinal analysis of talent selection procedures, which indicate that players newly selected for higher competition levels have a higher RAE and that players retained across consecutive age categories at the same competition level do not have a different RAE, are not consistent with the current findings.

As already described, no data was collected for this study that would allow measurable conclusions to be drawn about the causes of RAEs based on the models presented by Hancock et al. (16) and Wattie et al. (42). We can only make assumptions in this regard. It is possible that relatively older people experienced advantages within the system of social actors through Matthew effects, Pygmalion effects or Galatea effects (6), entered the "vicious circle" of the dynamic model through an initial advantage, with two self-reinforcing processes increasing their lead, or were best adapted to the interactions of their constraints with environmental and task-related constraints in the constraint-based model (42), resulting in their overrepresentation in the sample.

Given their positions on the field, goaltenders and defenders have bigger effect sizes in the birth quartile distribution (RAE) than midfielders and offenders. Nevertheless, significant RAEs were discovered for every field position except for the third division's goalkeeper position group. Our results align with the findings of Campos et al. (35) regarding the lack of RAE for goaltenders in the professional league examined in the study (third division). Still, the current results show a significant RAE for younger goaltenders (U19 and U17). It seems that the distribution is oriented on the overall distribution of RAE (U17 < U19 < third division) also for goaltenders. It is plausible that the different demands on goalkeepers lead to the difference in RAE. The "underdog hypothesis" can be cited as an explanation for the generally decreasing relevance of the RAE with the age of the athletes in the current study.

Nevertheless, the level of competition seems to be a moderation factor for RAE. Each group generally displays a moderate RAE, yet the last five clubs in the third league table see non-significant chi-square tests for RAE ($\chi^2 = 2.81$, $p = .422$, $V = 0.08$). When a team is ranked among the best teams in the league, the effect size for RAE is always bigger. The findings align with Grossmann and Lames (37) and Augste and Lames (8). They could show significant correlations between the final rank of the teams and the median. Thus, the older the team is (BQ1 < BQ4), the better the rank. We could not explain the differences in effect sizes between the different regions (north/north- east; west; south/south-west) because the compilation of the clubs leaves no room for speculation regarding performance of the different clubs and the prevalance of RAE. The only plausible reason for the higher effect sizes in the south/south-west group could be the high population numbers in these regions, which can lead to a high selection pressure overall.

Several limitations should be considered when interpreting the results of this study. First, the division of birth dates into quartiles is associated with a certain degree of arbitrariness, and it could result in a difference of one month (or even one day) having a more significant effect in one case and no effect at all in another, such as March 31 compared to January 31. Furthermore, the quartiles may contain different numbers of days, which can affect comparability (42). Secondly, the date of birth alone cannot reliably determine how mature a player is compared to other players his age. However, it was impossible to consider player maturity in the study. Only year of birth, birth quartile, position, and team ranking could be analyzed. Thirdly, in this study, the A and B junior national leagues were examined for the occurrence of an RAE. In addition, the birth dates of the 3rd division were analyzed because it was assumed that a certain number of players in the A and B junior national leagues initially switched to the 3rd division. It is also possible that many players trained at the youth academy and in the youth leagues move directly to the first or second division (German Bundesliga). However, the statistics, which show a sharp decline in the use of domestic U21 players in the first division (German Bundesliga) between 2017/2018 and 2019/2020, tend to suggest the opposite. A certain degree of inaccuracy must also be assumed concerning the data collected. The playing positions listed on the internet may not always correspond to reality. Positions are often swapped or changed for training, particularly at the junior level. In addition, players can interpret soccer positions differently, making distinguishing between offensive and defensive positions difficult. They may also make inaccurate assumptions about the cause of the birth distribution for certain positions. Furthermore, only the detailed

birth distribution of 2010 was available because this was a year of the census.

The current study shows an RAE for the highest German youth league could be identified. Furthermore, the youngest players are born earlier in the year than the older players in the third division of the German Bundesliga. Although, in contrast to maturity, relative age appears to be far less significant for physical performance in most cases (27), the selection process in the early years of talent development could impact the athletes' careers. At a high selection level, however, the realization remains that even relatively younger players show particularly high performance in motor performance diagnostics as well as for game intelligence, tactical, and psychological skills (Williams et al. (43) despite their age-related disadvantages (28). This makes their motor skills all the more important than those of relatively older players, which they must demonstrate to be accepted into the DFB talent development program (23). They must develop special physical, tactical and technical skills to be competitive (24). The problem is that young players who are not as physically developed could give up due to the constant disadvantage, which leads to high dropout rates in adolescence (1, 30).

Further research should focus on measures to reduce the RAE. For example, Sierra-Diaz et al. (20) recommend different strategies, such as altering or rotating the annual cut-off date, to create alternative ways to group athletes for competition (i.e., anthropometric attributes) or to develop internal reforms in soccer academies and enhance some competitive regulations. Further strategies could be to assess the biological maturity or stage of development oft he players.

A follow-up study seems rewarding because the German Football Federation revised the competition mode for the highest youth league (U19 and U17). The A and B Junior Bundesliga have been divided into three leagues. At the start of the 2024/2025 season, the U19 and U17 DFB Junior League will replace this tier system. There will be two phases: first, a regional preliminary round, and then, a main round in the second half of the season, which will be divided into League A and League B. The German champion is determined from the teams that qualify for League A. In the U 19 and U 17 DFB Junior League, Bundesliga and amateur clubs play in the same league from the outset. All clubs with a performance center are permanently qualified for the DFB Junior League. This change in competition mode could reduce RAE selection bias because the coaches could use their players more independently of their current performance and substitute seven players per game in the new mode. The follow-up study could show if the prevalence of RAE changes over time. Nevertheless, the decisive role of the coaches must be mentioned at this point. They have to be aware of the prevalance of RAE and have to take the findings into account in order to select or develop talents in German soccer.

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

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

FH: Conceptualization, Data Curation, Investigation, Methodology, Resources, Visualization, Writing – original draft. AK: Formal Analysis, Methodology, Software, Writing – review & editing. OS: Conceptualization, Data Curation, Resources, 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.2024.1432605/full#supplementary-material

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Career trajectories, transition rates, and birthdate distributions: the rocky road from youth to senior level in men's European football

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This study aimed to assess youth-to-senior transition rates, quantify the magnitude of relative age effect (RAEs), and evaluate how RAEs affect these transitions in 9,527 men's national football players of England, France, Germany, Italy, and Spain. Regardless of national team, only –15%, 25%, and 40% of U17, U19, and U21 players successfully transitioned to the senior team, respectively, whilst –14%–24% progressed to senior level without being selected during youth. Data suggested a skewed birthdate distribution favouring relatively older players at U17, U19, and U21 levels across all countries, whereas RAEs were also present in England, Italy, and Spain at senior level. Youth-to-senior transition rates were modulated by birthdate at U17 and U19, whereby Q4 players were –2 and 1.5 times more likely to successfully transition at senior level than Q1 players, respectively. Selection at youth international level does not guarantee selection at senior level, but does make it more likely. Moreover, relatively younger athletes are disadvantaged in youth categories, although are more likely to transition to senior level once they have entered the pathway.

KEYWORDS

transition rate, identification and selection processes, RAE, underdog hypothesis, soccer, talent development, athlete development

Introduction

To identify youth athletes with the potential of ascending to the higher echelons of senior competition more efficiently, sport's governing bodies and federations have implemented systematic recruitment strategies (1). Athlete development and ultimately achieving expertise in sport at adulthood, however, is a dynamic, highly contextual, and multifactorial process that is difficult to navigate (2, 3). For instance, current performance and future prospects in specific sport contexts can be influenced by performer (e.g., anthropometric, genetic, physiological, and psychological factors), task (e.g., deliberate practice and play, specialisation and sampling), and environmental (e.g., relative age, birthplace, cultural influences, and socioeconomic effects) constraints (4–9).

Nevertheless, it is still unclear how and to what extent an athlete's developmental trajectory is shaped by the interaction between these constraints across sports (4, 10–12).

This ambiguity makes the accurate selection of prospective high performing athletes extremely challenging, and is further confounded by the weak relationship that exists between early and future success in sport (2, 13). More specifically, being a high performer at youth levels does not guarantee that the athlete will also be a high performer at senior level. Many prospective and retrospective studies have reported similar results across different sporting contexts, whereby approximately 20% of senior international athletes also performed at the highest level during their youth (14, 15). These findings were reinforced by a recent review (16), which showed that 82% of international-level seniors had not reached youth international level, suggesting that successful youths and seniors are largely two disparate populations.

Identification and selection complexity exacerbate in team sports such as football (i.e., soccer), likely due to the added positional dimensions and the compensatory nature of athletic profiles, which makes it even more difficult to define "talent" or appraise "elite" performance (17–19). Combined with the selectors' cognitive biases when assessing the potential of athletes [see (20)], this reduces the potential accuracy and reliability of selection decisions, especially at younger ages (21). The predictive utility and validity of early identification processes in facilitating successful youth-to-senior transitions were weak in footballers across Europe [e.g., (1, 22–24)]. These studies indicate that being a high performer during childhood and early adolescence or selected for a youth international roster is a poor predictor to obtain a professional contract and overall success at senior level. An evaluation based on current performance rather than their future developmental potential may partially explain the low success during youth-to-senior transitions. Such a reliance on static, objective measurements at one-off timepoints and subjective preferences based on gut-instinct, as well as the emphasis of youth sport organisations towards short-term success, undoubtedly compromises long-term athlete development and the ability to achieve expertise (2, 13).

An additional consequence of the currently implemented practices, however, is that they create contexts whereby biases such as relative age effects (RAEs) can influence identification and selection processes (1, 11, 12, 25). RAEs are a well-known phenomenon in football that reflects the (dis)advantages generated by the interaction between chronological age and an annual cut-off criterion, which is commonly used to group youth players of similar developmental stages together. Consequently, however, there can be up to twelve months difference in the chronological age of players in the same annual age-group, or even twenty-four months in the case of biennial age groups. Being relatively older (i.e., being born near the start of a cut-off date) means these players will generally benefit from increased anthropometric, physiological, and psychosocial development to produce higher performance than their relatively younger peers (i.e., born near the end of a cut-off date) (8, 26, 27). As a result, more relatively older players appear to be (un)consciously selected by recruiters (e.g., coaches, scouts) compared to relatively younger players at youth level (1, 6, 28–30). The valuable developmental opportunities accompanying early selection (e.g., greater access to coaching, competition, facilities, specialist support) are afforded to these players, which may further confound identification and selection processes and ultimately youth-to-senior transitions.

RAEs in football depend on contextual factors, such as age group, competitive playing level, gender, playing position, and sociocultural context (i.e., attraction level, country, depth of competition, historical moment) (1, 6, 28–30). Of particular relevance is that RAEs at senior level are more complex than at youth level. Whilst some research found a residual bias (i.e., knock-on effects) whereby the overrepresentation of relatively older players during youth continues into senior levels [e.g., (30–32)], other studies found reversal effects [e.g., (6, 25, 30, 33, 34)]. Reversal effects may be explained by the comparatively greater challenge experienced by relatively younger players compared to their relatively older peers during early development (i.e., the "underdog hypothesis") (35). These experiences may improve psychological, social, technical, and tactical skills that become more evident at older chronological ages when being relatively older is less advantageous (35).

The mechanisms underpinning the youth-to-senior transition rate in football remain unclear. Research on RAEs predominately examined high performing European clubs or international competitions, whereas limited evidence exists on the national systems of countries and across different playing positions (1, 25). Moreover, studies in football typically investigate the phenomenon using a cross-sectional approach focused on one point in time, generally at youth levels, without considering the players' career at senior levels, leading to a lack of knowledge regarding the relationship between birthdates and the likelihood of successfully transitioning from youth to senior levels (29, 36). As England, France, Germany, Italy, and Spain are among the most influential footballing nations in both Europe and the world, in terms of historical success and impact on the development of the game, our study focused on these countries in order to highlight differences or common factors that influence player selection. Therefore, the aims of the present investigation were to: assess the rate of transitions from youth to senior level (Part I), quantify the prevalence and magnitude of RAEs across playing positions (Part II), and evaluate quartile youth-to-senior transition rate in the national teams of England, France, Germany, Italy, and Spain (Part III).

Methods

Football player data, including birthdates, playing positions (i.e., goalkeepers, defenders, midfielders, forwards), and number of call-ups (regardless of whether players played or not) of youth (i.e., U17, U19, U21) and senior national teams of England, France, Italy, Germany, and Spain, were obtained from open-access online databases provided by Transfermarkt in September 2023 (https://www.transfermarkt.com). The selection of these specific countries was based on their representativeness at a

European level and the availability of extensive data dating back to the year 2000, ensuring a valid and reliable analysis of trends over more than two decades. Specifically, the data consists of rosters for U17, U19, U21, and Senior categories from 2002 to 2022. A total of 9,527 players (U17 = 32.4%; U19 = 33.5%; U21 = 22.4%; Senior = 11.7%) were included for analysing RAEs. To analyse the youth-to-senior transition rates, we considered a subsample of players born between 1985 and 1998 (both years included) after removing duplicates. Thus, only players eligible for selection to Senior teams (i.e., all players who were called up at least once to their respective senior team) were included in the study. Due to the inclusion criteria (i.e., players born between 1985 and 1998), all the athletes considered were at least 24-years-old (1, 25). This sample comprised 3,001 players with representation from England (18.3%), France (19.7%), Italy (21.3%), Germany (23.6%), and Spain (17.1%). Only players eligible for selection to Senior teams were included in the study (25). Informed consent was not required as the data was publicly available. The study was conducted in compliance with the Ethics Committee of the University of Torino (protocol number: 0635113).

Procedure and statistical analysis

Part I. Youth-to-senior transition rate

To obtain a broad view of the youth-to-senior transition rate, we first considered the U17, U19, and U21 age groups as separate age groups in this way, we considered the direct transition to from U17, U19, and U21 to Senior teams. Then, given the possibility of various transition patterns from youth to senior careers, the following combinations were used:

- OnlyU17, OnlyU19, OnlyU21: Players only selected for the U17 or U19 or U19 national team and subsequently selected to the Senior national team.
- OnlySenior: Players who were never called to any youth category but selected directly to the Senior national team.
- U17, 19&21: Players selected for all youth categories and subsequently selected to the Senior national team.
- U17&19, U17&21, U19&21: Players selected for the U17 and U19, for the U17 and U21 or for U19 and U21 national teams and subsequently selected to the Senior national team.

For all these combinations, binomial proportion confidence interval (90% CI) was calculated.

Part II. Relative age effects

Players were divided into four quarters (i.e., Q1 = January–March; Q2 = April–June; Q3 = July–September; Q4 = October–December) according to the FIFA selection year (i.e., from January to December). The observed quartile distributions for each age cohort were then compared to the expected quartile distributions using chi-squared goodness-of-fit tests (χ^2). Due to birth distribution differences in the nations considered we arbitrary used as expected quartile distributions the 25% for each quartile. Cramer's V was considered as effect sizes (ϕ_c). The following thresholds was used: ϕ_c 0.06 trivial, $0.06 < \phi_c \leq 0.17$ small, $0.17 < \phi_c < 0.29$ medium, and $\phi_c \geq 0.29$ large. To compere the proportion of players in the Q1 and Q4 the odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. The analyses were performed separately for each nation, age groups and players positions. In addition, to evaluate RAEs according to the level of competition, we considered the median of the number of call-ups in the respective of age group and nation. Therefore, we arbitrary defined a low performer a player with a number of call-ups $\leq$ of the median and a high performer a player with a number of call-ups > of the median.

Part III. Quartile youth-to-senior transition rate

Binomial proportion confidence intervals (90% CI) were calculated to determine the proportion of players for each quartile (i.e., Q1, Q2, Q3, Q4) who could transition from U17, U19, and U21 to the Senior team. Furthermore, binary regressions with logit link were carried out to determine the impact of the birth quartile on transition rates. Due to the small number of players in each age group and quartile, all analyses involved merging the five national teams together.

Results

Part I. Youth-to-senior transition rate

Fewer than 15% of U17 players progressed to the Senior team: England 12.0% (9.0, 15.5), France 9.4% (6.8, 12.8), Germany 9.8% (7.2, 12.9), Italy 9.2% (6.5, 12.7), and Spain 14.6% (11.1, 18.6). For U19 players, less than 25% progressed to the Senior team: England 20.6% (16.9, 24.8), France 14.8% (11.7, 18.4), Germany 12.7% (10.0, 15.8), Italy 13.2% (10.7, 16.1), and Spain 22.1% (18.2, 26.5). Finally, fewer than 40% of U21 players progressed to the Senior team: England 37.4% (31.9, 43.2), France 21.1% (17.1, 25.4), Germany 32.5% (27.6, 37.8), Italy 28.0% (23.5, 32.9), and Spain 38.0% (32.5, 43.6). Figure 1 provides an overall visual inspection of the youth-to-senior transition rate for each national team.

Generally, fewer than 15% of players selected for U17s were able to progress to U19s and U21s and then advance to their respective national Senior teams. National success rates were: England 9.0% (6.4, 12.2), France 8.4% (5.9, 11.6), Germany 8.8% (6.4, 11.9), Italy 8.1% (5.5, 11.4), and Spain 12.7% (9.5, 16.5). Moreover, less than 5% of U17 players were able to transition to the U19 or U21 teams and then to the Senior team, whilst no players were selected solely in the U17 team and then progressed to the Senior team. However, 0.7% to 3.3% (depending on the national teams) were selected solely for the U19 team before reaching the Senior team, whilst the transition rate to the Senior team increased to 8.3% in only U21 players. Finally, 14.2% to

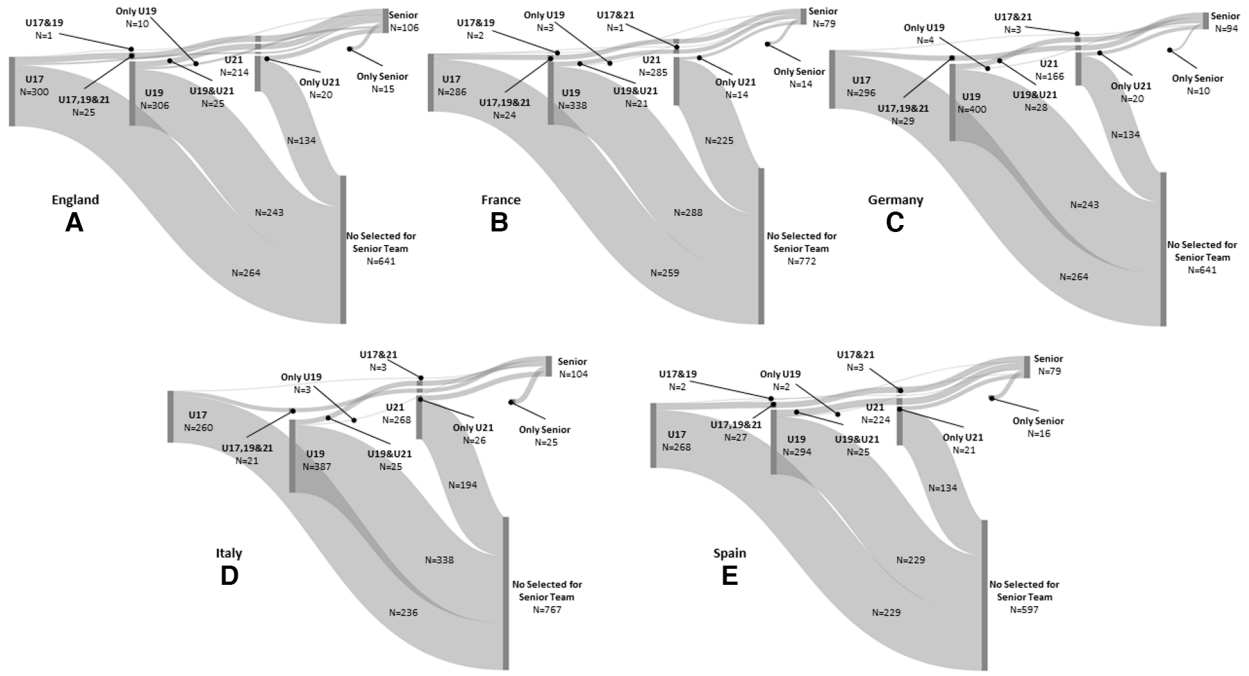


FIGURE 1
Overall visual inspection of the youth-to-senior transition rate in England (A), France (B), Germany (C), Italy (D), and Spain (E). The Sankey diagram provides the number of players able to reach the Senior national team from U17, U19, and U21 as well as the possible combinations. The figure also provides the number of players not selected for the Senior national team.

TABLE 1 Binomial proportion confidence interval [90% CI] of youth-to-senior transition rates in the different nations.

	England	France	Germany	Italy	Spain
U17 to senior	12.0 [9.0, 15.5]	9.4 [6.8, 12.8]	9.8 [7.2, 12.9]	9.2 [6.5, 12.7]	14.6 [11.1, 18.6]
U19 to senior	20.6 [16.9, 24.8]	14.8 [11.7, 18.4]	13.2 [10.7, 16.1]	12.7 [10.0, 15.8]	22.1 [18.2, 26.5]
U21 to senior	37.4 [31.9, 43.2]	21.1 [17.1, 25.4]	32.5 [27.6, 37.8]	28.0 [23.5, 32.9]	38.0 [32.5, 43.6]
Only U17	0	0	0	0	0
Only U19	3.3 [1.8, 5.5]	0.9 [0.2, 2.3]	0.9 [0.3, 2.0]	0.8 [0.2, 2.0]	0.7 [0.1, 2.1]
Only U21	9.4 [6.3, 13.3]	4.9 [3.0, 7.6]	8.1 [5.5, 11.6]	9.7 [6.9, 13.2]	9.4 [6.4, 13.2]
Only senior	14.2 [8.9, 21.0]	17.7 [11.0, 26.3]	10.6 [5.9, 17.4]	24.0 [17.3, 31.9]	15.2 [9.8, 22.2]
U17, 19&21 to senior	9.0 [6.4, 12.2]	8.4 [5.9, 11.6]	8.8 [6.4, 11.9]	8.1 [5.5, 11.4]	12.7 [9.5, 16.5]
U17&19 to Senior	0.3 [0.0, 1.6]	0.7 [0.1, 2.2]	0	0	0.8 [0.1, 2.3]
U17&21 to senior	2.7 [1.3, 4.8]	0.4 [0, 1.7]	0.9 [0.3, 2.4]	1.2 [0.3, 3.0]	1.1 [0.3, 2.9]
U19&21 to senior	8.3 [5.9, 11.4]	7.3 [5.0, 10.4]	8.5 [6.1, 11.5]	9.6 [6.8, 13.2]	10.1 [7.2, 13.6]

24.0% of players reached the Senior team without youth national selection. See Table 1 for overall transition rates.

Part II. Relative age effects

Table 2 summarises the relative age distribution and relative analysis of all players selected for the U17, U19, U21, and Senior national teams (i.e., playing positions individually and combined) in each nation. In addition, the table summarises the RAEs results considering the level of competition.

Regardless of the country, RAEs were observed in all positions for U17, U19, and U21 players, although decreasing with age. In U17, the effect size was large ($\phi_c = 0.40–0.35$), U19 ranged from large-to-small ($\phi_c = 0.37–0.15$), and U21 was medium-to-small ($\phi_c = 0.22–0.17$). The odd to be selected in Q1 was greater than in Q4, with mean OR values of 5.9, 3.2, and 2.2 in U17, U19, and U21, respectively. At the Senior level, medium-to-small RAEs persisted in English, Italian, and Spanish teams ($\phi_c = 0.26–0.17$), but were absent in French and German teams.

Similar trends were observed when analysing the distributions by playing position. At U17 and U19 levels, RAEs were present in all positions with a large-to-medium effect size ($\phi_c = 0.49–0.12$). For U21 teams, the Italian and French selections presented birth-skewed distribution in all positions ($\phi_c = 0.29–0.16$), the German selections presented birth-skewed distribution in all positions except goalkeepers ($\phi_c = 0.22–0.18$), and the English and Spanish selections presented birth-skewed distribution only in defenders

TABLE 2 Relative age outcomes.

	Age group	Playing position	N	Q1	Q2	Q3	Q4	χ^2 (V,ES cat)	Q1 vs. Q4	N	Q1	Q2	Q3	Q4	χ2 (V, ES cat)	Q1 vs. Q4	N	Q1	Q2	Q3	Q4	χ^2 (V, ES cat)	Q1 vs. Q4
			All competition level							Lower competition level							High competition level						
England	Under 17	All players	655	40.3	21.8	20.9	16.9	86.4*** (0.21, M)	2.4 (1.7, 3.2)	345	39.1	18.8	22.3	19.7	37.76*** (0.19, M)	2.0 (1.3, 3.0)	310	41.6	25.2	19.4	13.9	53.21*** (0.24, M)	3.0 (1.9, 4.8)
		Goalkeepers	72	41.7	18.1	26.4	13.9	13.0*** (0.25, M)	3.0 (1.4, 6.3)	48	35.4	22.9	27.1	14.6	4.33 (0.17, S)	2.4 (1.0, 6.2)	24	54.2	8.3	25.0	12.5	12.33** (0.41, L)	4.3 (1.2, 15.8)
		Defenders	208	40.4	23.1	19.7	16.8	27.88*** (0.21, M)	2.4 (1.5, 3.8)	111	38.7	20.7	18.0	22.5	11.54** (0.19, M)	1.7 (1.0, 3.1)	97	42.3	25.8	21.6	10.3	20.63*** (0.27, M)	4.1 (1.9, 8.8)
		Midfielders	209	41.1	20.6	20.1	18.2	29.48*** (0.22, M)	2.3 (1.5, 3.5)	104	39.4	14.4	25.0	21.2	13.92** (0.21, M)	1.9 (1.0, 3.4)	105	42.9	26.7	15.2	15.2	21.73*** (0.26, M)	2.8 (1.5, 5.4)
		Forwards	166	38.6	23.5	21.1	16.9	17.57*** (0.19, M)	2.3 (1.4, 3.7)	82	41.5	19.5	22.0	17.1	12.00** (0.22, M)	2.4 (1.2, 4.9)	84	35.7	27.4	20.2	16.7	7.14** (0.17, S)	2.1 (1.1, 4.3)
	Under 19	All players	561	35.8	21.6	22.1	20.5	35.9*** (0.15, S)	1.7 (1.3, 2.4)	303	32.7	22.1	22.1	23.1	9.57* (0.10, S)	1.4 (0.9, 2.2)	258	39.5	20.9	22.1	17.4	30.06*** (0.20, M)	2.3 (1.4, 3.7)
		Goalkeepers	68	35.3	20.6	22.1	22.1	3.88 (0.14, S)	1.6 (0.8, 3.2)	52	28.8	21.2	23.1	26.9	0.77 (0.07, S)	1.1 (0.5, 2.4)	16	56.3	18.8	18.8	6.3	4.00* (0.29, M)	9.0 (1.1, 72.9)
		Defenders	184	37.0	18.5	25.0	19.6	15.83*** (0.17, S)	1.9 (1.2, 3.0)	90	33.3	21.1	25.6	20.0	3.91 (0.12, S)	1.7 (0.9, 3.3)	94	40.4	16.0	24.5	19.1	13.08** (0.22, M)	2.1 (1.1, 4.0)
		Midfielders	166	33.1	26.5	19.9	20.5	7.57*** (0.12, S)	1.6 (1.0, 2.6)	90	30.0	23.3	17.8	28.9	3.39 (0.11, S)	1.0 (0.6, 2.0)	76	36.8	30.3	22.4	10.5	11.68** (0.23, M)	3.5 (1.5, 8.2)
		Forwards	143	37.8	20.3	21.0	21.0	12.36*** (0.17, S)	1.8 (1.1, 3.0)	71	38.0	22.5	22.5	16.9	6.94 (0.18, M)	2.3 (1.1, 4.8)	72	37.5	18.1	19.4	25.0	6.78 (0.18, M)	1.5 (0.8, 3.0)
	Under 21	All players	376	32.7	19.9	21.5	25.8	31.2*** (0.17, S)	1.3 (0.9, 1.8)	192	34.9	16.7	20.3	28.1	15.29*** (0.16, S)	1.2 (0.7, 2.1)	184	30.4	23.4	22.8	23.4	2.91 (0.07, S)	1.3 (0.7, 2.3)
		Goalkeepers	43	30.2	23.3	14.0	32.6	3.55 (0.17, S)	0.9 (0.4, 2.1)	31	29.0	19.4	12.9	38.7	4.63 (0.22, M)	0.8 (0.3, 1.9)	12	33.3	33.3	16.7	16.7	1.33 (0.19, M)	2.0 (0.4, 11.4)
		Defenders	140	35.0	17.1	25.0	22.9	9.31* (0.15, S)	1.5 (0.9, 2.6)	73	34.2	15.1	21.9	28.8	6.17 (0.17, S)	1.2 (0.6, 2.4)	67	35.8	19.4	28.4	16.4	6.18 (0.18, M)	2.2 (1.0, 4.9)
		Midfielders	104	29.8	26.0	21.2	23.1	1.77 (0.08, S)	1.3 (0.7, 2.3)	47	36.2	19.1	23.4	21.3	3.25 (0.15, S)	1.7 (0.7, 4.1)	57	24.6	31.6	19.3	24.6	1.79 (0.10, S)	1.0 (0.4, 2.3)
		Forwards	89	33.7	15.7	20.2	30.3	7.68 (0.17, S)	1.1 (0.6, 2.0)	41	39.0	14.6	19.5	26.8	5.70 (0.22, M)	1.5 (0.6, 3.4)	48	29.2	16.7	20.8	33.3	3.33 (0.15, S)	0.9 (0.4, 2.0)
	Senior	All players	219	31.1	17.8	21.0	30.1	18.40*** (0.17, S)	1.0 (0.6, 1.7)	112	34.8	17	18.8	29.5	9.86** (0.17, S)	1.2 (0.6, 2.4)	107	27.1	18.7	23.4	30.8	3.44** (0.10, S)	0.9 (0.4, 1.8)
		Goalkeepers	27	25.9	33.3	18.5	22.2	1.29 (0.13, S)	1.2 (0.4, 3.7)	20	25.0	40.0	10.0	25.0	3.60 (0.24, M)	1.0 (0.3, 3.9)	7	28.6	14.3	42.9	14.3	0.25 (0.11, S)	2.0 (0.2, 23.6)
		Defenders	76	30.3	14.5	23.7	31.6	5.58 (0.16, S)	1.0 (0.5, 1.9)	36	41.7	11.1	16.7	30.6	8.22 (0.28, M)	1.4 (0.5, 3.6)	40	20.0	17.5	30.0	32.5	2.60 (0.15, S)	0.6 (0.2, 1.8)
		Midfielders	55	36.4	18.2	14.5	30.9	6.93 (0.20, S)	1.2 (0.5, 2.5)	25	40.0	12.0	20.0	28.0	4.50 (0.24, M)	1.4 (0.5, 4.4)	30	33.3	23.3	10.0	33.3	4.25 (0.22, M)	1.0 (0.4, 2.8)
		Forwards	61	29.5	14.8	24.6	31.1	4.07 (0.15, S)	0.9 (0.4, 2.0)	31	29.0	12.9	25.8	32.3	2.63 (0.17, S)	0.9 (0.3, 2.6)	30	30.0	16.7	23.3	30.0	1.50 (0.13, S)	1.0 (0.3, 3.0)
France	Under 17	All players	647	49.0	25.5	17.5	8.0	237.90*** (0.35, L)	6.1 (4.2, 8.8)	335	50.7	23.0	17.9	8.4	132.82*** (0.36, L)	6.1 (3.7, 10.0)	312	47.1	28.2	17.0	7.7	107.72 (0.34, L)	6.1 (3.6, 10.4)
		Goalkeepers	74	54.1	20.3	20.3	5.4	36.74*** (0.41, L)	10.0 (3.5, 28.6)	53	50.9	24.5	18.9	5.7	23.46*** (0.38, L)	9.0 (2.6, 30.9)	21	61.9	9.5	23.8	4.8	17.80 (0.53, L)	13.0 (1.7, 101.8)
		Defenders	225	49.8	26.2	13.3	10.7	86.52*** (0.36, L)	4.7 (2.9, 7.6)	125	50.4	24.8	12.8	12.0	48.55*** (0.36, L)	4.2 (2.2, 80.0)	100	49.0	28.0	14.0	9.0	38.48 (0.36, L)	5.4 (2.5, 11.8)
		Midfielders	192	51.0	24.5	19.3	5.2	84.71*** (0.38, L)	9.8 (4.9, 19.5)	86	57.0	20.9	19.8	2.3	53.18*** (0.45, L)	24.5 (5.8, 104.3)	106	46.2	27.4	18.9	7.5	33.26 (0.32, L)	6.1 (2.7, 13.8)
		Forwards	156	42.9	28.2	19.9	9.0	38.41*** (0.29, M)	4.8 (2.6, 8.9)	71	43.7	21.1	23.9	11.3	15.50** (0.27, M)	3.9 (1.7, 9.0)	85	42.4	34.1	16.5	7.1	26.81 (0.32, L)	6.0 (2.4, 15.0)
	Under 19	All players	602	41.7	28.2	18.8	11.3	123.80*** (0.26, M)	3.7 (2.6, 5.2)	318	44.7	28.0	17.3	10.1	85.68 (0.30, L)	4.4 (2.7, 7.3)	284	38.4	28.5	20.4	12.7	41.38 (0.22, M)	3.0 (1.8, 5.0)
		Goalkeepers	60	45.0	25.0	18.3	11.7	14.93*** (0.29, M)	3.9 (1.6, 9.1)	40	45.0	25.0	20.0	10.0	10.4 (0.29, M)	4.5 (1.5, 14.0)	20	45.0	25.0	15.0	15.0	4.80 (0.28, M)	3.0 (0.8, 11.5)
		Defenders	199	42.7	30.2	15.6	11.6	48.30*** (0.28, M)	3.7 (2.2, 6.2)	114	44.7	30.7	15.8	8.8	34.55 (0.32, L)	5.1 (2.4, 10.8)	85	40.0	29.4	15.3	15.3	14.90 (0.24, M)	2.6 (1.3, 5.4)
		Midfielders	190	40.0	26.3	21.1	12.6	29.70 (0.23, M)	3.2 (1.9, 5.3)	89	44.9	24.7	18.0	12.4	21.86 (0.29, M)	3.6 (1.7, 7.7)	101	35.6	27.7	23.8	12.9	11.00 (0.19, M)	2.8 (1.4, 5.7)
		Forwards	153	41.2	29.4	20.3	9.2	34.18*** (0.27, M)	4.5 (2.4, 8.4)	75	44.1	29.3	17.3	9.3	20.26 (0.3, L)	4.7 (2.0, 11.4)	78	38.5	29.5	23.1	9.0	14.10 (0.25, M)	4.3 (1.8, 10.4)
	Under 21	All players	472	35.8	27.1	21.6	15.5	42.20*** (0.17, S)	2.3 (1.6, 3.4)	266	37.2	26.3	18.4	18.0	25.64*** (0.18, M)	2.1 (1.3, 3.3)	206	34.0	28.2	25.7	12.1	20.96*** (0.18, M)	2.8 (1.5, 5.1)
		Goalkeepers	52	40.4	26.9	13.5	19.2	8.46* (0.23, M)	2.1 (0.9, 4.7)	42	35.7	28.6	11.9	23.8	4.91 (0.20, M)	1.5 (0.6, 3.6)	10	60.0	0	20.0	20.0	0.67 (0.15, S)	3.0 (0.6, 15.6)
		Defenders	161	36.6	26.1	19.9	17.4	14.33** (0.17, S)	2.1 (1.3, 3.5)	96	42.7	24.0	14.6	18.8	17.75*** (0.25, M)	2.3 (1.2, 4.5)	65	27.7	29.2	27.7	15.4	3.31 (0.13, S)	1.8 (0.8, 4.3)
		Midfielders	136	33.8	25.0	26.5	14.7	10.12* (0.16, S)	2.3 (1.3, 4.1)	66	31.8	25.8	22.7	19.7	2.12 (0.10, S)	1.6 (0.7, 3.6)	70	35.7	24.3	30.0	10.0	10.00* (0.22, M)	3.6 (1.4, 9.0)
		Forwards	123	35.0	30.9	22.0	12.2	15.00** (0.20, M)	2.9 (1.5 5.4)	62	35.5	29.0	24.2	11.3	7.63 (0.20, M)	3.1 (1.2, 8.0)	61	34.4	32.8	19.7	13.1	7.93* (0.21, M)	2.6 (1.1, 6.5)
	Senior	All players	189	26.5	21.7	29.6	22.2	3.20 (0.08, S)	1.2 (0.7, 2.1)	95	26.3	24.2	29.5	20.0	1.79 (0.08, S)	1.1 (0.5, 2.4)	94	26.6	19.1	29.8	24.5	2.25 (0.09, S)	1.1 (0.5, 2.4)
		Goalkeepers	14	21.4	28.6	28.6	21.4	0.25 (0.08, S)	1.0 (0.2, 5.2)	10	20.0	30.0	40.0	10.0	0.33 (0.10, S)	0.5 (0.0, 5.9)	4	25.0	25.0	0.0	50.0	0.00 (0, T)	0.5 (0.0, 5.9)
		Defenders	70	22.9	17.1	34.3	25.7	4.22 (0.14, S)	0.9 (0.4, 1.9)	40	20.0	22.5	32.5	25.0	1.40 (0.11, S)	1.0 (0.3, 3.1)	30	26.7	10	36.7	26.7	4.25 (0.22, M)	1.0 (0.3, 3.1)
		Midfielders	62	37.1	19.4	24.2	19.4	5.13 (0.17, S)	1.9 (0.9, 4.3)	26	46.2	19.2	19.2	15.4	6.00 (0.28, M)	1.4 (0.5, 4.0)	36	30.6	19.4	27.8	22.2	1.11 (0.10, S)	1.4 (0.5, 4.0)
		Forwards	43	18.6	30.2	30.2	20.9	1.91 (0.12, S)	0.9 (0.3, 2.5)	19	15.8	31.6	31.6	21.1	1.40 (0.16, S)	1.0 (0.3, 3.9)	24	20.8	29.2	29.2	20.8	0.67 (0.10, S)	1.0 (0.3, 3.9)
Germany	Under 17	All players	695	50.2	28.5	14.4	6.9	327.80*** (0.40, L)	7.3 (5.0, 10.5)	368	48.6	28.5	14.9	7.9	142.13*** (0.36, L)	6.2 (3.8, 10.0)	327	52.0	28.4	13.8	5.8	161.01*** (0.41, L)	8.9 (5.1, 15.7)
		Goalkeepers	70	58.6	28.6	5.7	7.1	49.89** (0.49, L)	8.2 (3.2, 21.3)	46	60.9	23.9	8.7	6.5	33.50*** (0.49, L)	9.3 (2.7, 32.0)	24	54.2	37.5	0.0	8.3	18.33*** (0.50, L)	6.5 (1.4, 29.8)
		Defenders	227	49.8	29.5	13.7	7.0	98.12*** (0.38, L)	7.1 (4.0, 12.5)	120	48.3	27.5	13.3	10.8	42.60*** (0.34, L)	4.5 (2.3, 8.8)	107	51.4	31.8	14.0	2.8	57.52*** (0.42, L)	18.3 (5.5, 61.1)
		Midfielders	235	48.9	29.4	14.9	6.8	95.95*** (0.37, L)	7.2 (4.1, 12.7)	118	47.5	31.4	14.4	6.8	45.93*** (0.36, L)	7.0 (3.1, 15.6)	117	50.4	27.4	15.4	6.8	50.72*** (0.38, L)	7.4 (3.3, 16.5)
		Forwards	163	49.1	25.8	18.4	6.7	62.02*** (0.36, L)	7.3 (3.7, 14.2)	84	44.0	28.6	21.4	6.0	25.24*** (0.32, L)	7.4 (2.8, 19.8)	79	54.4	22.8	15.2	7.6	39.65*** (0.41, L)	7.2 (2.9, 17.8)

(*Continued*)

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TABLE 2 Continued

	Age group	Playing position	N	Q1	Q2	Q3	Q4	χ^2 (V,ES cat)	Q1 vs. Q4	N	Q1	Q2	Q3	Q4	χ2 (V, ES cat)	Q1 vs. Q4	N	Q1	Q2	Q3	Q4	χ^2 (V, ES cat)	Q1 vs. Q4
			All competition level							Lower competition level							High competition level						
	Under 19	All players	833	43.2	26.4	19.6	10.8	346.4*** (0.37, L)	4.0 (2.9, 5.5)	435	41.1	28.5	19.3	11.0	86.89*** (0.26, M)	3.7 (2.5, 5.6)	398	45.5	24.1	19.8	10.6	103.82*** (0.29, M)	4.3 (2.8, 6.7)
		Goalkeepers	91	44.0	33.0	15.4	7.7	29.35*** (0.33, L)	5.7 (2.5, 13.2)	57	49.1	29.8	12.3	8.8	23.93*** (0.37, L)	5.6 (2.0, 15.3)	34	35.3	38.2	20.6	5.9	8.67* (0.29, M)	6.0 (1.3, 27.8)
		Defenders	276	42.8	26.1	21.0	10.1	61.04*** (0.27, M)	4.2 (2.6, 6.7)	149	37.6	28.2	23.5	10.7	22.46*** (0.22, M)	3.5 (1.8, 6.7)	127	48.8	23.6	18.1	9.4	43.28*** (0.34, L)	5.2 (2.6, 10.4)
		Midfielders	258	41.9	27.9	19.0	11.2	53.08*** (0.26, M)	3.7 (2.3, 5.9)	130	39.2	31.5	18.5	10.8	25.15*** (0.25, M)	3.6 (1.9, 7.2)	128	44.5	24.2	19.5	11.7	30.13*** (0.28, M)	3.8 (2.0, 7.3)
		Forwards	208	45.2	22.1	20.2	12.5	49.54*** (0.28, M)	3.6 (2.2, 5.9)	99	44.4	24.2	18.2	13.1	22.20*** (0.27, M)	3.4 (1.7, 6.8)	109	45.9	20.2	22.0	11.9	28.11*** (0.29, M)	3.8 (1.9, 7.7)
	Under 21	All players	436	36.2	26.8	22.2	14.7	42.00*** (0.18, M)	2.5 (1.7, 3.6)	219	31.1	28.3	24.7	16.0	11.25* (0.13, S)	1.9 (1.1, 3.4)	217	41.5	25.3	19.8	13.4	37.83*** (0.24, M)	3.1 (1.8, 5.5)
		Goalkeepers	45	26.7	33.3	22.2	17.8	2.45 (0.13, S)	1.5 (0.6, 3.8)	27	22.2	29.6	25.9	22.2	0.43 (0.07, S)	1.0 (0.3, 3.3)	18	33.3	38.9	16.7	11.1	3.60 (0.26, M)	3.0 (0.6, 15.6)
		Defenders	153	34.0	30.1	21.6	14.4	14.24** (0.18, M)	2.4 (1.4, 4.1)	71	28.2	31.0	22.5	18.3	2.72 (0.11, S)	1.5 (0.7, 3.4)	82	39.0	29.3	20.7	11.0	13.81** (0.24, M)	3.6 (1.5, 8.2)
		Midfielders	142	38.7	27.5	21.1	12.7	20.28*** (0.22, M)	3.1 (1.7, 5.5)	74	33.8	31.1	25.7	9.5	10.32* (0.22, M)	3.6 (1.4, 9.0)	68	44.1	23.5	16.2	16.2	14.24** (0.26, M)	2.7 (1.2, 6)
		Forwards	96	40.6	17.7	25.0	16.7	14.08** (0.22, M)	2.4 (1.3, 4.6)	47	36.2	19.1	25.5	19.1	3.58 (0.16, S)	1.9 (0.8, 4.6)	49	44.9	16.3	24.5	14.3	11.75** (0.28, M)	3.1 (1.2, 8)
	Senior	All players	200	30.0	24.0	26.5	19.5	5.70 (0.10, S)	1.5 (0.9, 2.7)	101	25.7	22.8	31.7	19.8	3.16 (0.10, S)	1.3 (0.6, 2.9)	99	34.3	25.3	21.2	19.2	5.32 (0.13, S)	1.8 (0.8, 3.9)
		Goalkeepers	18	27.8	38.9	22.2	11.1	2.80 (0.23, S)	2.5 (0.5, 13.5)	13	23.1	38.5	30.8	7.7	0.83 (0.15, S)	3.0 (0.3, 30.9)	5	40.0	40.0	0.0	20.0	2.50 (0.41, L)	2.0 (0.2, 23.6)
		Defenders	68	25.0	29.4	26.5	19.1	1.53 (0.09, S)	1.3 (0.6, 3.0)	37	21.6	29.7	32.4	16.2	2.56 (0.15, S)	1.3 (0.4, 4.4)	31	29.0	29.0	19.4	22.6	0.88 (0.10, S)	1.3 (0.4, 4.0)
		Midfielders	70	34.3	21.4	24.3	20.0	3.40 (0.13, S)	1.7 (0.8, 3.7)	32	28.1	15.6	31.3	25.0	1.75 (0.14, S)	1.1 (0.4, 3.4)	38	39.5	26.3	18.4	15.8	5.00 (0.21, M)	2.5 (0.8, 7.5)
		Forwards	44	31.8	13.6	31.8	22.7	4.00 (0.17, S)	1.4 (0.6, 3.5)	19	31.6	10.5	31.6	26.3	2.20 (0.20, M)	1.2 (0.3, 4.5)	25	32.0	16.0	32.0	20.0	2.17 (0.17, S)	1.6 (0.5, 5.6)
Italy	Under 17	All players	539	47.5	28.6	16.5	7.4	179.70*** (0.33, L)	6.4 (4.3, 9.5)	282	47.2	24.5	21.3	7.1	92.54*** (0.33, L)	6.7 (3.7, 11.8)	257	47.9	33.1	11.3	7.8	110.67*** (0.38, L)	6.2 (3.4, 11.0)
		Goalkeepers	57	47.4	24.6	21.1	7.0	19.50*** (0.34, L)	6.8 (2.3, 19.7)	39	43.6	23.1	28.2	5.1	11.50*** (0.31, L)	8.5 (1.9,38.0)	18	55.6	27.8	5.6	11.1	10.00* (0.43, L)	5.0 (1.1, 23.6)
		Defenders	179	45.3	33.0	12.3	9.5	62.33*** (0.34, L)	4.8 (2.7, 8.4)	87	41.4	33.3	16.1	9.2	22.95*** (0.3, L)	4.5 (2.0, 10.3)	92	48.9	32.6	8.7	9.8	41.48*** (0.39, L)	5.0 (2.3, 10.9)
		Midfielders	172	50.0	25.0	18.6	6.4	69.63*** (0.37, L)	7.8 (4.0, 15.2)	88	54.5	15.9	25.0	4.5	48.36*** (0.43, L)	12.0 (4.1, 34.9)	84	45.2	34.5	11.9	8.3	31.90*** (0.36, L)	5.4 (2.3, 12.9)
		Forwards	131	47.3	29.0	17.6	6.1	48.21*** (0.35, L)	7.8 (3.6, 16.7)	68	47.1	25.0	19.1	8.8	21.29*** (0.32, L)	5.3 (2.1, 13.5)	63	47.6	33.3	15.9	3.2	28.31*** (0.39, L)	15.0 (3.5, 64.9)
	Under 19	All players	670	38.8	26.9	21.6	12.7	113.30*** (0.24, M)	3.1 (2.2, 4.3)	378	37.0	27.2	22.2	13.5	43.64*** (0.20, M)	2.7 (1.8, 4.2)	292	41.1	26.4	20.9	11.6	53.29*** (0.25, M)	3.5 (2.1, 5.8)
		Goalkeepers	65	43.1	29.2	18.5	9.2	16.81*** (0.29, M)	4.7 (1.9, 11.6)	43	37.2	34.9	18.6	9.3	9.00* (0.26, M)	4.0 (1.3, 12.6)	22	54.5	18.2	18.2	9.1	10.00* (0.39, L)	6.0 (1.3, 27.8)
		Defenders	236	38.6	28.0	19.1	14.4	32.10*** (0.21, M)	2.7 (1.7, 4.2)	125	43.2	20.8	21.6	14.4	23.84*** (0.25, M)	3.0 (1.6, 5.6)	111	33.3	36.0	16.2	14.4	16.75*** (0.22, M)	2.3 (1.2, 4.5)
		Midfielders	206	43.2	24.3	19.9	12.6	41.73*** (0.26, M)	3.4 (2.1, 5.6)	118	39.8	25.4	18.6	16.1	15.80*** (0.21, M)	2.5 (1.3, 4.6)	88	47.7	22.7	21.6	8.0	29.00*** (0.33, L)	6.0 (2.5, 14.3)
		Forwards	163	31.9	27.6	28.8	11.7	16.02*** (0.18, M)	2.7 (1.5, 4.8)	92	25.0	34.8	29.3	10.9	11.57*** (0.2, M)	2.3 (1.0, 5.2)	71	40.8	18.3	28.2	12.7	12.83*** (0.25, M)	3.2 (1.4, 7.3)
	Under 21	All players	468	36.8	27.1	21.2	15.0	48.00*** (0.18, M)	2.5 (1.7, 3.6)	249	35.3	28.1	21.7	14.9	23.05*** (0.18, M)	2.4 (1.4, 4.0)	219	38.4	26.0	20.5	15.1	25.98 (0.2, M)	2.5 (1.5, 4.4)
		Goalkeepers	50	46.0	20.0	18.0	16.0	11.54** (0.28, M)	2.9 (1.2, 6.7)	36	41.7	22.2	19.4	16.7	5.56 (0.23, M)	2.5 (0.9, 6.9)	14	57.1	14.3	14.3	14.3	2.50 (0.24, M)	4.0 (0.8, 19.7)
		Defenders	179	30.7	30.7	21.2	17.3	9.89* (0.14, S)	1.8 (1.1, 3.0)	104	31.7	27.9	26.9	13.5	7.92* (0.16, S)	2.4 (1.1, 4.9)	75	29.3	34.7	13.3	22.7	7.53* (0.18, M)	1.3 (0.6, 2.7)
		Midfielders	129	41.1	28.7	18.6	11.6	25.59*** (0.26, M)	3.5 (1.9, 6.6)	66	37.9	31.8	18.2	12.1	10.94* (0.24, M)	3.1 (1.3, 7.6)	63	44.4	25.4	19.0	11.1	15.06*** (0.28, M)	4.0 (1.6, 10)
		Forwards	110	37.3	22.7	25.5	14.5	11.50** (0.19, M)	2.6 (1.4, 4.8)	43	34.9	27.9	16.3	20.9	3.36 (0.16, S)	1.7 (0.7, 4.1)	67	38.8	19.4	31.3	10.4	12.53** (0.25, M)	3.7 (1.5, 9.3)
	Senior	All players	273	31.1	26.7	24.5	17.6	53.60*** (0.26, S)	1.8 (1.0, 3.0)	139	30.9	30.2	21.6	17.3	7.40 (0.13, S)	1.8 (0.9, 3.6)	134	31.3	23.1	27.6	17.9	5.35 (0.12, S)	1.8 (0.9, 3.5)
		Goalkeepers	23	43.5	17.4	17.4	21.7	4.17 (0.25, S)	2.0 (0.6, 6.3)	16	31.3	18.8	25.0	25.0	0.00 (0.00, T)	1.3 (0.3, 5.2)	7	71.4	14.3	0.0	14.3	3.25 (0.39, L)	5.0 (0.5, 46.1)
		Defenders	91	29.7	29.7	18.7	22.0	3.35 (0.11, S)	1.4 (0.7, 2.7)	45	28.9	37.8	13.3	20.0	6.27 (0.22, M)	1.4 (0.5, 4.0)	46	30.4	21.7	23.9	23.9	0.83 (0.08, S)	1.3 (0.5, 3.4)
		Midfielders	79	30.4	31.6	26.6	11.4	8.15* (0.19, S)	2.7 (1.1, 6.3)	39	33.3	30.8	20.5	15.4	3.30 (0.17, S)	2.2 (0.7, 6.6)	40	27.5	32.5	32.5	7.5	6.8 (0.24, M)	3.7 (0.9, 14.8)
		Forwards	80	30.0	21.3	31.3	17.5	4.30 (0.13, S)	1.7 (0.8, 3.7)	39	30.8	25.6	30.8	12.8	3.30 (0.17, S)	2.4 (0.7, 7.9)	41	29.3	17.1	31.7	22.0	2.3 (0.14, S)	1.3 (0.5, 3.7)
Spain	Under 17	All players	548	50.0	29.0	14.2	6.8	217.50*** (0.36, L)	7.4 (4.9, 11.1)	297	53.2	30.0	11.1	5.7	165.01*** (0.43, L)	9.3 (5.1, 16.9)	251	46.2	27.9	17.9	8.0	79.86*** (0.33, L)	5.8 (3.2, 10.5)
		Goalkeepers	64	42.2	35.9	14.1	7.8	21.25*** (0.33, L)	5.4 (2.0, 14.4)	49	40.8	36.7	14.3	8.2	15.75** (0.33, L)	5.0 (1.6, 15.3)	15	46.7	33.3	13.3	6.7	5.13*** (0.34, L)	7.0 (0.8, 58.2)
		Defenders	193	52.3	30.6	14.0	3.1	106.98*** (0.43, L)	16.8 (7.2, 39.5)	104	57.7	26.9	12.5	2.9	71.46*** (0.48, L)	20.0 (6.0, 66.5)	89	46.1	34.8	15.7	3.4	39.41*** (0.38, L)	13.7 (4.1, 46.0)
		Midfielders	156	53.8	23.7	14.7	7.7	77.28*** (0.41, L)	7.0 (3.7, 13.3)	78	59.0	28.2	7.7	5.1	56.60*** (0.49, L)	11.5 (3.9, 33.5)	78	48.7	19.2	21.8	10.3	25.10*** (0.33, L)	4.8 (2.1, 10.8)
		Forwards	135	45.9	29.6	14.1	10.0	42.50*** (0.32, L)	4.4 (2.4, 8.2)	66	48.5	31.8	10.6	9.1	27.18*** (0.37, L)	5.3 (2.1, 13.5)	69	43.5	27.5	17.4	11.6	16.41*** (0.28, M)	3.8 (1.6, 8.7)
	Under 19	All players	527	41.7	26.9	20.3	11.0	102.20*** (0.25, M)	3.8 (2.6, 5.5)	285	38.6	28.4	20.7	12.3	43.11*** (0.22, M)	3.1 (1.9, 5.2)	242	45.5	25.2	19.8	9.5	65.80*** (0.30, L)	4.8 (2.7, 8.5)
		Goalkeepers	52	19.2	36.5	28.8	15.4	5.69 (0.19, M)	1.3 (0.5, 3.3)	35	20.0	37.1	28.6	14.3	4.11 (0.20, M)	1.4 (0.4, 4.6)	17	17.6	35.3	29.4	17.6	0.13 (0.05, T)	1.0 (0.2, 5.1)
		Defenders	194	50.0	28.4	13.9	7.7	81.22*** (0.37, L)	6.5 (3.6, 11.7)	103	46.6	29.1	14.6	9.7	33.73*** (0.33, L)	4.8 (2.3, 10.2)	91	53.8	27.5	13.2	5.5	48.91*** (0.42, L)	9.8 (3.7, 26)
		Midfielders	149	41.6	22.8	22.8	12.8	26.14*** (0.24, M)	3.3 (1.9, 5.7)	78	44.9	23.1	19.2	12.8	17.70*** (0.28, M)	3.5 (1.6, 7.6)	71	38.0	22.5	26.8	12.7	9.28* (0.21, M)	3.0 (1.3, 6.8)
		Forwards	132	38.6	25.8	23.5	12.1	18.73*** (0.22, M)	3.2 (1.7, 5.8)	69	29.0	29.0	27.5	14.5	4.18 (0.14, S)	2.0 (0.9, 4.6)	63	49.2	22.2	19	9.5	21.56*** (0.34, L)	5.2 (2, 13.1)

(*Continued*)

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TABLE 2 Continued

Age group	Playing position	All competition level								Lower competition level								High competition level							
		N	Q1	Q2	Q3	Q4	χ^2 (V,ES cat)	Q1 vs. Q4		N	Q1	Q2	Q3	Q4	χ^2 (V, ES cat)	Q1 vs. Q4		N	Q1	Q2	Q3	Q4	χ^2 (V, ES cat)	Q1 vs. Q4	
Under 21	All players	385	39	24.9	20.5	15.6	54.20*** (0.22, M)	2.5 (1.7, 3.7)		214	39.3	20.6	21	19.2	23.15*** (0.19, M)	2.0 (1.2, 3.5)		171	38.6	30.4	19.9	11.1	29.47*** (0.24, M)	3.5 (1.8, 6.7)	
	Goalkeepers	36	19.4	38.9	22.2	19.4	3.78 (0.19, S)	1.0 (0.3, 2.9)		21	23.8	33.3	28.6	14.3	1.80 (0.17, S)	1.7 (0.4, 7.3)		15	13.3	46.7	13.3	26.7	0.63 (0.12, S)	0.5 (0.1, 2.8)	
	Defenders	142	49.3	19.0	19.7	12.0	46.17*** (0.33, L)	4.1 (2.3, 7.4)		84	47.6	16.7	17.9	17.9	22.95*** (0.30, L)	2.7 (1.3, 5.4)		58	51.7	22.4	22.4	3.4	26.80*** (0.39, L)	15.0 (3.4, 66)	
	Midfielders	116	37.1	26.7	19.8	16.4	11.59** (0.18, M)	2.3 (1.2, 4.1)		56	39.3	19.6	21.4	19.6	6.14 (0.19, M)	2.0 (0.9, 4.5)		60	35.0	33.3	18.3	13.3	8.40* (0.22, M)	2.6 (1.1, 6.5)	
	Forwards	91	33.0	26.4	22.0	18.7	4.13 (0.12, S)	1.8 (0.9, 3.4)		53	32.1	22.6	22.6	22.6	1.46 (0.10, S)	1.4 (0.6, 3.3)		38	34.2	31.6	21.1	13.2	4.20 (0.19, M)	2.6 (0.9, 7.8)	
Senior	All players	232	34.5	26.7	20.3	18.5	28.30*** (0.20, S)	1.9 (1.1, 3.2)		116	37.9	26.7	16.4	19.0	13.03*** (0.19, M)	2.0 (1.0, 4.1)		116	31.0	26.7	24.1	18.1	4.07 (0.11, S)	1.7 (0.8, 3.6)	
	Goalkeepers	23	17.4	26.1	17.4	39.1	2.83 (0.20, S)	0.4 (0.1, 1.5)		16	18.8	25.0	18.8	37.5	0.25 (0.07, S)	0.5 (0.1, 2.2)		7	14.3	28.6	14.3	42.9	0.25 (0.11, S)	0.3 (0.0, 3.4)	
	Defenders	77	41.6	24.7	18.2	15.6	12.79** (0.24, S)	2.7 (1.2, 5.8)		37	35.1	32.4	10.8	21.6	5.67 (0.23, M)	1.6 (0.6, 4.6)		40	47.5	17.5	25.0	10.0	12.60*** (0.32, L)	4.8 (1.4, 16.1)	
	Midfielders	69	36.2	31.9	20.3	11.6	10.53* (0.23, S)	3.1 (1.3, 7.6)		34	50.0	26.5	17.6	5.9	13.56*** (0.36, L)	8.5 (1.8, 40.9)		35	22.9	37.1	22.9	17.1	3.00 (0.17, S)	1.3 (0.4, 4.4)	
	Forwards	63	30.2	23.8	23.8	22.2	0.94 (0.07, S)	1.4 (0.6, 3.0)		29	37.9	20.7	20.7	20.7	2.71 (0.18, M)	1.8 (0.6, 5.8)		34	23.5	26.5	26.5	23.5	0.22 (0.05, T)	1.0 (0.3, 3.1)	

Q1, first quartile percentage; Q2, second quartile percentage; Q3, third quartile percentage; Q4, fourth quartile percentage; χ^2, chi-square value; V, Cramer's V effect size; effect size category: T, trivial = V ≤ 0.06; S, small = 0.06 < V ≤ 0.17; M, medium = 0.17 < V < 0.29; L, large = V ≥ 0.29; OR, odds ratio and 95% confidence intervals (95% CI); Q1 vs. Q4, first versus the last quartile.
*p<0.05, **p<0.01, ***p<0.001.

and defenders/midfielders, respectively ($\phi_c = 0.33–0.15$). At the Senior level, only midfielders in the Italian team and defenders/midfielders in the Spanish team showed a birth-skewed distribution. However, the overall mean indicated that players born in the first half of the year (%) were more frequently represented than those born in the second half (%).

The median number of calls required to identify the players called up was 4–5 for the U17s, 3–5 for the U19s, 5–7 for the U21s, and 7–14 for Senior teams. When considering high and low performers, RAEs were more pronounced, with a higher effect size for high performer players. High performers born in Q1 were more likely to be selected than those born in Q4, with mean ORs (merged for all nations) of 6.0, 3.6, and 2.6 at U17, U19, and U21, respectively. In low performers, the ORs were 6.1, 3.0, and 1.9 at U17, U19, and U21, respectively. As expected, the magnitude of RAEs decreased with age and is less pronounced in the Senior teams. Interestingly, a significant inverse RAE was observed for England in high performer players. See Supplementary File S1 for quartile distribution based on nation, playing positions, and competition level.

Part III. Quartile youth-to-senior transition rate

Figure 2 provides the transition rate by quartile for players selected in U17, U19, and U21. A higher percentage of players born in Q4 transitioned to Senior teams compared to Q1 players, especially in U17 and U19 teams (overall average: Q1 = 9.0 (7.2, 11.2) vs. Q4 = 16.4 (11.5, 22.5) and Q1 = 14.6 (12.4, 17.0) vs. Q4 = 20.0 (16.0, 24.6) for U17 and U19, respectively). For the U21s, the trend was similar (overall average: Q1 = 28.7 (25.3, 32.3) vs. Q4 = 33.5 (27.8, 37.6).

The Q4 players of U17 and U19 had 1.98 (1.15, 3.32) and 1.47 (1.00, 2.13) higher odds of transitioning to the Senior teams when compared to Q1 players, respectively. Contrastingly, in U21, the transition trends were similar for the quartile with no differences observed in logistic regression [e.g., OR =1.25 (0.87, 1.80) for Q1 vs. Q4]. See Supplementary File S2 for binary regressions with logit link.

Discussion

Using five European national teams, this study aimed to assess the rate of transition from youth to senior level (Part I), evaluate the prevalence and magnitude of RAEs across different nations and playing positions (Part II), and assess the quartile transition rate from youth to senior level (Part III). Regardless of national team, −15%, less than 25%, and less than 40% of U17, U19, and U21 players, respectively, were successfully selected for their Senior team. Additionally, −14%–24% of players (depending on national team) were selected only at Senior level (Part I). Moreover, data suggested a skewed birthdate distribution favouring relatively older players at U17, U19, and U21 level (on average Q1 = 38.7% vs. Q4 = 15.2%), while RAEs were present depending on the national context at Senior level (Part II). RAEs were also prevalent in all player positions to some extent, most

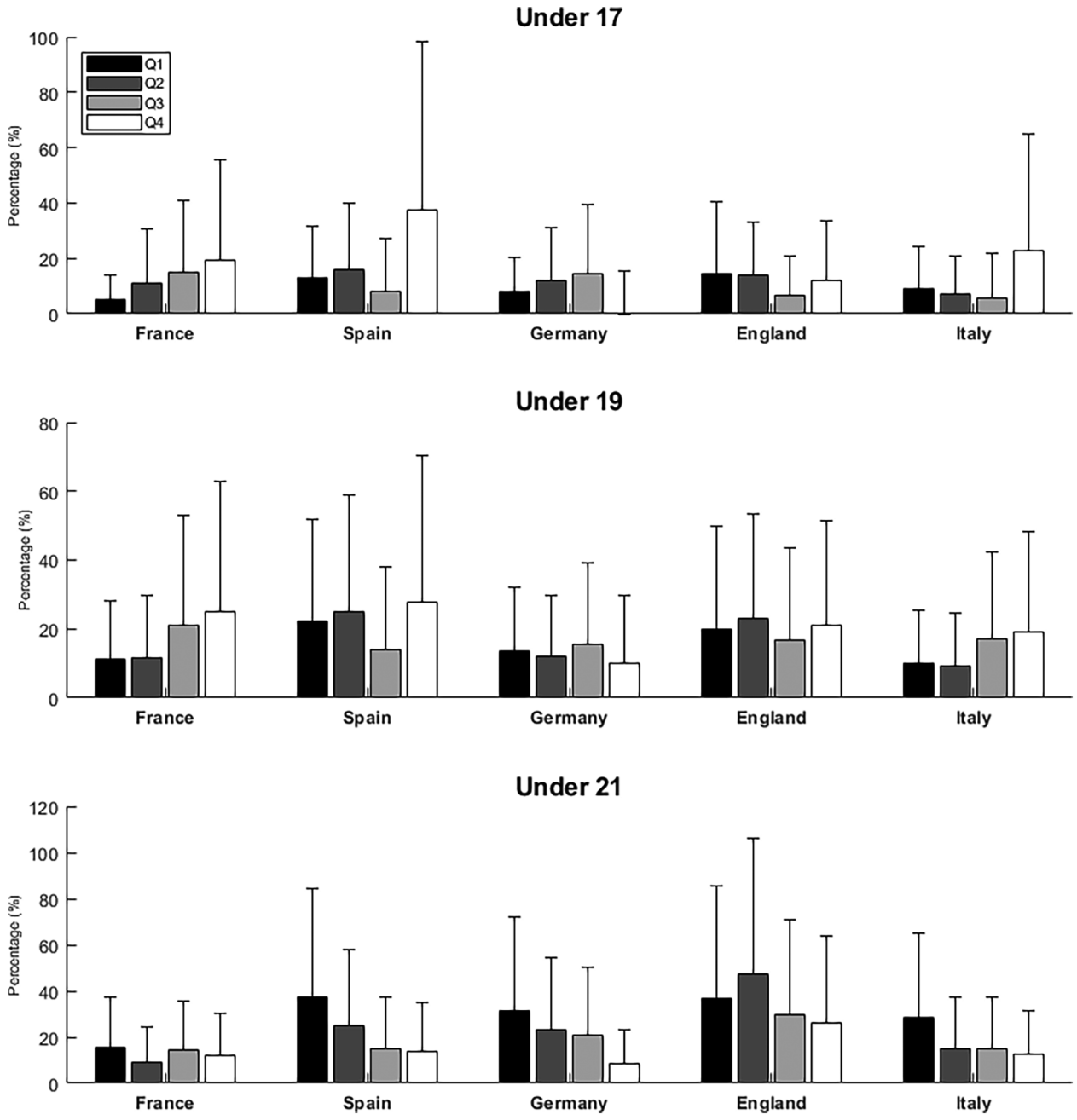


FIGURE 2
Figure present the frequency of successful birth quartile transition rate for players in U17, U19, and U21.

notably at U17 and U19 with medium/large effect sizes. Moreover, RAEs were pronounced at higher competition level (i.e., players who had been called up to the national youth team more often). Finally, the youth-senior transition rate is modulated by birthdate at U17 and U19, where Q4 players were −2 and 1.5 times more likely to transition to the Senior team than Q1 players, respectively (Part III).

Analysis of the youth-to-senior transition rate suggests that, irrespective of national context, players selected at youth national level are not necessarily successful at Senior level. Indeed, only −25% were able to successfully transition to Senior teams in the U17 and U19 categories. As players got older, however, around a third who were selected at U21 level successfully transitioned to their Senior team (from 21.1 to 38.0%). Moreover, selected later-born players had an increased likelihood of completing the transition (24, 30). These results are in line with previous studies in male (1) and female (25) footballers, and underline how transition rates are modulated by age group (i.e., an increasing likelihood of being selected in older age groups). For instance, Boccia et al. (1) revealed that less than 10% of U16 national team players successfully transition to Senior teams, while −40% of U21 players were eventually chosen for Senior teams.

In terms of national comparisons, when the transition rates for all youth categories were combined, England (23.3%) and Spain (24.9%) presented the highest rates followed by Germany (18.5%), Italy (16.6%), and France (15.1%). Overall, these results suggest that, independent of national context, selection in national youth teams cannot be considered a key factor for future selection at the Senior level. It is interesting to note that the transition rates drop significantly when considering the direct transition from a youth category (i.e., U17, U19, or U21) to the Senior category (i.e., less than 9% of players). These findings highlight that being selected in at least two youth national teams may increase the chances of being selected for the Senior team (1). Conversely, around a quarter of the senior players were not selected at youth level. Put simply, youth categories are likely underachieving as there is no clear pathway, especially considering that the majority of players in the youth categories are not selected again. It should also be noted that, at the youth levels, there tends to be a lot of selection initially followed by a significant amount of exclusion, further highlighting the complex and nuanced trajectories from youth to senior levels. Taken together, the data shows a high turnover of youth players and low likelihood of being selected for Senior teams (37), which is likely due to repeated (de)selection procedures throughout childhood and adolescence rather than early selection and long-term continuous development (23).

RAE analysis showed that, regardless of the cultural context, there were consistent asymmetries in quartile distribution within U17, U19, and U21 categories, whereby relatively older players overrepresented compared to relatively younger equivalents (−36% in Q1 vs. −19% in Q4). Specifically, players born in Q1 were −6, −3, and −2 times more likely to be selected than those born in Q4 in U17, U19, and U21, respectively. On the other hand, however, although the magnitude of RAEs were small at Senior levels, they were still present in English, Italian, and Spanish teams ($\phi_c = 0.17$–0.26). These results confirm that age modulates the magnitude of RAEs, and that this decreases with increasing age (38). Interestingly, in some senior national contexts (i.e., England, Italy, Spain), our data showed a residual bias indicating knock-on effects. These findings highlight the ongoing over-representation of relatively older players from youth to senior levels, highlighting the complex dynamics of age-related advantages in football and suggesting that the impact of RAEs may evolve and manifest differently depending on the national context.

The analysis of the playing position offers additional information regarding the mechanisms of RAEs in European football rosters. RAEs were also prevalent in all player positions, most notably at U17 and U19 with medium/large effect sizes. Regardless of nationality, goalkeepers born in Q1 were on average −7 and 4 times more likely to be selected than those born in Q4 at U17 and U19, respectively. For other playing positions, the magnitude of the RAE changes in relation to the national context. For example, at U17 level, RAEs were more prevalent among midfielders in France, defenders in Spain, midfielders and forwards in Germany and Italy, whilst being similar in all player positions in England. This data may suggest how the magnitude of RAEs is higher in players position where more developed physical qualities may provide a competitive advantage. From the U21 level onwards, RAEs were only observed for some player positions, depending on the socio-cultural context. For example, the lowest OR was observed in England and Spain, suggesting that these two countries were able to mitigate RAEs through a more balanced selection policy. The results suggest that the impact of chronological age in the playing position varies according to the socio-cultural context (29, 32, 38). These differences may be based on the country-specific differences and playing styles. However, these are only speculations, and given that the nations included are among the most influential footballing nations in Europe, both in terms of historical success and impact on the development of the game, this aspect should be addressed in future studies.

In accordance with previous studies (26, 38), data suggested that RAEs were more pronounced at higher competition level (i.e., players who had been called up to the national youth team more often were generally relatively older). Additionally, players born in Q1 were −6, 4, and 3 times more likely to be selected than those born in Q4 at high competition level, while players born in Q1 were −6, 3, and 2 at U17, U19, and U21 for the low competition level, respectively. Overall, data confirms that country, playing position, and competition level influence the extent of RAEs, which is likely varies according the national team philosophy and subsequent playing style (39).

Focusing on the quartile transition, the results show how players born in Q4 had an advantage in the youth-to-senior transition, highlighting a reversal of the relative age advantage at senior level and consequently confirming the "underdog hypothesis" (35). Q4 players were more likely to make the transition from U17 or U19 to senior level than Q1 players (i.e., −2 and 1.5 times more likely than those born in Q4, respectively). At U21 level, a trend was also observed, although it was not statistically significant (i.e., 1.25 times more likely). These inverse effects can be explained by the "underdog hypothesis", whereby relatively younger players face a greater challenge in comparison to their relatively older counterparts during early development. These experiences may enhance a higher degree of psychological resilience and toughness (40), as well as higher skill proficiency (i.e., social, technical, tactical skills) that allows relatively young players to overcome initial birthdate disadvantages and increase their chances of making senior level (35, 41). However, it is important to remember these suggestions remain hypothetical and the exact mechanisms contributing to these trends have yet to be determined.

Limitations

This study did not explore factors influencing player development trajectories, such as injuries, coaching quality, socioeconomic background, or motivation. We have defined inclusion in the Senior category based on having at least one call-up. Consequently, this criterion may introduce a selection bias when interpreting the results. Moreover, our study describes the youth-to-senior transition rate, considering national call-ups, but did not examine youth development structures. Whilst this

approach was taken for simplicity, it did not allow us to investigate the mechanisms that underpin the selection process. There is scope for further investigation, including female contexts, career trajectories across the lifespan, and long-term outcomes of players who were not selected for national teams but may still excel in high-level club competitions.

Conclusion

Our results show that being a high-performing youth international player is not a sufficient proxy for reaching senior national team level. In addition, the data suggest that, although RAEs can influence selection, especially in youth categories, individuals born further from the cut-off date have a higher likelihood of successfully transitioning through to senior teams once selected into the national team pathway.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.transfermarkt.com/.

Ethics Statement

The study was conduced in compliance with the Ethics Committee of the University of Toronto (protocol number: 0635113). Informed consent was not required for this study as publicly available datasets were used.

Author contributions

PB: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing. AM: Writing – original draft, Writing – review & editing, Methodology. AU: Writing – review & editing, Methodology. AK: Writing – original draft, Writing – review & editing, Methodology.

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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 reviewer [ADR] declared a past co-authorship with the author [ALK] to the handling editor.

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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.2024.1420220/full#supplementary-material

SUPPLEMENTARY FILE S1
Birth quartile percentage distributions presented individually for all playing positions (i.e. goalkeepers, defenders, midfielders and forwards) for U17, U19, U21 and senior for each nation.

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An investigation on main effects and interactions of relative age effects and playing position in female elite football in Germany

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Athlete age-grouping and age-banding has been shown to impact sport participation and athlete development. The current study examined the impact of within-year (WYEs) and between-year effects (BYEs), and their interactions with playing position, on female participation in elite German football. The sample of 1,378 German first-league players revealed expected participation inequities within-year with relatively older players being over-represented and younger players being under-represented. From a between-year perspective there were no participation differences. The interaction of WYEs and BYEs revealed an over-representation of odd-year players in Q1, and Q2 in even years. With respect to the interaction between year effects and playing position, for WYEs the expected effect was present for goalkeepers and defenders, while there was no significant interaction for BYEs. Overall, the results offer insight regarding the impact of system structure on participation, and highlight unique characteristics associated with playing positions.

KEYWORDS

athlete development, constant year, within year, between year, birth advantage, competition structure, age cohort

1 Introduction

Research examining sport-related relative age effects (RAEs) is concerned with training, competition, and selection (dis)advantages experienced by members of the same age-grouped cohort. When examined within the context of sport, RAEs are assumed to be present when patterns of over-/under-representation are observed with respect to the participants' birthdates and their respective relationship to the organizational cut-off date used for age groupings (1). To illustrate the effect within a one-year cohort, an individual born in January (i.e., relatively oldest) may be more likely to participate and advance in certain sport settings than an individual born in December (i.e., relatively youngest) due to inherent chronological age differences (2). RAEs are most commonly investigated as *within-year effects (WYEs)* when examined within the same birth year but can also include (dis)advantages experienced by athletes grouped into two-year age bands (i.e., *between-year effects; BYEs*) where disadvantages will be more pronounced. For instance, at age 12 children can vary by 22.5 cm (girls) or 24.4 cm (boys) with respect to attained height, and by 28.2 kg (girls) or 25.7 kg (boys) for weight based on longitudinal data (3); the size range would be even greater within a two-year age band. Here it is important to note that RAEs can become

exacerbated in combination with a second, closely connected and interacting but different factor/bias influencing player development: variations in biological maturity[1] (4, 5). A variety of RAEs have been documented across sport and cultural contexts over the years (for reviews, see 6, 7). Generally, patterns of over-representation of relatively older athletes are found at the developmental level in both team-based (e.g., soccer, ice hockey) and individual (e.g., tennis, swimming) sport contexts, particularly when physical demands are an inherent element of the activity (6, 7).

1.1 RAEs in sport

The magnitude of RAEs can vary depending on age level, competitive tier, and sex/gender (8). For instance, existing meta-analyses have found that RAEs in male athlete samples peak during the adolescent years (6) when physical differences between peers are most extreme due to developmental processes (9, 10). In (female) athlete samples, the magnitude of RAEs peak earlier before dissipating (7), reflecting differences in biological growth (11) and earlier completion of maturation processes (i.e., typically 12–14 and 13–15 years for females and males, respectively 8). Furthermore, RAEs are believed to be more common when physical development/size provides a competitive advantage in a given sport (10), and when athlete selection processes (particularly at young ages) or competition for a small number of playing positions are inherent in the organizational structure of the sport (12). These trends align with the frequently cited 'maturation-selection' hypothesis [see (13, 14) for further discussion]; however, multiple factors could potentially contribute to the magnitude and nature of these effects during the course of development, e.g., socio-cultural factors [for further discussion, see (10, 15, 16)].

Typically, RAEs are seen within one year across a single cohort (WYEs). In sport contexts, athletes often participate in an age-grouping category and a competition age-band (e.g., under-16) simultaneously. When athletes enter year one of a multi-year (mostly two-year) age-band they are members of an age-group. When this group progresses to year two, a new annual age-group enters year one of the age-band. In this situation, each year of the age-band represents a *constituent year* where a player can be in the younger year group in year one of an age-band and in the older year group in year two of the age-band, with relative age being a dynamic characteristic (1, 17–19). That is, constituent year effects represent one type of BYEs and it is the interaction of WYEs and BYEs that has provided an opportunity to look at athlete development in new ways. The other type of BYEs are *constant year effects* where multi-year age-groups are fixed and constant throughout development, and all players move together from one age-band to the next. In this system, the oldest players remain the oldest across the different age-bands and conversely the youngest players are always the youngest, and may consistently be at a disadvantage. In some cases, like in the following study, constant year effects and constituent year effects can interactively affect the same sample simultaneously when two development systems (e.g., the club and German national talent development system) are working in parallel.

1.2 Interaction of BYEs and WYEs

Previous work examining both WYEs and BYEs simultaneously has been limited, with some variation in the observed trends depending on the context (e.g., team vs. individual sport) and age group (e.g., junior vs. senior/professional). For instance, Steingröver and colleagues (20) examined WYEs and BYEs at the highest level of (male) German U16 and U19 basketball, observing a statistically significant interaction in the U16 division, and statistically significant main effects for both effects in the U19 age group. Likewise, Steingröver et al.'s (21) study revealed an interaction of WYEs and BYEs across a sample of (male) soccer players competing in U17 world cup tournaments, suggesting that younger players are less likely to enter the national athlete development system. However, there did not appear to be a carry-over effect in a subsequent sample of world cup athletes, although some WYEs were replicated. Moreira and colleagues (22) reported the presence of both WYEs and BYEs with respect to junior tennis players' rankings by the International Tennis Federation, with 19% of the variance explained by the presence of both effects. For national and international table tennis, no interaction was found between WYEs and BYEs, but various subsample analyses suggested main effects (17). In summary, the first studies investigating the interaction of WYEs and BYEs all show main effects for both WYEs and BYEs while an interaction is only rarely found.

1.3 Interaction of playing position and with WYEs or BYEs

Previous research has also examined the influence of playing positions as a moderator of RAEs (8, 23). Several studies have documented variation in magnitudes of *WYEs* depending on playing position within this context. For instance, Baker and colleagues (24) documented positional differences with respect to WYEs in a male/female, youth and adult sample competing at the national level for USA soccer. Playing position has also been identified as a moderator in other sport contexts, such as ice hockey (e.g., 25) and handball (e.g., 26). While variation is observed in the soccer/football-related findings published to date,

[1]Biological maturity refers to the progression of bodily systems toward the adult state. Children of the same chronological age can vary significantly with respect to the stage (pre-pubertal, pubertal, or post-pubertal), timing, and rate/tempo of maturation (4, 5, 9). While RAEs are observed in childhood and continue throughout the developmental years, maturational differences are associated with selection bias during the adolescent period (5).

WYEs generally tend to be greater in magnitude among subsamples designated as defense or goalkeepers (24, 27–29), and also for the midfield position (24, 27, 30) when birth distributions are compared across position categories within a sample.

For BYEs, there are to the best of our knowledge no studies that analyzed the interaction of BYEs and playing position. Therefore, with respect to soccer/football, moderation of *BYEs* with respect to playing position remains unexamined.

1.4 Aim of the study

The complexity of WYEs and BYEs operating simultaneously (both uniquely and as interacting variables) in sport development systems remains largely unexamined, particularly in female contexts. Thus, the aim of this study was to investigate (1) both WYEs and BYEs in combination with the playing position, and (2) their possible interaction among elite female athletes competing in German league soccer.

For the WYEs, a clear over-representation of the first quartile in comparison to other birth quartiles was hypothesized. For the BYEs, the hypothesis is less straight forward, because the German female football system comprises of two different development systems. On the one hand, the national development system is a constant year system with fixed two-year age bands, with the relatively older year group constantly being the older ones. On the other hand, the club development system acts on a constituent year approach in which the seniority changes every year. Here, player groups are the older one for one year and the next year they are the younger one. All players will participate in the club system, while only some will make it into the national development teams. Therefore, a clear hypothesis in this regard cannot be stated and this effect was explored openly. For playing position, current tactical systems in soccer/football require a different number of players per position and therefore, clear differences were expected (i.e., less goalkeepers than strikers, than defenders and midfielders).

For the interaction of BYEs and WYEs, only very limited empirical studies can be found in the current literature (20, 21). Thus, this investigation was exploratory without clear hypotheses as previous research investigated only younger age divisions. For the interaction of playing position and WYEs, statistically significant effects were hypothesized as previous research has shown variable WYEs, or more general RAEs, magnitudes for different playing positions although the interaction was not specifically tested in those studies. No specific hypotheses were generated for playing position given the novelty of this portion of the analysis with respect to BYEs.

2 Methods

2.1 Data acquisition and processing

For this study, birthdates and playing positions of 1,387 players were obtained from official websites covering the first German football league (https://www.kicker.de/frauen-bundesliga/vereine/). The players were born between 1977 and 2001. Their mean age was 24.32 years. For the German Football Association, January 1st was defined as the cut-off date. For WYEs, birth dates were recoded into four quartiles (Q1: January–March, Q2: April–June, Q3: July–September, Q4: October–December). For BYEs, birth years were divided into odd and even years. However, as mentioned above, these odd and even years cannot be attributed as older or younger because of the changes in the club system. For playing position, players were divided into groups of goalkeepers, defenders, midfielders, and strikers. In this study, we included only German-born players, because the developmental systems all over the world might be different from the German structure.

2.2 Statistical analyses

IBM SPSS Statistics 29.0 and G*Power 3.1 were used for statistical analyses (31). Asymptotic chi²-analyses were conducted to (1) consider differences among birth quartiles (WYEs), (2) test for differences among the number of participants in odd or even years, respectively (BYEs), and (3) test for differences in number of players per position. In addition, asymptotic chi²-analyses were conducted to test for two-way interactions between the three factors. For all analyses, an equal distribution of births across all quartiles and years was assumed and the alpha-level was set at .05. For each effect size, the 90% confidence interval was calculated based on the noncentral chi²-files provided online by Michael Smithson (http://www.michaelsmithson.online/stats/CIstuff/CI.html).[2]

3 Results

The results section follows the two aims of the study. First, single factor effects were checked for WYEs, BYEs, and playing position effects. Second, two-way interactions between the three factors were reported.

For WYEs, a statistically significant effect of small size was revealed, $\chi^2(3,\ n = 1{,}378) = 12.54,\ p < .01,\ w = .10,$ 90%CI[.03; .14]. In the first quartile, 28% of players were born and therefore the first quartile was over-represented in comparison to the other quartiles (Q2 = 26%; Q3 = 23%, and Q4 = 23%; cf. Figure 1). For BYEs, no statistically significant effect was found, $\chi^2(1,\ n = 1{,}378) = 0.19,$ $p = .67,\ w = .01,$ 90%CI[.00; .06], with 51% of players being born in the odd years and 49% of players in even years. For the factor of

[2]The SPSS-script provided by Michael Smithson calculates the non-centrality parameter for the non-central distributions under which a particular chi²-value cuts off an area of α% (here: 5%) to the right (λ_{low}) and left (λ_{low}). Based on these calculations, the lower (w_{low}) and upper (w_{upp}) bound of the confidence interval on Cohen's *w* are obtained via the formula w_{low}=sqrt[λ_{low}/N] and w_{upp}=sqrt[λ_{upp}/N], respectively.

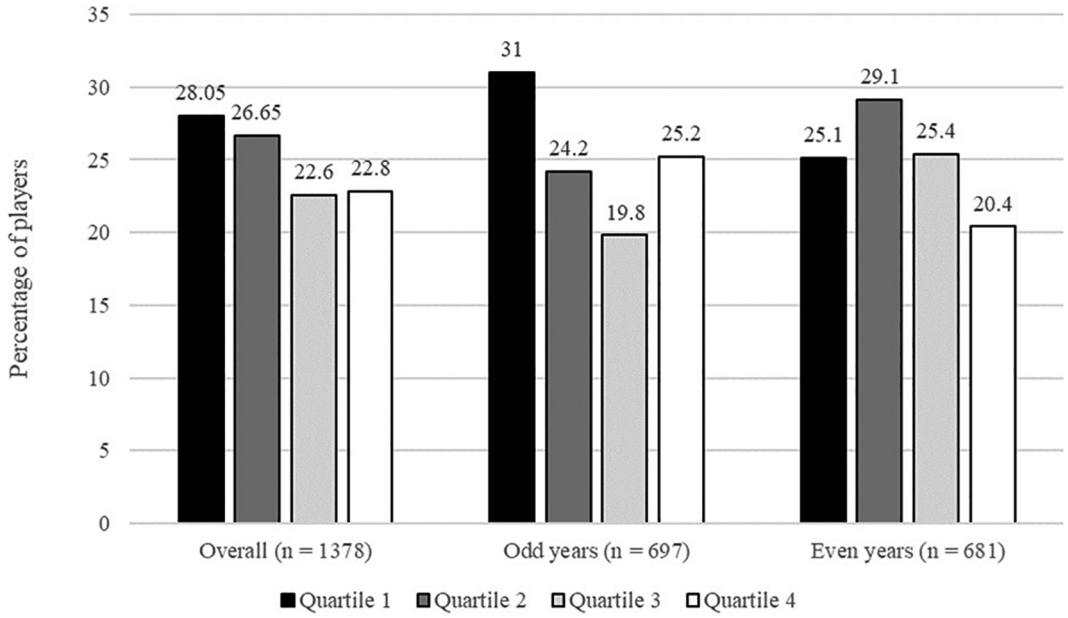


FIGURE 1
Interaction of BYEs and WYEs.

playing position, a statistically significant effect of medium size was found, $\chi^2(3, n = 1{,}378) = 181.07$, $p < .01$, $w = .36$, 90%CI [.31; .41]. As expected, there were fewer goalkeepers (13%) in the sample compared to strikers (20%), defenders (31%) and midfielders (36%).

The first two-way interaction analyzed was for WYEs and BYEs. As can be seen in Figure 1, for odd years the expected over-representation for the first quartile was found. For even years, Q2 had the greatest representation. A two-way chi²-analyses revealed a statistically significant interaction, $\chi^2(3, n = 1{,}378) = 15.57$, $p < .01$, $w = .11$, 90%CI[.04; .15]. This interaction is small to non-existent as shown by the effect size confidence interval.

For the interaction between playing positions and WYEs, a varying pattern of results were found. For goalkeepers, the expected WYE was found (cf. Figure 2). For defenders, the pattern for Q1, Q2 and Q3 was the same, but Q4 showed a higher number of players than expected. For midfielders, an over-representation for Q2 and Q3 and under-representation for Q1 and Q4 was observed. The opposite trend is demonstrated for strikers. Overall, the interaction was statistically significant with a small effect size, $\chi^2(9, n = 1{,}378) = 50.99$, $p < .01$, $w = .19$, 90%CI[.12; .23].

For the interaction between playing positions and BYEs, similar patterns of results were found as with WYEs (cf. Figure 3). As described for the playing position effect, the overall number of players increased from goalkeeper to strikers, defenders, and to midfielders, however, this trend was similar for both odd and even years as shown by the effect was not statistically significant effect and the effect size was below small, $\chi^2(3, n = 1{,}378) = 0.61$, $p = .89$, $w = .02$, 90%CI[.00; .05].

4 Discussion

The purpose of this study was to examine WYEs and BYEs, their possible interaction, and playing position effects in elite female athletes competing in German league soccer.

4.1 Single factor effects

Findings were consistent with hypotheses for WYEs, with a statistically significant over-representation of relatively older athletes in German first-league football. However, effect sizes were small for these WYEs, because while WYEs overall mimic and support those published previously and highlighted in the meta-analysis by Smith et al. (7), the pattern of over-representation was different for odd and even years with an over-representation in Q1 for odd years and Q2 for even years.

Analyses of BYEs were exploratory in nature and suggested no significant main effects among German-born female athletes. This means that being born in the first or second year of a two-year age band was not associated with any relative advantage or disadvantage with respect to German first league participation. The lack of BYEs may be explained by the overwhelming role of the clubs' development system (incorporating a dynamic, constituent system wherein athletes alternate being oldest and youngest from year to year) in contrast to national activities (where the year to year advantage remains fixed). It might also reflect, that not all women reaching the first league in Germany were actually part of the national talent development system. Therefore, its influence might be smaller. In essence, the BYEs may potentially be masked by players at similar stages of

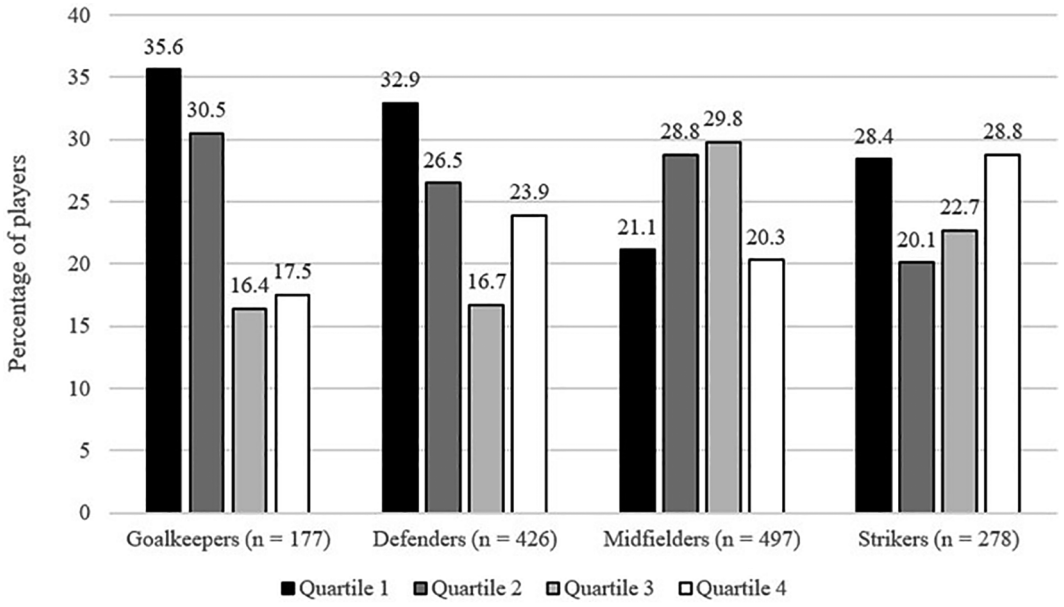


FIGURE 2
Interaction of WYEs and playing position.

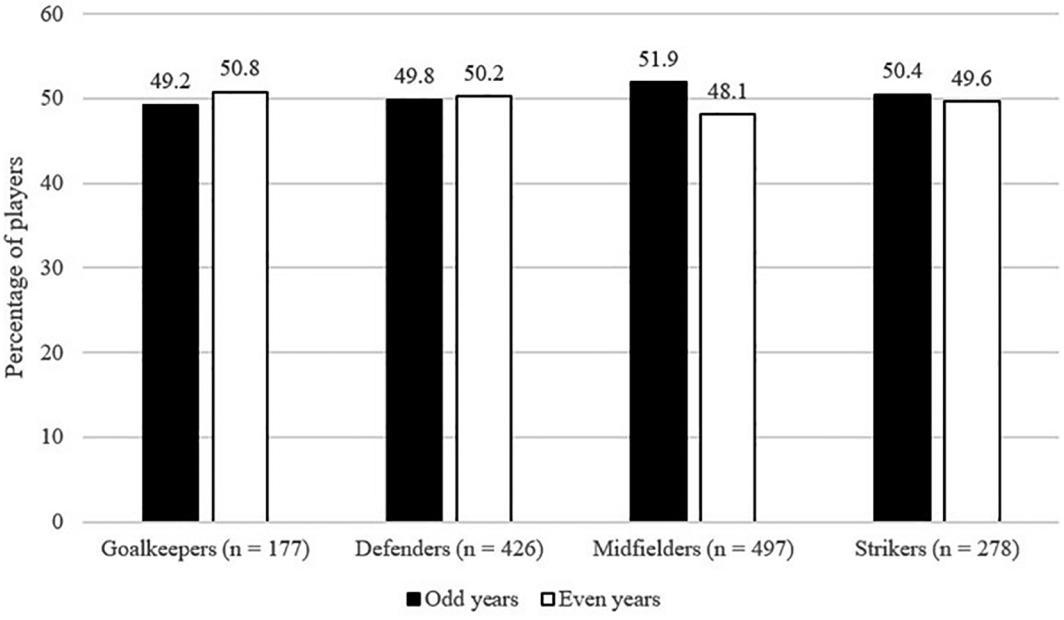


FIGURE 3
Interaction of BYEs and playing position.

maturation or physical development despite the constant year system where those born in odd years are always older than those born in even years. However, additional work is needed to further explore findings related to BYEs.

Single factor analyses for playing position revealed clear differences in the number of players for each position category, as expected. This aligns with current tactical systems in football/soccer and reported findings in previous work (29, 30).

4.2 Interaction effects

Visual inspection of Figure 1 suggests subtle (descriptive) differences in the pattern of birth quartile representation (WYEs), when comparing odd and even years (BYEs), with the greatest percentage of players born in Q1 (odd) vs. Q2 (even). Previous analyses of female samples have shown similar trends (7). While an over-representation of Q1 is theoretically expected

according to the classic patterning of RAEs, it is not uncommon for Q2 over-representation to be reported, suggesting RAEs are not as clearly defined in female samples. However, the practical significance of an interaction between WYEs and BYEs in this study is likely minimal, as indicated by the effect size.

With respect to playing position, only the interaction with WYEs was significant, supporting previous research. While all playing positions showed variation of representation across birth quartiles, only goalkeepers and defenders displayed a traditional over-representation in Q1 and under-representation in Q4. This is similar to the findings of Romann and Fuchslocher (27) who reported stronger birth quartile effects for goalkeepers and defenders in female Swiss soccer. Other studies have shown more consistent birth quartile effects across playing positions in soccer, handball and volleyball, but differences in structures of leagues and developmental systems and tactical requirements are likely responsible for study specific differences (32, 33). These tactical requirements may also partly explain why the (traditional) profile of a smaller, agile and smart midfielder and striker is not as prone to be influenced by RAE-related characteristics such as height and strength.

As can be observed in Figure 3, there was no interaction found between playing position and BYEs. While the overall number of players varied between position categories, there was no associated advantage with being born in an odd vs. even year within any position category. This too might be explained by the influence of the club development system, in which athletes experience varying relative age positions from year to year (i.e., constituent year effects). Examinations of playing position and BYEs in other sport contexts are not available for comparison.

4.3 General discussion

As stated in the introduction, recent research has emphasized the important differentiation between RAEs and biological maturity differences (4, 5, 34). While RAEs appear to be present from childhood on, maturity differences start occurring mainly with puberty onset and increase afterwards (5). That is, the two distinct factors certainly have interacting effects on player development before adulthood. In this regard, recent research in male soccer/football has shown that coaches have strong biases towards relatively older and maturer players when making selection and release decisions, potentially with greater impacts of maturity differences compared to RAEs (4, 35). As another example in a different sport, Papadopoulou et al. (36) examined anthropometric and physiological differences across birth quartiles in a population of female volleyball players. While they revealed strong birth quartile effects, they found no differences in anthropometric/physiological measures, suggesting and supporting the idea that not only age but also other maturation-related factors are responsible for these effects. While transferring findings of research on male players and/or other sport systems to female contexts must be done with caution, this certainly opens up promising avenues for future research.

While statistically significant effects were revealed for WYEs in the single factor and interaction analyses, the effect sizes were small to non-existent. Thus, the current data may support that those who are relatively younger and "survive" in the system are equally represented at the national level. The underdog hypothesis (37) proposes that relatively younger athletes may have the greatest potential for success in the long run. In order to be retained in the development system, relatively younger players "must either possess and/or develop superior technical, tactical and psychological skills" [p. 148 (38)]. These skills become more salient as the athlete moves through the developmental years towards adulthood. Yet, many relatively younger athletes may be lost due to the disadvantages that they experience.

4.4 Strengths & limitations

This study provided a novel analysis of BYEs and playing position in a female sample from the first German league, in addition to the more traditionally examined WYEs. The limitations of this study include those inherent in all cross-sectional, quantitative studies of RAEs. The patterns observed cannot be fully explained given the multitude of factors contributing throughout the athletes' development over many years. One associated limitation in the present study is a lack of information regarding biological maturity in this sample. While RAEs and their assessment alone certainly have great value for both researchers and practitioners, maturational status has been identified as a significant contributor to selection advantages during the adolescent years (5, 34). Thus, including measures of biological maturity (e.g., Age at Peak Height Velocity) can provide additional information and facilitate the implementation of effective solutions. It is also difficult to fully disentangle the contributions of the club system (i.e., constituent year effects) and national system (i.e., constant year effects) in German football.

4.5 Future directions

Future studies should consider the various types of RAEs (WYEs and BYEs) interacting with other moderators (e.g., playing position, sex/gender) during the course of athlete development. Looking at the statistical significance of each analysis and effect sizes, this study shows how important it is for researchers to calculate, interpret and report effect sizes and confidence intervals. This allows for the assessment of practical relevance of findings. With RAEs and maturity differences having varying impacts at different phases of development, practical strategies to address the different factors should be considered. For example, birthday banding for RAEs (39) or bio-banding for maturity differences (40) should be implemented at the right time during development to mitigate selection biases.

5 Conclusions

The findings of the present study suggest the presence of WYEs in female German-born first league players, with minimal evidence

of BYEs or an interaction between the two types of RAEs. Playing position was found to be an important moderator with respect to WYEs, highlighting unique characteristics for each position. No such trends were identified for playing position with respect to BYEs. Continued work is needed to fully unravel the contribution of RAEs (and maturation) on athlete selection.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.kicker.de/frauen-bundesliga/vereine/.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

KS: Writing – original draft, Writing – review & editing. TK: Data curation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing. PW: Writing – original draft, Writing – review & editing. JS: Conceptualization, Data curation, Formal Analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Looking beyond relative age to understand relative advantage and disadvantage in talent development

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In this perspective article, we argue for a broader consideration of relative advantages and disadvantages in youth sport; a lens that considers the complex biopsychosocial factors that influence athlete development beyond relative age. We begin with a brief overview of Relative Age Effects (RAEs), with a particular focus on the proposed underlying mechanisms, followed by a discussion of the cultural and organisational considerations and implications that talent systems must consider when implementing interventions to counteract RAEs. We conclude by proposing key directions for future research in respect to RAEs and talent development more broadly. We argue that there is a need to consider the highly complex nature of RAEs, but also that there are no clear solutions to the issue of RAEs in youth sports, and that proposed solutions may come with unintended consequences. This should encourage us to experiment more, not less, with diverse ways of providing meaningful sports experiences that promote learning, psychosocial development, and performance. We suggest an urgent need for greater practical and research focus on supporting coaches, as they have the greatest capacity to understand the needs of individual athletes. In addition, systemically working towards equal access to skilful coaches. We encourage a shift in focus beyond descriptive methodologies of RAEs toward transformative research methodologies that include action-based research, complex interventions that incorporate context-sensitive qualitative methods, and other participatory research approaches.

KEYWORDS

athlete development, relative age effects, youth sport, talent identification, talent systems

Introduction

Talent development (TD) in sport is well established as a complex, dynamic, and typically non-linear process, with a range of biopsychosocial variables having the potential to impact a young athlete's progression (1, 2). In youth sport, national federations and their respective clubs are typically responsible for identifying and nurturing young athletes through this developmental process to the senior elite level (3).

In some contexts, young athletes can be recruited into formalised TD systems from as young as five years of age (4). Early selection is proposed to maximise the long-term provision of significant developmental resources to the most talented athletes to facilitate their transition to the elite senior level (3, 5). However, evidence across several TD contexts indicates that the traditional identification and selection of young athletes may often lead to the over selection of those with early advantages (i.e., experiential, physical) relative to peers (6–9). This is of further significance given that junior and senior success in sport are not synonymous (10).

One extensively studied concept proposed as providing significant early advantage is advanced relative age (11–13). Relative age represents one's chronological age relative to the individual birthdate and competition cut-off date (9). In a sporting context, Relative Age Effects (RAEs) are a selection bias in favour of those athletes born earlier in the selection year or biannual competition cycle, who are chronologically older, at the expense of those born later in the selection year, in a given cohort. The proposed early advantage is a population level effect with significant evidence of selective TD system populations, prior to the elite level, slanted towards those youth athletes born in the first two quartiles of the year at the expense of those born in the third and fourth quartiles (3, 7–9, 14–17). For example, in an investigation of 1,212 male players aged 8–18 years from 17 professional soccer academies in the United Kingdom, players born in the first quartile were 49% of those selected, with players born in quartile four comprising just 9% (7). In the United Kingdom, U13 male 100 m sprint athletes born in the first quartile made up 48% of those selected, with those born in quartile four representing just 8% (18). In an investigation of the female American soccer talent system, youth players born in the fourth quartile of the year accounted for just 14% of all players selected at the club, national and international level (13). In a 16-year longitudinal study of the TD system in Spanish handball (organised in biannual cycles), relatively older U19 and U21 male and female players (Q1) accounted for 18% of those selected to compete internationally, compared to 8% of relatively young players (Q8) (19).

Despite contextual differences and variations between biological sexes, the disproportionate over selection of athletes born in the first two quartiles of the selection year appears relatively consistent (although with variation in magnitude) across a multitude of contexts in both male youth [i.e., (8, 9, 20)], and to a lesser extent, and female youth [i.e., (13)], spanning from local to international levels (3, 14, 16, 17, 19, 21). In some instances (e.g., male soccer in the United Kingdom), RAEs have been observed in early-mid childhood (7, 9). Indeed, RAEs may also be present at earlier stages of the pathway, before selection into formalised TD systems occur (22, 23). Further, RAEs have been shown by some authors to be present at the youth level but to dissipate at the senior level (24). Other authors, however, have shown that RAEs may too persist at the senior level (25). Moreover, some research underlines the relevance of RAEs in the selection and re-selection of players for U17, U19 and even senior national teams (25, 26). These findings have sparked a multitude of investigations to explore the mechanisms underpinning RAEs, with a view to provide recommendations to promote developmental equity within TD systems (27).

Mechanisms underpinning relative age effects

Several factors have been proposed to cause RAEs, the majority of which relate to factors associated with differences in age and experience. Musch and Grondin (11) suggested that the mechanisms underpinning RAEs are multifactorial and related to a combination of physical, cognitive, emotional, motivational, and social factors. In discussions relating to male youth soccer, it has been suggested that RAEs may be attributed to a variety of factors including: age associated differences in sport knowledge and understanding, decision making, cognition, and psychosocial development (9, 28). Recently, Fitzgerald et al. (20) discussed how RAEs may be partially related to age-associated differences in neural development. With the development of the brain and nervous system showing rapid changes during infancy and early childhood, and a single chronological year representing a difference of more than 20% total neural development from age 2–3 years, this can present an advantage for a relatively older athlete within a given cohort (20). On the other hand, Wattie et al. (29) considered that the existence or non-existence of a RAE must necessarily be understood from how individual, task, and environmental constraints facilitate performance in the specific sport context. Rather than being attributable to several direct factors, McCarthy et al. (30) suggest that RAEs are a more complex population-level consequence of a constellation of factors that are difficult to measure or quantify. In short, RAEs being something that we cannot directly attribute to a defined set of tangible factors, particularly as the extent of proposed advantages (and the factors providing the advantage) differ between individuals and contexts (30). Moreover, at the individual level, some relatively older athletes may not benefit from advantages at all (28, 30–32). As one example, in Swiss female youth TD programmes, relatively older alpine skiers and tennis players are overrepresented and appear advantaged, yet relatively older snowboarders, fencers and table tennis players are underrepresented and appear disadvantaged (33). Data in female Italian soccer show the same proportion of relatively older and younger players represent the international team at the senior level in absolute terms (34). Further, Kelly et al. (35) show that relative advantages or disadvantages in sport go beyond just age and experience. In this regard, contextual elements of the athlete's environment and an interaction with their sporting experiences influence relative advantages in sport, and subsequent progression through the pathway (35). Considering the influence of context, De La Rubia et al. (36) demonstrated that advantages/disadvantages associated with RAE influenced competition performance. This, ultimately, highlights the contextually driven complexity of RAEs with so much still unclear, despite 40 years of research in sport. At this point, it is important to acknowledge that the vast majority of investigations

focussed on RAEs in sport have been dominated by research specific to males (37). Indeed, Curran et al. (37) note that of the research focussed on RAEs or biological maturation published between 1999 and 2019, 63% is specific to male populations. Indeed, this is a broader issue in the TD research, whereby female specific investigations represent just 9% of the data (37). We urge the reader to acknowledge the sex gap in the RAE literature, and TD literature more broadly, considering such implications when reading our article.

Independence of relative age and biological maturity

Although it was initially suggested that RAEs may be attributable to differences between individuals in biological maturation (and the associated physical, functional and physiological advantages conferred by advanced biological maturity) (38, 39), there is now a substantial evidence base to highlight that biological maturation and relative age are independent and uncorrelated (8, 9, 28, 31). Indeed, there is data showing that the relatively oldest selected athletes within a given cohort have been amongst the more delayed in biological maturity (8, 9, 17). Biological maturation is the process of progression toward the mature adult state and is defined in terms of status, timing, and tempo (40–42). Significantly, youth of the same chronological age can differ up to 6 years in skeletal age and somatic maturity, both of which are established indices of biological maturity status and timing (31, 43–45). The individual differences in biological maturation between youth of the same chronological age are primarily attributable to inherent genetic factors, although the influence of environmental factors (e.g., chronic malnutrition, disease, climate) have also been noted, to a lesser extent (46). Note that none of these factors relate to differences in age and experience between individuals within the same chronological age cohort.

Advanced biological maturity provides several distinct physical, functional and physiological sporting advantages (e.g., increased stature, body mass, lean muscle mass, peak force production, absolute muscular strength and power) (40, 47–52) (although varying markedly in magnitude between biological sexes, with a substantially disproportionate evidence base in favour of male youth), none of which are directly correlated to advanced relative age (8, 9, 17, 20, 31). The selection advantages conferred by advanced biological maturity in youth team sport are typically observed at the onset of puberty (8, 9), whereas those associated with relative age have been observed in childhood (7, 9). For a more substantial discussion on the distinct differences between biological maturity and relative age, see the work of Towlson et al. (31).

Cultural and organisational considerations

The landscape of TD and elite sport systems varies significantly across different cultural and organisational contexts, requiring tailored strategies that recognise these differences without uncritically adopting imported solutions (53). For instance, in the United Kingdom, the centralised approach and focus on early engagement within soccer academies contrasts sharply with the more dispersed, multicentric and grassroots-based approaches observed in the Scandinavian countries (21). Whilst early selection and a focus on early engagement affords the opportunity to shape the developmental journey, a consequence is that large numbers of young athletes are excluded access to such systems from early ages (27). On the other hand, a multicentric and grassroots-based approach promotes a breadth of engagement opportunities but presents additional challenges to the shaping of athlete experience, particularly in ensuring quality coaching and specialised support (27). Strategies to manage unequal opportunities for access and learning due to relative age should, therefore, be tailored to specific contexts, whilst remaining mindful that regardless of specific approach, there may be unintended consequences as a result of implementation. In selection-based TD systems, one such strategy is to allow for flexible entry points and progression routes, ensuring that grassroots settings are of sufficient quality so that so called; “late developers”, those subject to relative early disadvantage, are not entirely excluded (54).

Mitigating inequalities related to relative age will also differ between sports depending on the age of selection to the system. For example, as a contrast to the pre-adolescent first selection point in professional English soccer, in rugby union, large cohorts of players are first selected to formal academies from 15 years of age, with evidence of significant subsequent selection and deselection.[1] Similarly, TD systems in Spanish handball carry out the first selection of player cohorts around the age of 12–13 years at the regional/national level (the time at which athletes leave school sport) and at the age of 15–16 years to compete in international contexts. Again, this contrasts to European soccer, whereby players may compete internationally from 14 years (17, 32, 55). Cultural differences within the same sport, both across countries and local contexts, may also dampen or amplify issues related to relative age, and even biological maturation, such as whether the distinct culturally significant ways of playing the sport favours physical or refined technical-tactical prowess (56, 57). A final consideration that organisations need to address is the disruption of social relationships with peers in sport. Given that the quality of social relationships among peers are essential to continued participation, learning and performance in organised sports (58), any strategy used to target advanced relative age should only be implemented as complementary measures and carefully adopted in conversation with the individual children themselves. Creating opportunities for periodic practice and competition with relatively older athletes (i.e., playing up), for example, may aid development, provided

[1]Shelly A, Behan S, Taylor J, MacNamara Á, Sajwan V, Scriney M, et al. The impact of high-potential status on progression and conversion within a male rugby union talent system. *J Sports Sci.* (In Review).

that the children themselves perceive it as appropriate, meaningful for development, challenging, encouraging, and fun (59–62). Additionally, alternating age categories used in national and international competition so that players can adapt to playing with both relatively younger and older players, and experience different relative levels of individual performance, should also be considered (36). By acknowledging and addressing these cultural and organisational differences, and by implementing strategies to mitigate inequalities related to relative age, sport organisations can create more equitable and effective TD systems that not only enhance performance, but also support the psychosocial development of young athletes.

Implications for relative advantage and disadvantage in talent systems

The identified distinction between relative age and biological maturation points to differential means of intervention or non-intervention. This, in turn, presents significant considerations with the implementation of strategies aimed toward optimising talent system processes or promoting equity of selection. In the case of relative age, significant research attention has been focused toward generating selection practices that lead to greater numbers of later born athletes being selected (12, 63). Yet it appears that across some sporting settings, those selected few born later in the selection year, *if retained within the system*, may also benefit from exposure to the demands associated with competing with relatively older athletes (64, 65). However, it should be noted that in absolute terms, relatively younger athletes were still underrepresented at the senior level in these studies (66, 67). There is also somewhat similar evidence presented in the context of biological maturation (68). Further, there is a need for due consideration to the potential for non-selection or dropout of relatively younger athletes at the youth level, but also the notable dropout of relatively older athletes at latter stages of the pathway (69). As such, not only do we need to consider the highly complex nature of RAEs, but also the lack of systematic evaluation of the impact of interventions that have sought to alter its magnitude. More broadly, consideration must be given to the potential unintended consequences if a given intervention is "effective".

There is then a need to make decisions related to the bar at which interventions might be necessary. As there is growing pressure on sporting organisations to present equitable access to talent systems, there becomes a question for National Sporting Organisations (NSOs) to consider the extent to which individual National Governing Bodies (NGBs) are responsible for wider societal issues such as equitable access to facilities and equipment, especially in sports with high barriers to entry based on cost. As an example, whilst English Premier League soccer academies are often criticised based on early selection practices, it appears that selected players represent a highly socially diverse population (70). Yet, the solution of providing extensive support to an economically and socially diverse population, including transport, from an early age is clearly beyond the reach of nearly all other contexts. In similarly resource rich systemic contexts, we should be looking to capture longitudinal data that might provide proxies to understand performance related challenge factors (e.g., biological maturation), population trends (e.g., RAEs), and non-performance relevant factors (e.g., proxies for socio-economic status, such as post/zip code). These types of data should inform systemic choices. Alternatively, in a system whereby selection is delayed until such a point whereby the dynamics of adolescence are dampened, without access to high quality coaching and support, we may simply be creating a situation whereby those with access to advantages such as good coaching and early perceptions of competence are simply further advantaged, at least at the first point of selection. That is to say that there are no contextless solutions that can be deployed against the complexity of problems presented by relative advantages and disadvantages (53, 71).

The alternative proposal is that as increasing inequity is identified across youth sport, perhaps the most equitable thing that any individual can have is access to high quality coaching. Whilst the temptation for sporting organisations might be to seek out increasingly elaborate forms of control through regulation, our proposal is to put sustained, genuine effort into the development and leadership of coaches. A change in focus that would require a profound shift in the focus of resourcing for many sporting organisations. To be clear, this is not the somewhat stereotypical research implication that "coaches should be educated to understand RAEs". Despite 40 years of research, we do not appear to be in a position to offer implications for the individual coach specifically related to RAEs. This proposal is far more radical; one that aims calls for the lofty aim of equal access to high quality coaches that can individualise based on the complexity of relative advantage and disadvantage, with a long-term view of development. As such, our proposal for this special edition is that the scope and spectrum of research in sport needs to reach beyond RAEs toward understanding a breadth of relative advantage and disadvantage if it is to genuinely enhance practice.

Directions for future research

In respect to RAEs to date, arguably, we are yet to move the research base forward beyond acknowledging its existence through analysing the proportion of TD system populations slanted towards a particular quartile and how that may vary in magnitude across different sports and contexts, or in the transition from the youth to senior level. One primary reason for this is likely due to the fact that the overwhelming majority of research into RAEs has been observational and descriptive in nature. Indeed, there is still no clear understanding of the mechanisms underpinning RAEs. Yet, with a push for researchers to implement interventions to counteract RAE's (12, 63, 72, 73), how can developmental solutions be implemented if there are no clear mechanisms to target? Based on the conceptualisation we reference in this paper, relative advantages or disadvantages in the youth sport domain likely qualify as being a "wicked problem", a problem that changes based on intervention (74) and is therefore immune to simplistic solutions.

Despite a plethora of research investigating developmental interventions that attempt to manipulate RAEs, promote developmental equity, increase opportunity or adjust the interpretation of performance based upon relative age [e.g., (12, 63, 72, 73, 75)], there are still no prospective and longitudinal investigations that support the implementation of any intervention in respect to long-term TD in sport. This is not to say that interventions do not have the capacity to enhance developmental equity in the long term, but that there is currently no evidence in their favour over the long term. Such findings are not possible without utilising a range of methods prospectively; research that is simply yet to be conducted. This research should involve both large sample sizes across contexts and also socially situated phenomenological work to understand the breadth of developmental experience between individuals. One promising area for research is also the implementation of flexible methods for organising practice and competition within sports clubs and organisations, moving beyond the traditional age-segregated groups. This may include, for example, flexible and consistently evolving age groups, as well as moving athletes between and across age groups based upon specific and individually identified athlete needs (61, 76). This allows for the exposure of athletes to those that are both older and younger and an overall diversity of experience. In essence, diversifying learning experiences in sport may offer greater potential compared to the homogenized training methods and experiences common in many academy or talent pathway systems to date.

By promoting equitable practices, we can support the development of young athletes by contributing to the implementation of more sustainable athlete development models. However, this pathway must be compatible with the possibility of offering those with ambitions for sports careers focused on high performance just that in the same context (e.g., club). Thus, the stage at which the domain becomes more TD towards high performance focused, when inclusion becomes less of *a priori*ty, should be an active strategic decision and one that informs research. As demonstrated, there are no clear solutions to the issue of relative age in sports, and all proposed solutions come with unintended consequences. This reality should encourage us to *experiment more, not less,* with diverse ways of providing meaningful sports experiences that promote learning, psychosocial development, and performance. To achieve this, transformative research methodologies are encouraged, including action research, complex interventions that incorporate context-sensitive qualitative methods, and other participatory research approaches.

Author contributions

LS: Conceptualization, Writing – original draft, Writing – review & editing. AR: Conceptualization, Writing – original draft, Writing – review & editing. JT: Conceptualization, Writing – original draft, Writing – review & editing. CB: Conceptualization, Writing – original draft, Writing – review & editing.

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Relative age effects in ice hockey extends to coaching

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Date of birth influences the chances of success in sports. Compared to players born just before a cutoff date for marking the admissibility in a category (age groups), players born soon after are overrepresented. However, it is not yet known whether the effect of date of birth in sports applies beyond the players' active participation in the game. The aim of the study was to determine whether there is a date of birth effect among ice hockey's coaches. The birthdates of 3,380 coaches in minor league hockey for the 2023–2024 season were obtained from Hockey Québec. The investigation indicated that people born in the first half of the year were more likely to become minor hockey coaches than those born in the second half. This significant birthdate effect is observed with coaches born in 1980s (53.42% vs. 46.58%) and after 1989 (55.73% vs. 44.27%), but not with coaches born before 1980 where the effect tended to reverse. This finding is interpreted as a consequence of the birthdate effect during the development as a hockey player and suggests a loss of potential coaches to the ice hockey system.

KEYWORDS

relative age effect, coaching, sport, ice hockey, birthdate effect

Introduction

Many studies have shown that the time of birth in the year is a determining factor in sport participation and success among children and adolescents [for reviews, see (1, 2)]. This influence is caused by the fact that groupings into categories in amateur sport are based on chronological age. Children born just after the eligibility date are the oldest in the cohort (i.e., in the age category). Compared to younger children who evolve in the same cohort, they are more likely to have greater physical (height, weight, strength, speed) and psychological (affective and cognitive) maturity, and more experience in the game (2). Consequently, relatively older children can appear to be "better" or more talented at a given sport compared to their relatively younger peers who evolve in the same cohort, which affects their likelihood of being selected in more competitive teams, getting more exposure, which improve their chance for future success such as being selected to competitive teams and/or drafted for upper echelons of competition (3). For example, when January 1st is used as the cutoff date, elite athletes in a given sport are more likely to be born in the first than in the last months of the year (1, 2).

Ice hockey was the first sport for which the impact of birthdate on sport participation was measured (4, 5). While there have been additional reports since exploring Canadian hockey and the National Hockey League (NHL), where most players historically were Canadian [see (6–12)], the problem of grouping players according to age categories in ice hockey extends to other countries (13–15).

Importantly, the issues created by grouping into categories based on chronological age are not restricted to ice hockey. There is an abundant literature showing that these problems are observed in many other sports [see (1, 2) for reviews]. For instance, the distribution of athletes' birthdate is still very biased in football (soccer), with an advantage for children born early in the year (16). The problem also occurs around the world in sports like weightlifting (17) and karate or fencing [de (18)] that are not as popular as football. The problem is also prevalent in female sport (19), and even extends to the risk of developing sedentary behaviors, with relatively younger people being less likely to engage in physical activity (20).

Since early born players (e.g., first 6 month of a birth year) are most likely to persist in competitive sport (1, 2) or, at least, to receive priority in terms of early selections, it is possible they are more likely to develop the interest and expertise necessary to become a coach. While becoming a coach does not necessarily require having been a good or successful player, based on the differences in early engagement in sport between relatively older and younger youth, and the relationship between feelings of competence and enjoyment with sustained engagement over time, it is reasonable to posit the hypothesis that there might be a birthdate effect among ice hockey coaches. This hypothesis is even more plausible considering that a study by Cobley and colleagues (21) on the history of elite soccer in Germany (in the Bundesliga) revealed a birthdate effect applying to elite coaches but not to referees. Similarly, Schorer et al. (22) revealed an overall birthdate effect amongst leadership (i.e., coaches, referees, and commissioners) in elite basketball.

The outcomes of relative age effects are well known, but we know considerably less about these effects on the likelihood of becoming a coach. Therefore, the purpose of this study was to examine whether the birthdate distribution in a large sample of ice hockey coaches reflected the bias observed among players. Considering the previous German studies in elite sport, we posited the hypothesis that there would be a birthdate effect on chances to become a coach. This hypothesis will be tested in the present investigation on a large pool of coaches in a sport (ice hockey) and province (Québec) where the birthdate effect amongst players in known to be strong (5).

Methods

Participants

The study population consisted of coaches involved in Québec minor ice hockey leagues (i.e., coaching players being 5–21 years old). All coaches in the sample ($n = 3,380$) were registered to Hockey Québec for the 2023–2024 season. Hockey Québec is the main organization dedicated to the development of ice hockey in Quebec and brings together approximately 85,500 players and more than 18,500 coaches.

A dataset was prepared and provided as an Excel file by the Program and Training Director of Hockey Québec. The file contained information about coaches' birthdate, town of residence, and gender. The file was verified by the first author to make sure there was multiple entries about a coach.

Birthdates of 3,380 coaches were analyzed. Participants were born between 1952 and the end of 1979 (n = 949), between 1980 and 1989 ($n = 1,855$) or from 1990 to 2009 (n = 576).

This study was approved by the *Comité d'éthique et de la recherche de l'Université Laval*.

Material and procedure

The Excel file with the birthdate of coaches was sent by the Program and Training Director of Hockey Québec to the first author. This information was then classified as a function of birth trimester and birth semester, and as a function of the year of birth.

Because the majority of coaches were born in the 1980s, we divided the sample into three periods (1952–1979; 1980–1989; 1990–2009), each with a large sample. People born in the 1980s were about 33–43 years old at the beginning the 2023–2024 season; it is reasonable to assume that in this age range, coaches have a child in age to be registered in a minor hockey league.

The coach data were contrasted with the distribution of births, by trimester and by semester, in the general Québec population for the same year-of-birth periods. Note that particularly for the 1990–2009 group, dividing into trimesters (Jan–Mar; Apr–June; July-Sept; Oct–Dec) and semesters (Jan–June; July–Dec) comes with an artifact that cannot be controlled. Some of these coaches may have played a part of their minor hockey between 2002 and 2008. During these years, the cutoff date for assigning players into categories was not January 1st, but October 1st. This artifact probably also touches some of the coaches born at the end of the 1980s.

Birth data since 1995 from the general Québec population were available on the internet [*Institut de la statistique du Québec* website (23)]. Birth data from 1975 to 1994 were provided by the *Institut de la Statistique du Québec* (data sent to the first author). Data from 1958 to 1972 were drawn from Grondin (24). The mean distribution of births from 1980 to 1989 and from 1990 to 2009 served to establish the expected distribution of coaches' births for these periods. For the 1952 to the 1979 period, the expected value was based on the mean for years 1958–1972 and 1975–1979.

The distribution of births in the general population in the 1990–2009 group was: 24.09% for Trimester 1 (January–March), 25.99% for Trimester 2 (April–June), 26.23% for Trimester 3 (July–September), and 23.68% for Trimester 4 (October–December). For the 1980–1989 group, the distribution was (in the same order): 24.31%, 26.18%, 25.71%, and 23.80%. For the other group (1979 and less), the distribution for Trimesters 1–4 was: 24.60%, 26.68%, 25.55%, and 23.17%.

Results

The distribution of birthdates of coaches is presented as a function of three periods: born before 1980, in the 1980s, and after 1989. This distribution is presented per trimester and per semester in Table 1.

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TABLE 1 Distribution of birthdates per trimester and per semester of coaches born before 1980, in the 1980s, and after 1989.

Trimester	Before 1980	%	1980s	%	After 1989	%
Jan–Mar	222	23.39	465	25.07	155	26.91
Apr–Jun	245	25.82	526	28.36	166	28.82
Jul–Sept	233	24.55	451	24.31	130	22.57
Oct–Dec	249	26.24	413	22.26	125	21.70
Semester		%		%		%
Jan–Jun	467	49.21	991	53.42	321	55.73
Jul–Dec	482	50.79	864	46.58	255	44.27
Total	949		1,855		576	

The distribution of coaches' birthdates was contrasted with the distribution of births in the general Québec population using chi square analyses. For the group of younger coaches (born since 1990), the analysis by trimester did not reveal any significant differences, $\chi^2(3) = 7.56$, $p = .06$. However, when the data was analyzed by semester, there were significantly more coaches born in the first semester than in the second, $\chi^2(1) = 7.33$, $p = .006$. Similarly, for coaches born from 1980 to 1989, the analysis revealed no differences in the distributions by trimester, $\chi^2(3) = 7.04$, $p = .07$, but a significant effect when examined by semester, $\chi^2(1) = 6.38$, $p = .01$. For the group of older coaches (born before 1980), the distributions differ neither when analyzed by trimester, $\chi^2(3) = 5.06$, $p = .17$, nor by semester, $\chi^2(1) = 1.62$, $p = .20$ (see Figure 1).

Discussion

The objective of the study was to determine if there is a birthdate effect amongst coaches in minor league hockey. The data indicated a significant birthdate effect amongst coaches in the two younger groups of coaches. Those born in the first semester of the year were more likely to become coaches in youth ice hockey than coaches born in the second semester of the year. To our knowledge, there is no explanation for this biased distribution of births amongst coaches other than as a consequence of the birthdate effect amongst players. It is possible that many individuals who become coaches were former players. Because older players in a given cohort are more likely to access higher participation and competition levels in ice hockey, they are more likely to develop expertise in the field and an attachment with the discipline. This could positively influence the motivation to pursue involvement in ice hockey after their career as an active player. Alternately, younger players of a cohort are less likely to have success and to reach higher levels and are, therefore, less likely to develop the expertise in the discipline necessary to become a coach. In other words, the consequences of the relative age effect in youth sports go beyond player development; they affect chances to contribute to that sport later as an adult.

Knowing that there are more coaches born in the first half of the year, it is less surprising to observe that there are more coaches at higher levels born earlier in the competition year in sports like soccer (21). As well, if a longer participation in a sport provides expertise, attachment or identification to that sport, with the motivation to contribute somehow, it is not surprising to see a birthdate effect amongst other contributors to the game at higher levels, like referees or umpires (22).

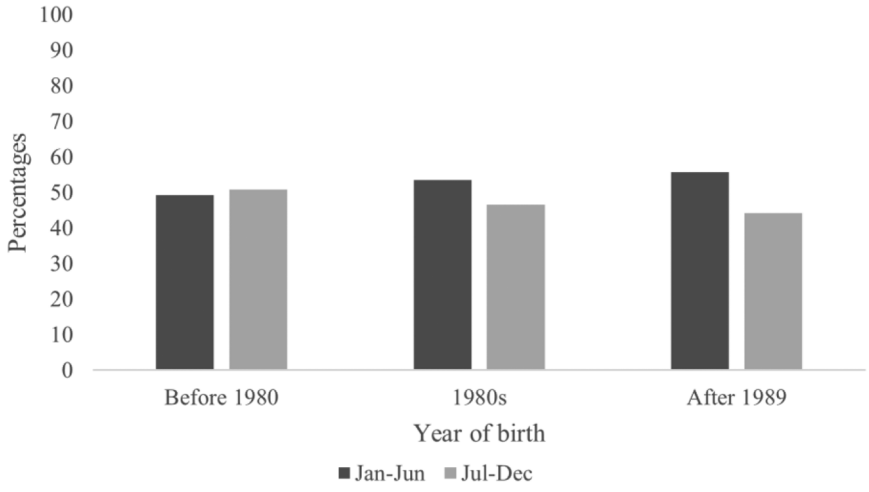


FIGURE 1
Percentages of births of coaches per semester in each group.

In the groups of youngest coaches (born after 1989), the difference between Semester 1 and Semester 2 was quite large (11.5%). A closer look at the data indicates that the difference between Trimester 3 and Trimester 4 for this group was quite small (less than 1%) considering the distribution of births in the to population for these trimesters. This small difference could be due, as indicated in the Methods, a small artefact in our sample, and it was not possible to correct it in our dataset. Assuming that the birthdate effect in coaches is due to the relative age effect as a player, it becomes important to note that, in Québec, from the hockey season 2002–2003 to season 2007–2008, the cutoff date for categories was not January 1st, but October 1st (note that cutoff date for school in Québec is Oct 1st and that it was changed back to Jan 1st in hockey since 2008). This change in the cutoff date rapidly moved back the age advantage [Trimester 4 became Trimester 1; see (25)]. Therefore, a part of players born in the 1990s may have had a portion of their curriculum where the October–December trimester was not the fourth of the competition cohort, but the first. It was not possible to quantify the effect of this on the persistence of players and on their eventual chances to become coach, but it helps to understand why there was not much difference in the representation of coaches in Trimester 3 (4 during a brief period) and 4 (1 during a brief period), although there are much more births in the Québec population after 1989 in the Jul–Aug period than during the September–December period.

Interestingly, the birthdate effect was absent amongst coaches born before 1980. This effect would make sense if the birthdate effect on players was less pronounced for people born before 1980; however, this hypothesis can be rejected considering old data on the relative age effect in ice hockey. In Grondin et al. (5), for the 1981–1982 season in Québec, there was already a very striking effect in youth players, in other words for players born in the 1960s and 1970s [see (26)]. In addition, there was already a relative age effect in the NHL for that season (5). Around the same period, Barnsley et al. (4) also observed the same phenomenon amongst minor league players in Western Canada.

It is possible that the fading of the birthdate effect for the older group of coaches is connected to, or indicative of, the "reversal effect" seen amongst players. This effect is related to the decline of the strength of the birthdate effect as players get older, that is reaching higher levels of competition like the NHL in the case of ice hockey (27, 28). The reversal effect refers to the tendency to have more players who, when developing in minor hockey, were among the youngest in their age group than players who were among the oldest. This reversal effect has also been observed in elite football (soccer) leagues, in taekwondo (29), and in U17 football in the case of athletes from Africa (30). However, this reversal in player samples is often related to declines in the age advantage over the years; there could be no such direct effect amongst coaches. It may be that the youngest (disadvantaged by the birthdate effect) players who have been able to persevere in the practice of ice hockey do so because of skills [e.g., self-regulation; (31)] that relate to becoming a good coach. This idea is consistent with Andronikos et al. (29) who argued that a long-term benefit of being amongst the younger athletes in an age group is the necessity to develop early the toolbox of essential skills, skills that will eventually be necessary for competing at senior elite levels. For instance, key self-regulation skills are planning and reflection, which would obviously be useful tools for developing coaching capabilities. This might explain why they are less likely to quit coaching as they get older. While this hypothesis is highly speculative, our results suggest the influence of birthdate (and its reversal) extends beyond an athlete's playing career.

Despite the intriguing results of the current study, our investigation had some limitations. One limitation, noted above, is related to the changes in the cutoff birthdate used for age grouping where our sample was drawn (Québec). It is possible that what is called Trimester 4 in our analysis may have also been, for a brief period, Trimester 1 for some coaches when they were playing. This certainly induces a bias in our analyses, and indeed if we look at the number of coaches born in Trimesters 3 and 4 in the second half of the 1980s (1985–1989; i.e., for a segment where coaches may have had a part of their years as a player under the Oct–Dec trimester as Trimester 1), the distribution is approximatively equal. When looking at the first half of the 1980s, there were about 53% and 47% of coaches born in Trimester 3 and 4, respectively. Note that the potential consequence of this bias is that it probably reduces the magnitude of the birthdate effect observed with coaches.

Although not, strictly speaking, a limitation of the study, the nature of the sample, should be kept in mind when reading the study. There were many more coaches born in the 1980s than in the 1990s or 1970s. As indicated in the Methods, at the time of the study (the 2023–2024 season), coaches born in the 1980s were between 33 and 43 years old, ages where people often have their own children, old enough to play minor league hockey. It is reasonable to posit that a good proportion of these parents had children on the team (32). Once their child quit organised hockey, the parent of the child often leaves as well. Only people having real aptitude for coaching, having for instance more planning and reflection skills, will keep being involved in ice hockey. This would explain why the relative age effect fades in the sample of older coaches: there is no reason to believe that planning and reflection skills are related to birthdate.

The first practical implication of this finding is that grouping young athletes into categories based on chronological age not only provokes a potential loss of talented players, it may also eventually lead to a loss of potential coaches. A second implication is the tendency observed in the data to have a reversal effect with older coaches, which may reflect the need for the younger athletes in an age group to develop more rapidly essentials skills (29), including psychological skills and reflection (31).

The findings of the present study suggest several areas for future investigations. Because ice hockey is so popular in Canada, a first step would be to extend the investigation to other Canadian populations where the cutoff date has never been changed. This would not only clarify the magnitude of the birthdate effect in coaches, but also its potential reversal with older coaches. Such investigations about ice hockey could also be conducted in other countries where the birthdate effect, for ice

hockey, was larger or smaller than in Québec [e.g., Russia; (13)], to see if the effect amongst coaches is modulated by these fluctuations, and to see if there is any such effect in countries adopting different criteria to become a coach. And of course, the investigation relative to the month, trimester or semester of birth of coaches must be extended to other sports, such as soccer and rugby where strong birthdate effects have been regularly reported (1, 2). In the context of the shortage of coaches in many sports, it is important to explore and understand the administrative and psychological elements underpinning this phenomenon.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://osf.io/64kt5/?view_only=573da4101af14ac58fcee3363024130fOpen Science Framework.

Ethics statement

The studies involving humans were approved by Comité d'éthique et de la recherche de l'Université Laval. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

SG: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. DF: Formal Analysis, Writing – original draft, Writing – review & editing. JL: Writing – review & editing. FT: Writing – review & editing. JB: Writing – review & editing.

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40-years of relative age effects: life is not fair!

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This paper explores the Relative Age Effect (RAE) after nearly 40 years since its initial examination in sports. Two original studies identified significant participation differences between relatively older and younger players in age-grouped elite hockey and soccer. In the current study, we replicate the original analyses using 2023 data. By comparing data from the original studies and 2023, focusing on Major Junior A hockey in North America and the Under-17 and Under-20 World Soccer Tournaments, we observe remarkably similar RAE patterns. For instance, both the original and the 2023 studies indicate that about 40% of elite young adult players were born in the first quarter of the age cohort, compared to just 10% in the last quarter. This paper underscores the ongoing advantages and disadvantages created by RAE and calls for greater focus on strategies to mitigate its unfair effects in sports and education.

KEYWORDS

relative age effect, RAE, hockey, soccer, replication, mitigation

Introduction

In 2008, Malcolm Gladwell published "Outliers: The Story of Success" which was met with overwhelming interest and worldwide sales of over 1.6 million copies (1). Chapter one of "Outliers" was entitled "The Matthew Effect" and yet, was substantially influenced by the research article "Hockey Success and Birthdate: The Relative Age Effect" (2). This article, which was the first to use the term "Relative Age Effect" (RAE), reported a striking relationship between a hockey player's success, and their relative standing in an age cohort.

In 2022, Malcolm Gladwell contacted me (3). At this time, Gladwell was producing a podcast entitled "Revisionist History". He explained that he was working on an update to "Outliers" and would again like to discuss RAEs. Our interview took place in January 2022 and began with Gladwell asking me to join him in looking at the player roster from the 2020–21 Canadian national junior hockey team. Together, we read aloud the players' birthdates. As we finished, there were a few moments of silence and then Gladwell said, "Not much has changed, has it?". This quick peek at the pattern of these players' birthdates seemed to indicate that they were remarkably like the 1983 player rosters (2).

Gladwell and I shared our disappointment that after 40 years, it appeared that RAEs in hockey had continued unabated. If little, or no progress, in mitigating RAEs had been achieved, then it would seem reasonable to assume that parents and sport administrators were either unaware of the impact of RAEs, or how to bring about change. Surely, in the context of this special issue which celebrates the 40th anniversary of the "Relative Age Effect", it is appropriate, if not essential, to initiate a broader discussion on "Has anything changed?"[1]

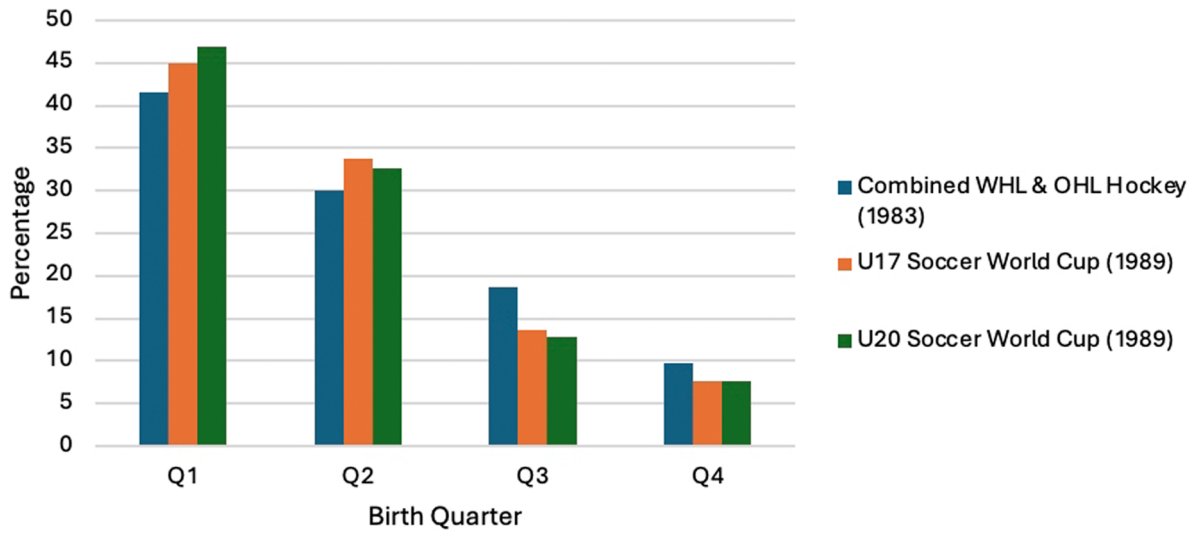


FIGURE 1
Early RAE studies.

Hockey and soccer: the early studies[2]

In 1984 Simon Grondin reported birthdate effects in hockey and volleyball (5). Unaware of these findings, in that same year Paula Barnsley observed unusual and significant patterns of birthdates in the rosters of Canadian Major Junior A hockey players. Following her observation, Paula and I reviewed National Hockey League (NHL) players' birthdates. The result, based on 715 players from the 1982/83 team rosters, indicated that 61.8% of the players were born in the months of January through June, whereas only 38.2% were born in the months of July–December.

Subsequently, A. H. (Gus) Thompson and I obtained the birthdates of 1,048 players from 1983 rosters of teams in the Western (WHL) and Ontario (OHL) Major Junior A Hockey Leagues. (These were generally considered two of the main developmental leagues for professional teams in the NHL). The combined results from these two leagues were striking. The number and percentage of players born in the four quarters (Q) of the year were: Q1 (January–March) 435, 41.5%; Q2 (April–June) 315, 30.0%; Q3 (July–September) 196, 18.7%; and Q4 (October–December) 102, 9.7%. Remarkably, over four times more players had been born in January, February and March than in October, November and December. These results (2) are found in Figure 1.

Several years later Phil Legault, who at the time was employed by the Canadian Soccer Association, told us that he suspected that RAEs would be strongly evident in soccer (football) world-wide. Working together, the birthdates of players in (1) the 1989 Under17s World Tournament and, (2) the 1989 Under-20s World Tournament were analyzed. The results, which can be seen in Figure 1, were published in "Family planning: football style: The relative age effect in football" (6).

This paper demonstrated striking RAEs from both World Tournaments even though each tournament was comprised of 16 different nations. In fact, the distribution of birthdates was strongly, if not identically, parallel to the findings of the Canadian Major Junior A Hockey Leagues. Again, the cohort analysis by "Quarter" indicated that: over 40% of the players were born in Q1; over 30% in Q2; approximately 13% in Q3; and less than 8% in Q4. Basically, the results indicated that soccer players born in the Q1 months, were five times more likely to be selected to play International Youth Elite Soccer than players born in Q4.

The development of the relative age effect

Clearly, these findings demonstrated that in hockey and soccer, success was significantly impacted by the inequitable and unfair opportunities created by a player's birthdate. To understand the development of RAEs in hockey, we decided to analyze the birthdates of all players in a large minor hockey league

[1]It is recommended that readers listen to "Outliers, Revisited", Season 7 of the podcast "Revisionist History"

[2]As I was concluding the preparation of this manuscript, I became aware of Simon Grondin's publication "To be or not to be born at the right time: lessons from ice hockey" (4). In this paper Simon contemplates his early RAE publications; comments on the present state of RAE research; and recommends that more attention should be paid to mitigating RAEs. This paper explores a number of issues discussed by Grondin, and therefore, it should not be surprising that in our "40th anniversary" reflections, we are generally agreed on the path forward.

association. To this end, the Edmonton Minor Hockey Association (EMHA) provided team rosters and birthdays of all 7,313 players registered for the 1983–84 hockey season.

The EMHA was organized into "age grouped" divisions and "competitive-based tiers" or leagues. The divisions (under 8; 9 & 10; through to 19 & 20) were comprised of those players born between January 1 of the first year to December 31 of the following year. Each division included 2, 3, or 4 competitive-based leagues.

Players within each age division were annually assigned to a particular team and league based upon skill performance and assessment by the leagues coaches. First, players were chosen for the highest tier teams; followed by selections for the second level teams and so on until all players were placed on a team in an appropriate performance-based league. Basically, the lower tier leagues were recreational, whereas the higher tiers were progressively more competitive with the top tier teams being highly competitive "Rep" (representative) teams for elite players.

The rosters of all EMHA teams were examined in relation to the birthdates of the players and the results were reported in "Birthdate and Success in Minor Hockey: The Key to the NHL", (7). From this article three basic principles can be identified that produced the "Relative Age Effect".

Performance-based selection

Players are assigned to a particular league/tier based on the assessment of their hockey skill or performance. As the older players in an age group will generally be more experienced, physically mature, bigger and stronger, it is not surprising that the top tier teams predominantly include the relatively older players. The makeup of the top tier teams in the EMHA clearly demonstrated this relative age effect.

Differentiated experience

The purpose of the leagues within each division is to facilitate equitable participation and a levelling of competition for all players. However, because of the skill and performance differences between the tiers, different programs and experiences are created to meet the needs of the players. For example, competition, practice time, number of games, quality of coaches, equipment, etc. are generally varied with the highest tier players gaining many advantages. Over time, these differentiated experiences further exacerbate the relative age differences that were created by the selection procedures.

Participation rate

The RAE was not evident in the "under 8 through 10 years" division probably because in the beginning all boys wanted to play hockey. However, starting with the 11-year-olds, lower participation numbers of the younger players contributed to the RAE. Presumably, younger players in the age cohort had dropped out for lack of success and enjoyment.

To summarize, it appears that the following conditions during childhood will lead to RAEs: (1) Children are grouped in age cohorts to facilitate the organization and delivery of an activity; (2) Children are selected and assigned to differentiated groups in the their age cohort based upon such factors as size, skill, or achievement; (3) These differentiated groups usually experience different program opportunities; and (4) Children who are disadvantaged tend to "drop out" and stop being participants in the activity.

Hypothetical examples

To depict RAEs with an example, consider the following two hypothetical player experiences in minor hockey. Both Sam and Mike were enthusiastic hockey fans and with their parents' support began playing minor hockey when they were eight years old.

Sam was born on February 9 and as the minor hockey league was structured with age groups based on January 1 to December 31, Sam was one of the older and more mature boys. At the organizational practice, where the players demonstrated such skills as skating and stick handling, Sam stood out from most of the other boys because of his size, speed and coordination. Sam was one of first players "drafted" and found himself on a team in the top tier. As a "top tier" player, Sam had more practice time, played more games and had more chance to travel and play in tournaments. Each succeeding year, Sam was one of the first boys chosen and he continued to improve and succeed. As a young teenager, Sam, his parents and his coaches, believed that he could realistically receive a scholarship to play university hockey or be chosen to play Major Junior hockey.

Mike, who turned out to be a late maturer, was born on November 15. In his first few years of hockey, Mike enjoyed the game, and his parents appreciated that despite his smaller size, he received equal playing time. However, Mike and his dad had hoped that he would get more time to practice and an opportunity to play in some tournaments, but that seemed to be reserved for the higher tiered teams. And, by the time he was 12, Mike had lost interest and motivation for recreational hockey. As weekend practices were interfering with family ski trips, and because Mike wasn't experiencing success, he dropped out of minor hockey. Later, as an adult, Mike started going to the rink again and found out how much he missed the game. Sunday morning hockey scrimmages with his buddies became the highlight of his week. Mike often wondered how his hockey experience would have been different if he had been born two months later on January 15.

Hockey and soccer after 40 years

The imaginary stories of Sam and Mike underscore the unfairness of the minor hockey system in 1984. And the

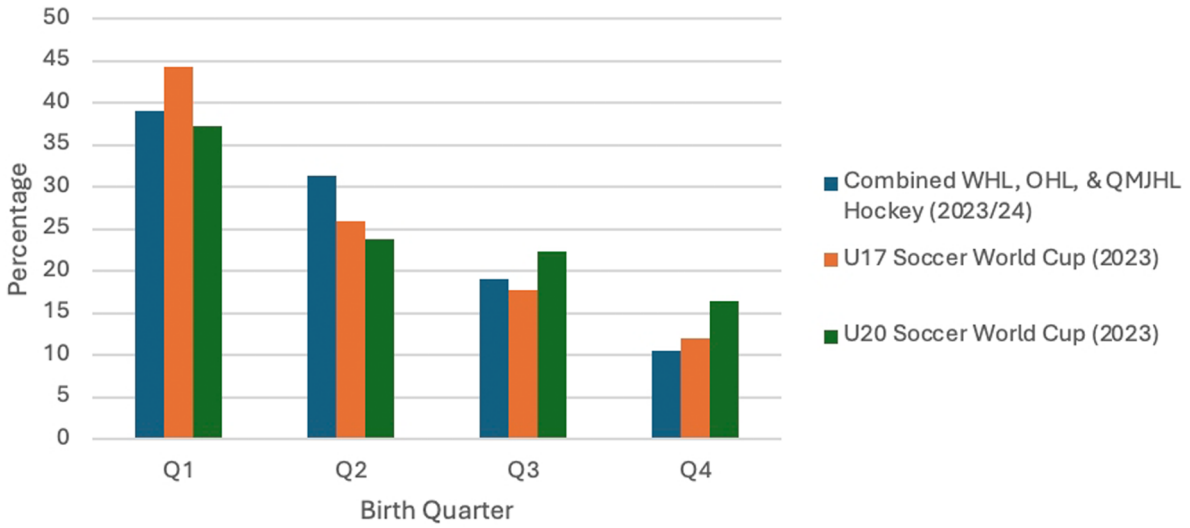


FIGURE 2
Replicating the early studies of hockey and soccer.

occurrence of similar RAEs in International Youth Elite soccer, certainly highlight the need for change. One wonders how players, coaches, parents and communities in general, can accept and continue with systems that are so biased and unfair that children born in the last quarter of an age cohort are up to five times less likely to succeed than those players who were in the older age cohort.

Given these striking differences and the disadvantages for the younger players, it would seem reasonable to expect that after 40 years, knowledge would have been gained and actions taken that would mitigate, or at least substantially reduce the size of RAEs. To consider this expectation, an informal analysis using data from 2023 was carried out for each sport. The results are found in Figure 2. Clearly, simple visual and descriptive comparisons between the hockey players in 1983 (see Figure 1) and those in 2023 indicate that RAEs are essentially identical. (It should be noted that the hockey data has been expanded through addition of players from the Quebec Major Junior Hockey League.)

Regarding the soccer data, there are two notable differences between the 1989 and 2023 tournaments. First, 2023 tournaments comprised 24 national teams rather than the 16 represented in 1989. Secondly, and perhaps more importantly, the age cohort for the 2023 teams had changed to January 1 to December 31; whereas, in 1989, the age cohort was established between August 1 and July 31. Regardless of these two changes, the soccer data also strongly suggest that very little has changed.

The consistency of the data from players and leagues 40 years apart is remarkable. It is apparent that for males aspiring to play professional hockey, those born between January and the end of June are still more than twice as likely to have success than those born from July to December. Or, it can also be said that those born between October and December are four times less likely to be successful than those born in January, February, or March. And, for those males who desire to play elite youth soccer on their journey to a professional career, their birth month provides the same substantial advantage or disadvantage that defines success in hockey. Obviously, RAEs selectively privilege individuals born early in the cohort year with unearned advantages. While at the same time, those born late in the cohort year encounter disadvantageous conditions that have a high probability of inhibiting their success.

Other areas impacted by RAEs

This chapter has been focused largely on hockey and soccer research. This choice was made to reflect on our early studies and to update them in the context of the 40th anniversary of the "Relative Age Effect". Of course, recognition and praise are clearly due to the large volume of RAE research that has taken place over the years. Investigating the role of RAEs in a wide variety of sports (8) continues to capture the interest of most researchers.[3]

It is beyond the scope of this paper, but the role of RAEs in education and associated areas should be briefly reviewed. I have found it both interesting and informative to consider that the RAEs in hockey and soccer provide a useful metaphor or, model for understanding the effect of RAEs in education. Comparatively, K-12 education and youth hockey are quite similar as schools are also generally organized into grades based upon age cohorts. And these age cohorts renew annually and continue for upwards of twelve years.

[3]Parenthetically, this retrospective has largely dealt with male-based studies. For a discussion of RAEs in female populations, readers are referred to "Relative Age Effects in Female Athletes" (9).

Research in education and associated areas has unsurprisingly demonstrated that RAEs develop because of procedures similar to hockey and soccer. In addition to age cohort grouping, K-12 education often includes specialized program enrolment and opportunities based upon RAE performance and achievement. Interestingly, the reduced participation rate for disadvantaged young children generally observed in sports activities is not found in schools as attendance is mandatory. However, RAEs have been identified in significant areas of education. For example, RAEs have been found in (1) University participation rates (10–12); (2) Academic achievement (13, 14); and (3) Special education classifications such as in Gifted and Talented programs and children who are Learning Disabled (15–17).

Further, a strong case can be made that some areas of personality and mental health (18) emerge as corollaries from the effects of the child's position in the school age cohort. For example, RAE research has demonstrated that leadership abilities (19, 20) are related to the advantages enjoyed by the older students in the school-based age cohort. Levels of self-esteem (21) are generally related to RAEs, and unfortunately, younger students in the school-based age cohort have been found years later to be more prone to suicidal behavior than their older classmates (22). It is interesting to hypothesize that the negative mental health and personality outcomes related to the younger members of the school-based age cohort might emerge as a behavioral accommodation to mandatory school attendance and inflexible age grouping.

Closing thoughts

The past 40 years have produced a wealth of RAE research. One indicator is that our first article (2) has received almost 700 citations and the soccer article (6) has been cited over 400 times (Google Scholar). Although RAEs have now been identified in many different sports and educational areas, it appears that research addressing factors or procedures to reduce RAEs have been minimal. After 40 years one would have thought, or at least hoped, that procedures for mitigating RAEs would have been found or were being investigated.

Unfortunately, it seems that few people are aware or bothered by the unfairness of RAEs, and to my knowledge formal surveys of RAE awareness have not been done. Over the years, discussions that I have initiated with a range of people suggest widespread unfamiliarity. And for those who are aware of RAEs, discussions often lead to comments such as "It's just swimming, or hockey, or football", or "There are enough professional players", or "Why should I care?", or my cynical favorite "Life is not fair". Indeed, these attitudes can be found in all categories of stakeholders: athletes, parents, coaches, educators, policy makers and politicians. Clearly, those of us interested in mitigating factors must provide leadership to create awareness and concern for the negative impacts of RAEs.

Nevertheless, changes that could minimize RAEs have been proposed (23); and, reviewed (24). Suggested solutions have included: (1) Changing the size of the age cohort group; (2) Alternating the cutoff dates of the age cohort; (3) Reducing competition with additional focus on skill training and development; (4) Delaying the age for performance-based selection; and other options. However, such suggestions cannot be implemented without evidence of effectiveness and, realistically it is very difficult for researchers to gain permission and consent to try such innovations. Without evidence, there is no motivation or, imperative for policy makers to revise programs that are long-standing, traditional, and expensive to change.

Of course, the fundamental ingredient in the search for protocols, activities, structures, or systems that would minimize or eliminate the RAEs in sports, depends on research. It is re-assuring that RAE researchers are increasingly focusing on these issues. For example, research investigating effectiveness of age-ordered shirt numbering [(25) and (personal communication, Dixon and Horton, 2024)] is encouraging. And a recent publication (26) demonstrated that changing the comparative selection procedures for swimmers, some top talent athletes who previously would have been rejected were now retained. Stephen Cobley (personal communication, 2024) recently shared that an Australian swimmer who won a gold medal at the Paris Olympics would have been eliminated by the old selection procedure because of RAEs. Clearly, the success of such research projects should provide the incentive, enthusiasm and confidence for other research groups to accept the challenge of finding much needed solutions to the negative impacts of RAEs in sports.

I believe that it is reasonable to expect that RAE stakeholders and the relevant organizations should be aware and informed of RAEs and their negative consequences. The past 40 years has produced volumes of RAE information and enthusiastic researchers have reliably reported the results in peer reviewed, respected journals. Unfortunately, the stakeholders who need this information do not usually read professional journals. It is "much easier said than done" but research findings need to be communicated broadly and, in a style and format that is accessible to the various audiences of RAE stakeholders, including journalists, and readers of popular publications. This observation is probably relevant to all areas of human research; however, few other areas so directly impact, both positively and negatively, the life choices and successes of most people.

To conclude, the presence and scope of RAEs in sports and education is both remarkable and wrong. Clearly the randomness of a person's birthdate should not be related to one's success and overall achievement in life. The unequitable and enduring effects of RAEs make a compelling case that as researchers, we cannot and should not remain silent, neutral, or restrained. Every time and everywhere that RAEs are evident, there are individuals who are privileged and gain an advantage; and, a comparable number of people who are disadvantaged, limited, or excluded. These outcomes are unfair, unjustified and wrong. After 40 years, the time to address these issues is long overdue!

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

RB: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing.

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Relative age effects in European soccer: their association with contextual factors, impact on youth national teams' performance, and presence at the senior level

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Introduction: Soccer systems promote early identification and specialisation practices to satisfy short- and long-term goals—both from sporting performance and financial gains perspectives. In this context, players are (de)selected based on observed performance level and on their ability to conform to given organisational demands, leading to the proliferation of selection biases, such as relative age effects (RAEs), which research has shown to influence both developmental experiences and senior career achievements. Accordingly, this study aims to: (a) investigate the magnitude of RAEs among youth national teams competing in the UEFA U17 European Soccer Championship, and their associations with teams' final ranking, (b) examine whether RAEs magnitude could be linked to cultural and contextual factors, and (c) further explore RAEs at senior level.

Methods: Birth quarter (BQ) distribution of youth national teams ($n = 80$) that competed in one of the five editions (2018, 2019, 2022, 2023, and 2024) of the UEFA U17 European Soccer Championship was recorded. Teams were classified based on their country of origin, RAEs magnitudes, final ranking in the tournament, FIFA points, and national population. Furthermore, the BQ distribution of senior national teams ($n = 24$) that competed at the 2024 UEFA Senior European Soccer Championship was recorded.

Results: Chi-square statistics revealed BQ1s were overrepresented at the U17 level ($p < 0.001$) and showed teams exhibiting low RAEs magnitudes recorded the highest likelihood (odds ratio: 5.67) of finishing the tournament in the bottom four positions. Correlation analyses recorded small to moderate positive correlations between RAEs magnitude and national population (.25) and FIFA points (.33). Further chi-square statistics revealed BQ1s continued to be overrepresented at the senior level, albeit with a weaker effect ($p < 0.001$). However, when the senior BQ distribution was compared to the expected distribution taken from the U17 population, this recorded more BQ4s and fewer BQ1s than expected ($p < 0.001$).

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Discussion: The findings presented the focus on youth success, the increased talent pool size, and the competition for selection interact to reiterate RAEs' prevalence in European soccer. Moreover, they highlighted initial RAEs define players' journey within the soccer system, whereby relatively older players remain overrepresented at the senior level, albeit to a weaker and lesser extent.

KEYWORDS

relative age effects, birth advantages, youth soccer, talent identification, selection bias, talent development

Introduction

Talent identification (TID) entails the detection of young players displaying the potential to succeed in the future (1). It occurs as early as the first developmental stages, usually resulting in early entrance to soccer high-performance environments at under nine (i.e., 8–9 years of age) (2). Talent development (TD) aims to provide selected players with optimal learning environments to facilitate and accelerate their progression through to the elite levels of sport (1). Both TID and TD processes in soccer have become critical issues and increasingly professionalised for clubs and national federations. Large sums of money are invested (3) and many figures (i.e., scouts, managers, players' agents, families, and intermediaries) are involved in the process of identifying, selecting, and developing talented youth players (4). This is largely due to the organisational structures, at both federations and club levels, which often employ deterministic models of talent pathways (5). These deterministic models encourage early identification and specialisation practices to facilitate players' skill-acquisition processes and to satisfy academies' short- and long-term goals—both from sporting performance and financial gains perspectives (4). Entrance into such learning environments is characterised by a high level of competitiveness, whereby players are continuously assessed, valued, and ranked. Indeed, institutional (and financial) support is offered only to the few players who have received social recognition and validation of their talent to be noticed and considered for the next developmental stage (6). In line with this, during TID and TD processes, players are (de)selected based on their *observed* performance level and *perceived* potential (7), coupled with their ability to conform to given organisational demands and standards (i.e., meet pre-determined developmental and competitive goals) (8, 9).

However, past studies have highlighted the limitations of selecting a few players based solely on early ability, athleticism, and performance standards. This causes the removal from the system of the many unable to comply with the organisational demands, not considered for further development, who may decide to drop out from the sport in question (10, 11). Further emphasising the potential inefficiencies of early selection, research conducted on analysing players' career trajectories highlighted how, contrary to expectations, the vast majority of early selected players are unable to complete the youth-to-senior transition (12–14). As an example, Höner et al. (15), in their prospective study conducted on German soccer, found that only 0.6% of the U12 players selected for a national training program developed into professional-level soccer players. This suggested that an early entrance (i.e., ≤12 years) into professional soccer academies is not a prerequisite for senior success (16). Indeed, there are multiple pathways to reach the highest level of soccer competition (i.e., playing in the FIFA World Cup), as developmental pathways are shaped by cultural and contextual factors. Even in geographical areas with strict-selection policies, such as Europe, nearly half of the players of the 2022 FIFA Men's World Cup began their professional academy training after the sampling years (i.e., >12 years). In line with this, Boccia et al. (17) revealed how less than 10% of players selected to represent Italy at the U16 level were subsequently able to complete the transition (i.e., playing with the senior national team) and suggested it is only as players get older (i.e., ≥21 years) that their youth performance correlates with their senior performance. Similarly, Brustio et al. (18), investigating career trajectories of U17 players representing the English, French, German, Italian, and Spanish national teams, have shown fewer than 15% of them progressed to their respective senior teams.

Further research on this area has highlighted that an increased level of competition and selection pressures cause soccer systems to select players based on their current level of performance, causing the proliferation of selection biases (19). Relative age effects (RAEs) are the most studied selection biases across the soccer landscape. These arise from the decision of soccer organisations to adopt a cut-off criterion that groups children into (bi)annual age groups. From the very first stages of development, players born at the beginning of the selection year are favoured compared to those born at the end (20). Past research has shown the presence of RAEs in male youth soccer worldwide (21, 22) and indicated that player selection procedures, coupled with increased competition for selection, play an important role in the proliferation of this selection bias (23, 24). Specifically, studies revealed relatively older players (a) are more represented at national and international levels compared to regional and/or recreational (25–27), and (b) are favoured at an increasing level of competition for the few available positions (i.e., larger talent pools), whereby RAEs are less pronounced in smaller soccer nations (i.e., small population, lower soccer culture, or performance levels) (28–30). This body of literature proposed that early born players receive more openings into talent pathways due to age-related differences consisting of more time to practice, compete, and develop (31), and highlighted the importance of considering cultural and contextual factors when analysing RAEs presence and prevalence.

In line with this, research suggested RAEs are more prevalent in performance-oriented contexts when there is a need for competitive advantages (32, 33). Indeed, studies conducted on investigating the presence of RAEs and its correlations with team performance highlighted that selecting players born earlier in the year is an important aspect for successful performance outcomes in youth soccer, as results revealed that older teams record significantly higher points per game [e.g. (33),]. Moreover, in German youth soccer, Augste and Lames (34) found a significant and positive correlation between teams' median birth date and final ranking (i.e., an earlier median birth correlated with a better ranking). Similar results were obtained in Swedish youth soccer, where Söderstrom et al. (35) revealed a correlation between positive match outcomes and the higher presence of early born players. Accordingly, in a system characterised by higher competition pressures, relatively older players are preferred over their younger peers (36, 37), emphasising how coaches (and clubs) are focussed on performance outcomes rather than player development. In line with this, past research has presented that raising awareness about the existence of RAEs and their implications does not contribute to their eradication from youth soccer (38, 39). Nevertheless, from an organisational perspective, studies have proposed systemic interventions like rotating cut-off dates (40, 41), a more flexible chronological approach (42) and grouping teams using the average team age method (33) to pursue fairer youth soccer participation and competition.

Theoretical frameworks explaining the mechanisms of RAEs from a sociocultural perspective presented how such advanced developmental opportunities (i.e., early entrance into a high-performance environment) experienced by early born players may further exacerbate age-related differences (43, 44). More specifically, studies conducted in senior soccer have highlighted that early born players continue to be overrepresented (45–47). For instance, Yagüe et al. (48) showed how RAEs were present in 9 out of 10 of the top-10 European leagues. However, whilst these "knock-on-effects" exist, the strength of them decreases. Indeed, recent research aimed at investigating whether relative age (dis)advantages interact with players' ability to complete the youth-to-senior transition has showed that relatively younger players, once selected, have the greatest likelihood of completing the transition, a phenomenon known as the "underdog hypothesis" (18, 37, 46). As such, this body of knowledge shows multiple interacting effects associated with RAEs within soccer that occur on different timescales of the talent pathway and highlights the need for further research.

Accordingly, this study aims to: (a) investigate the prevalence of RAEs among teams competing at the UEFA U17 European Soccer Championship, by outlining their presence and associations with teams' final ranking in the tournament, (b) examine whether RAEs prevalence among national teams could be linked to cultural and contextual factors, such as FIFA points and national population, and (c) further explore relative age (dis)advantages at senior level. For this reason, this study was divided into two parts. Part 1 explored the birthdates of European youth soccer players who have competed at the UEFA U17 Championship and calculated the RAEs magnitude for each national team competing in the tournament to explore relative age associations with on-field results, FIFA points and national population. Part 2 recorded the birth quarter distribution of European senior soccer players who competed at the UEFA Senior Championship to explore relative age (dis)advantages influence on senior career achievements. For Part 1 of the study, it was hypothesised that RAEs were largely present and would influence teams' final rankings at youth levels. For Part 2 of the study, it was hypothesised an increase in the presence of relatively younger players at the senior level, compared to youth levels.

Materials and methods

Subjects

In Part 1 of this study, a total sample of 1,565 male European youth soccer players, who competed at the UEFA U17 male European soccer championship, born between 2001 and 2007 (both years included), was considered for the statistical analyses. To be eligible for inclusion, a player must have played in the UEFA U17 male European soccer championship throughout one of the following editions: 2018, 2019, 2022, 2023, and 2024 seasons. The analysis excluded the 2020 and 2021 seasons because the tournaments were not held due to the COVID-19 pandemic. In Part 2 of this study, a total sample of 624 male European senior soccer players, who competed at the UEFA Senior male European soccer championship, born between 1983 and 2007 (both years included), was considered for the statistical analyses. To be eligible for inclusion, a player must have played at the 2024 edition of the UEFA Senior male European soccer championship. Because all data were freely available from the internet and reported anonymously, no approval by an ethical committee was required.

Procedures

The data for this study (i.e., players' team selection, birthdates, national teams' final rankings) were publicly available and retrieved online from the Transfermarkt website (Part 1 of the study: https://www.transfermarkt.it/u17-europameisterschaft-2024/startseite/pokalwettbewerb/7E24, accessed on 28th July 2024; Part 2 of the study: https://www.transfermarkt.it/euro-2024/startseite/pokalwettbewerb/EM24, accessed on 10th August 2024). Players were classified based on their birthdate [Birth Quarter 1 (BQ1) = January, February, and March; BQ2 = April, May, and June; BQ3 = July, August, and September; and BQ4 = October, November, and December], cohort of play (Youth or Senior), and respective national team (Youth National Teams included in the study = 80; Senior National Team included in the study = 24). The observed birthdate distribution of each cohort was calculated for each BQ. The observed BQ distribution of the youth cohort was compared to the expected distribution of an assumed equal number of players; whereas in order to gain a full understanding of any age bias effects the observed BQ distribution of the senior cohort was compared to both the uniform distribution and the U17 distribution.

Moreover, to comprehend RAEs influences on youth performance outcomes, for Part 1 of the study, youth national teams were classified based on their RAEs magnitude (i.e., Low RAEs, Medium RAEs, Strong RAEs, and Very Strong RAEs; these were obtained through Cramér's V analysis, further details will be given in the following section), and on their final ranking in the tournament (i.e., Level 1 teams = first four positions; Level 2 teams = from 5th to 8th position; Level 3 teams = from 9th to 12th position; Level 4 teams = from 12th to 16th position). Furthermore, to understand whether national teams' RAEs magnitude values were influenced by cultural and contextual factors, national teams' FIFA points and national population were also collected for each team included in Part 1 of the study. FIFA points were publicly available and retrieved online from the Inside FIFA website (https://inside.fifa.com/fifa-world-ranking/men; accessed on 25th August); whereas nation population were also publicly available and retrieved online from the Wikipedia website (https://it.wikipedia.org/wiki/Pagina_principale; accessed on 5th September).

Data analysis

In Part 1 of the study, a chi-square goodness-of-fit test (χ^2) was used to compare the observed U17 BQs distribution for the whole sample, for each youth national team, and for each country, to an assumed equal number of players (i.e., 25% for each quartile), as already done in other international RAEs studies (14). Since chi-square statistics cannot reveal the magnitude and the direction of an existing relationship for significant chi-square outputs, effect sizes (Cramér's V) and odds ratios (ORs) were also calculated. Cramér's V were used to classify youth national teams based on their RAEs magnitude and were interpreted as follows: values between 0.120 and 0.278 indicated low RAEs prevalence in the team, 0.279 and 0.340 indicated medium RAEs, 0.341 and 0.410 indicated strong RAEs, and 0.411 or more indicated very strong RAEs (49). The ORs and 95% CIs were used to compare BQs for the achievement of youth European status. These were calculated with the youngest group used as reference (BQ4). CIs including 1 (i.e., 95% CI 0.90–1.10) marked no association. Subsequently, a chi-square test for independence (χ^2) was used to investigate youth national teams' RAEs magnitude (set as the independent variable) influence on final ranking in the tournament (set as the dependent variable). Furthermore, the Pearson correlation coefficient (r) was also calculated to explore associations between national teams' RAEs magnitude and their cultural and contextual factors (e.g., national teams' FIFA points and national population). Pearson's r values below 0.10 indicated trivial associations, between 0.11 and 0.30 small associations, 0.31 and 0.50 moderate association, and 0.51 or more indicated large association (50).

In Part 2 of the study, a chi-square goodness-of-fit test ($\chi 2$) was used to compare the observed BQs Senior distribution to both the uniform distribution [i.e., assumed equal number of players (25%) for each quartile], and the U17 distribution.

Results

The observed BQs distribution for the U17 European soccer players, as well as the expected distribution, are separately displayed in Figure 1. The results revealed a significantly skewed birthdate distribution favouring BQ1 players [$\chi 2$ (3) = 432;

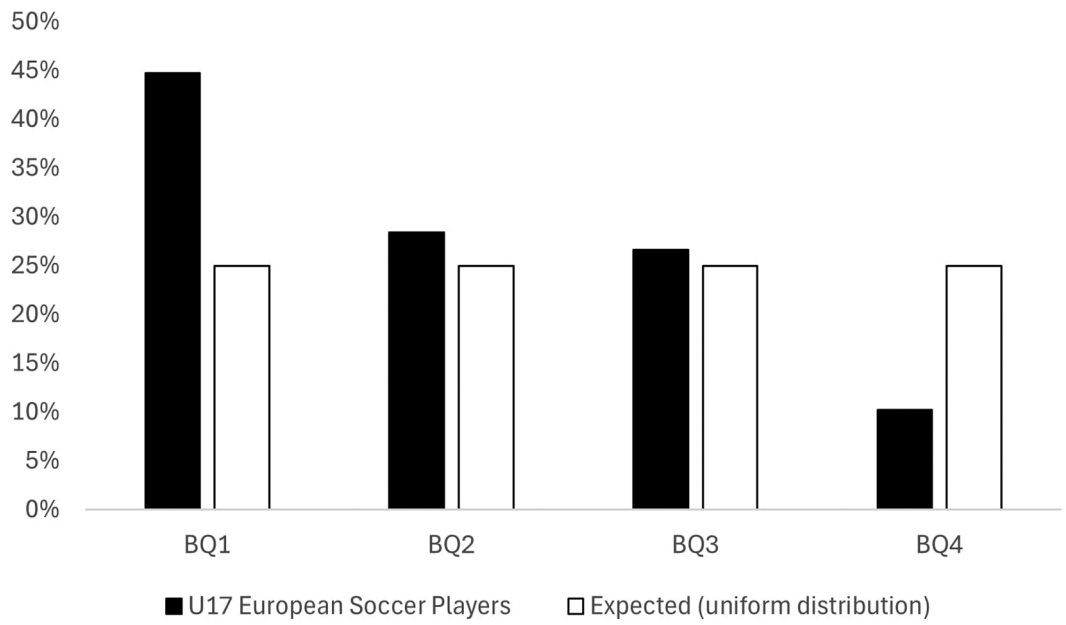


FIGURE 1
The observed BQs distribution for the U17 European soccer players compared to the expected distribution taken from an assumed equal number of players for each BQ.

TABLE 1 Bqs distribution of the Youth European soccer players from a country-level perspective compared to the expected distribution taken from an assumed equal number of players for each BQ.

Youth National Teams	BQ1: % (expected)	BQ2: % (expected)	BQ3: % (expected)	BQ4: % (expected)	$\chi 2$	*P*	*V*	ORs BQ1 vs. BQ4
Austria	45 (25)	25 (25)	20 (25)	10 (25)	10.4	**0.01**	0.29	**4.50 (1.12–18.13)**
Belgium	42.1 (25)	29.8 (25)	21.1 (25)	7 (25)	14.9	**<0.01**	0.29	**6.00 (1.65–21.76)**
Bosnia and Herzegovina	57.9 (25)	26.3 (25)	5.3 (25)	10.5 (25)	12.8	**<0.01**	0.47	5.50 (0.77–39.51)
Bulgaria	30 (25)	20 (25)	35 (25)	15 (25)	2.0	0.57	0.18	3.00 (0.40–22.71)
Croatia	52.5 (25)	17.5 (25)	17.5 (25)	12.5 (25)	16.5	**<0.001**	0.37	**4.20 (1.13–15.59)**
Cyprus	35 (25)	25 (25)	20 (25)	20 (25)	1.2	0.75	0.14	1.75 (0.31–10.02)
Czechia	50 (25)	25 (25)	15 (25)	10 (25)	15.2	**<0.01**	0.35	2.00 (0.63–6.38)
Denmark	46.7 (25)	25 (25)	13.3 (25)	15 (25)	16.9	**<0.001**	0.30	**3.11 (1.10–8.78)**
England	45.5 (25)	28.6 (25)	14.3 (25)	11.7 (25)	22.3	**<0.001**	0.36	**3.89 (1.48–10.23)**
France	45.5 (25)	28.6 (25)	14.3 (25)	11.7 (25)	20.3	**<0.001**	0.29	**5.33 (1.83–15.58)**
Germany	46.8 (25)	33.8 (25)	10.4 (25)	9.1 (25)	31.3	**<0.001**	0.36	**5.14 (1.84–14.36)**
Greece	40 (25)	15 (25)	30 (25)	15 (25)	3.6	0.30	0.24	2.67 (0.43–16.39)
Hungary	30.8 (25)	28.2 (25)	25.6 (25)	15.4 (25)	2.1	0.54	0.13	2.00 (0.53–7.50)
Iceland	63.2 (25)	15.8 (25)	10.5 (25)	10.5 (25)	14.9	**<0.01**	0.51	6.00 (0.84–42.78)
Ireland	42.4 (25)	30.5 (25)	18.6 (25)	8.5 (25)	15.2	**<0.01**	0.29	**5.00 (1.50–16.62)**
Israel	43.6 (25)	25.6 (25)	17.9 (25)	12.8 (25)	8.4	**0.03**	0.26	3.40 (0.89–12.92)
Italy	53.5 (25)	28.3 (25)	12.1 (25)	6.1 (25)	53.4	**<0.001**	0.42	**8.53 (3.21–24.29)**
Luxembourg	38.9 (25)	33.3 (25)	16.7 (25)	11.1 (25)	3.7	0.28	0.26	3.50 (0.45–27.02)
Netherlands	52.5 (25)	27.5 (25)	12.5 (25)	7.5 (25)	39.2	**<0.001**	0.40	**7.00 (2.43–20.13)**
Norway	44.4 (25)	44.4 (25)	11.1 (25)	0 (25)	9	**0.02**	0.39	8.00 (0.69–20.13)
Poland	50 (25)	27.6 (25)	15.5 (25)	6.9 (25)	24.3	**<0.001**	0.37	**7.25 (2.03–25.92)**
Portugal	57.5 (25)	27.6 (25)	15.5 (25)	6.9 (25)	69.5	**<0.001**	0.48	**11.40 (3.91–33.21)**
Russia	60 (25)	30 (25)	5 (25)	5 (25)	16.4	**<0.001**	0.52	**12 (1.10–130.59)**
Scotland	28.2 (25)	25.6 (25)	28.2 (25)	17.9 (25)	1.1	0.77	0.09	1.57 (0.43–5.76)
Serbia	38 (25)	22 (25)	13 (25)	14 (25)	9.5	**0.02**	0.20	2.14 (0.88–5.22)
Slovakia	25 (25)	40 (25)	20 (25)	15 (25)	2.8	0.42	0.22	1.67 (0.25–11.07)
Slovenia	28.9 (25)	44.7 (25)	13.2 (25)	13.2 (25)	10.4	**0.01**	0.30	2.20 (0.55–8.81)
Spain	43.4 (25)	30.3 (25)	19.2 (25)	7.1 (25)	28.6	**<0.001**	0.31	**6.14 (2.32–16.27)**
Sweden	47.4 (25)	28.2 (25)	15.4 (25)	9 (25)	26.9	**<0.001**	0.33	**5.29 (1.90–14.70)**
Switzerland	32.4 (25)	32.4 (25)	16.2 (25)	18.9 (25)	1.5	0.66	0.18	1.71 (0.47–16.31)
Turkiye	36.8 (25)	15.8 (25)	36.8 (25)	10.5 (25)	4.3	0.22	0.27	3.50 (0.46–26.43)
Ukraine	70 (25)	20 (25)	5 (25)	5 (25)	22.8	**<0.001**	0.62	**14 (1.30–150.90)**
Wales	26.3 (25)	23.7 (25)	36.8 (25)	13.2 (25)	5.2	0.15	0.21	2.00 (0.49–8.11)

Bold = statistically significant at <0.05.

$p < 0.001$; very strong effect size]. The descriptive ORs shown an increased likelihood of players born in BQ1, BQ2, and BQ3 of playing at the U17 European level compared to players born in BQ4 [ORs BQ1 vs. BQ4 (95% CI) = 4.38 (3.52–5.46); BQ2 vs. BQ4 = 2.78 (2.21–3.50); BQ3 vs. BQ4 = 1.63 (1.28–2.07)].

Table 1 reports the results from the chi-square goodness-of-fit test conducted from a country-level perspective. Findings confirmed the UEFA U17 European Soccer Championship appears as an early born player affair, as 23 out of 34 countries that have lined up at least one national teams during the investigated editions presented an underrepresentation of relatively younger players and suffered from RAEs (67.6%). More in detail, Bosnia and Herzegovina, Croatia, Czechia, Germany, Iceland, Italy, Netherlands, Norway, Poland, Portugal, Russia, and Ukraine were the countries to select most BQ1s for their UEFA U17 campaigns (strong and very strong RAEs magnitudes; please see Figure 2 for more details on this). Overall, ORs statistics presented BQ4s' decreased likelihood of competing at the U17 highest European level for very strong RAEs magnitudes' countries (ORs ranging from 5.50–14.00), strong RAEs magnitudes' countries (ORs ranging from 2.00–8.00), and medium RAEs magnitudes' countries (ORs ranging from 2.20–6.14).

When investigating each youth national team participating in the four investigated editions of the UEFA U17 European Soccer Championship, independently of its country, descriptive statistics revealed 28.7% of them exhibited very strong RAEs prevalence ($n = 23$), 26.3% strong RAEs ($n = 21$), 21.2% medium RAEs ($n = 17$), and 23.7% low RAEs ($n = 19$).

The chi-square test for independence revealed a significant association between youth national teams' RAEs magnitude and their final ranking in the tournament [$\chi 2$ (9) = 20.1; $p = 0.017$; very strong effect size]. More in detail, Figure 3 separately displays the distribution of youth national teams' RAEs magnitude divided per final ranking. Teams with very strong and strong RAEs magnitudes recorded the highest proportions of teams finishing in the top four positions (30.4% and 28.6%, respectively). In contrast, national teams with medium and low RAEs magnitudes were more likely to finish in the bottom four positions (23.5% and 52.6%, respectively). In line with this, results from the ORs exhibited low RAEs magnitude teams were

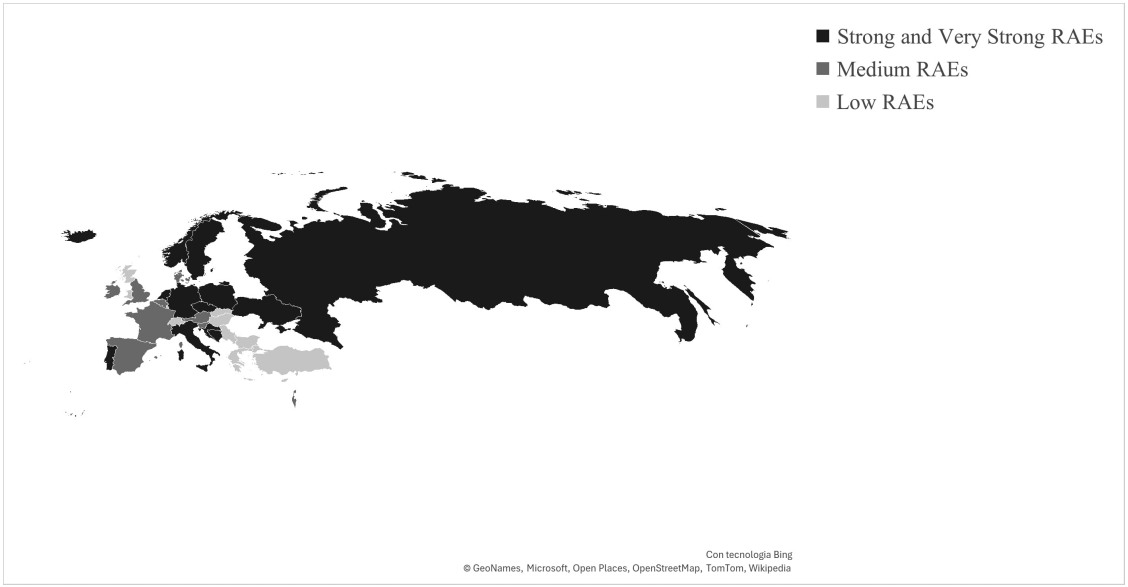


FIGURE 2
Youth National teams' RAEs magnitudes from a country-level perspective.

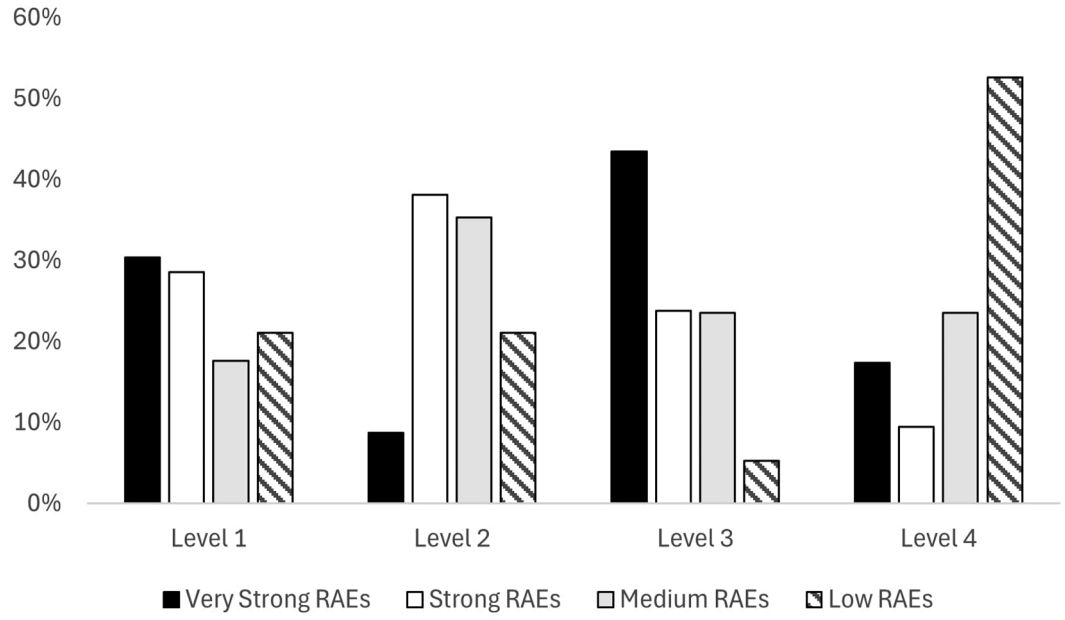


FIGURE 3
Youth National teams' RAEs magnitudes divided per final ranking.

5.67 (1.84–17.5) more likely to rank as Level 4 teams and reported a tendency (not statistically significant) of youth national teams exhibiting very high RAEs magnitude of finishing the championship in the top 4 positions [1.48 (0.50–4.37)].

Regarding the correlation analysis, a small to moderate positive correlation was recorded between national teams' RAEs magnitude and national population [r (78) = .25; $p = 0.02$], as well as FIFA points [r (78) = .33; $p < 0.01$].

The observed BQs distribution of the Senior European soccer players, as well as the uniform distribution and the expected distribution obtained from the U17 distribution, are separately displayed in Figure 4. Results revealed early born players

continue to overrepresented at senior level, albeit to a lesser and weaker extent [$\chi 2$ (3) = 20.3; $p < 0.001$; moderate effect size]. Indeed, further chi square analysis revealed a statistically significant differences between the U17 BQ distribution and the Senior BQ distribution [$\chi 2$ (3) = 93.5; $p < 0.001$; strong effect size], whereby the latter recorded more BQ4s than expected [BQ4 (expected value) = 20% (10.2)], and fewer BQ1s than expected [BQ1 (expected value) = 31% (44.7%), see Table 2 for more detailed information]. In line with this, ORs highlighted how BQ4 players were more likely to be represented at Senior European level than at the U17 level compared to BQ1s, BQ2s, and BQ3s [ORs BQ4 vs. BQ1 (95% CI) = 2.80 (1.96–3.98); BQ4 vs. BQ2 = 2.13 (1.47–3.09); BQ4 vs. BQ3 = 1.50 (1.01–2.23)].

Discussion

This study's aim was threefold: (a) to investigate the prevalence of RAEs among teams competing at the UEFA U17 European Soccer Championship, by outlining their presence and associations with teams' final ranking in the tournament, (b) to examine whether RAEs prevalence among national teams could be linked to cultural and contextual factors, such as FIFA points and national population, and (c) to further explore relative age (dis)advantages at senior level. The results from Part 1 of this study revealed the population of the U17 European soccer players is overrepresented by relatively older players, who are more likely to represent their country at the international youth level. In line with this, 28.7% of youth national teams exhibited very strong RAEs prevalence and recorded the highest proportion of teams finishing the tournament in the top four positions. In contrast, youth national teams with low RAEs prevalence (23.7%) had the highest likelihood of completing the tournament in the bottom positions. Further investigations exploring associations between relative age prevalence and cultural and contextual factors, revealed a moderate association between national teams' RAEs magnitude and their FIFA points. Results from Part 2 of this study presented early born players remained overrepresented at the senior level, albeit with a lower and weaker effect. Indeed, results also showed the BQ distribution of senior European players recorded more BQ4s and fewer BQ1s than expected [BQ4 (expected value) = 20% (10.2); BQ1 (expected value) = 31% (44.7%)].

The results from Part 1 of this study demonstrated how youth players' participation at the UEFA U17 European Soccer Championship is biased toward favouring early born players and confirmed RAEs in male youth soccer are widespread internationally (51), as most of the countries who lined up their youth national team in at least one of the five investigated editions have reported from medium to very strong RAEs magnitudes. Findings are in line with past research conducted at

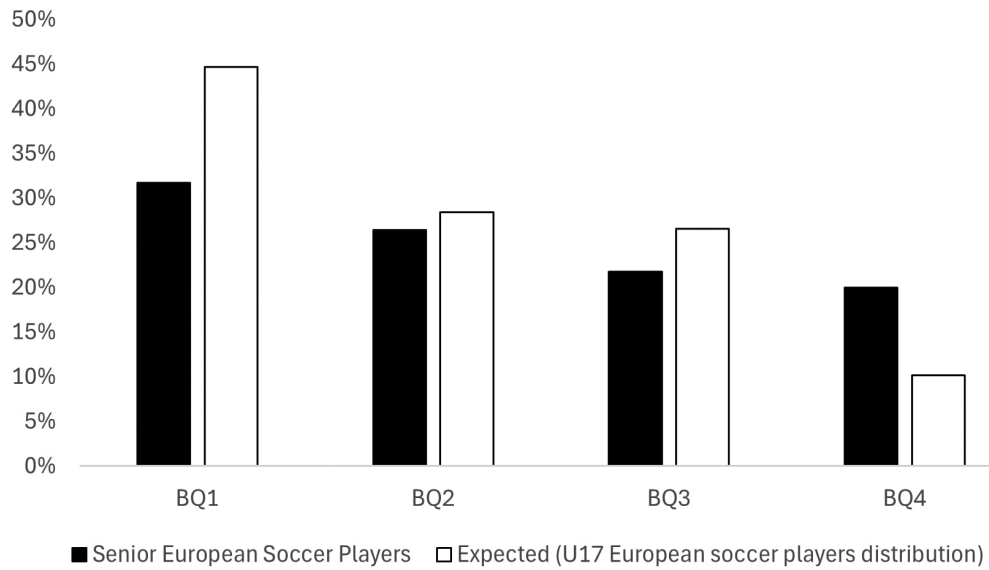


FIGURE 4
The observed BQs distribution for the Senior European soccer players compared to the expected distribution taken from the U17 cohort.

TABLE 2 Bqs distribution of the senior European soccer players compared to the expected distribution taken from the U17 distribution.

Senior European Players	BQ1 (expected)	BQ2 (expected)	BQ3 (expected)	BQ4 (expected)	$\chi 2$	*P*	*V*
N	198 (279.2)	165 (177.4)	136 (103.7)	125 (63.7)	93.5	**<0.001**	Strong
%	31.7 (44.7)	26.4 (28.4)	21.8 (16.6)	20 (10.2)			

Bold = statistically significant at <0.05.

the UEFA youth level (21, 22, 36) and linked to the climate youth soccer systems operate in, which is characterised by financial and results pressures (4). Barraclough et al. (7) have recently highlighted that in soccer, youth players' current performance standard is strongly and positively correlated to coaches' perceptions of their potential and is used to guide selection procedures and to differentiate between player's skill and ability levels (i.e., the formation of elite underage groups). In line with this, past research has shown selection decisions in youth soccer aim to find the most promising young players (2, 52) who align with club's requirements (i.e., required attributes and style of play) (6, 53). However, researchers have already presented that when selection processes are driven by the need to answer to specific functional demands such as the need to build winning age-group teams (54, 55) soccer systems indirectly cause the proliferation of selection biases (i.e., RAEs). This phenomenon is particularly pronounced as born players are favoured due to a combination of age-related differences (31) and sociocultural and environmental factors (20, 42, 56). Specifically, they experience more time to practice, compete, and develop, as well as greater opportunities to build vital cognitive and psychosocial skills (57). This allows them to achieve higher performance standards in the early stages of development which guarantee them more openings into talent pathways, resulting in early access to better training facilities, competent technical staff, and higher competition levels (4, 58). This, in turn, leads to a further rise in performance and soccer-specific skills as well as the opportunity to build important relationships with coaches (i.e., social visibility), resulting to advantages on different timescales (i.e., short- and long-term effects of RAEs) (42).

Part 1 of this study has also investigated the possible relationship between RAEs and cultural and contextual factors. Results recorded positive correlations between national teams' RAEs magnitude and their FIFA points and national population, thus indicating the higher the FIFA points and the national population, the higher the RAEs magnitudes of the respective national team. These findings confirm previous research conducted in this area, as past studies have already presented RAEs presence is more prevalent as levels of competition increase (i.e., competing for selection) (23, 24). More in detail, in Scottish youth soccer, Dugdale et al. (29) found the presence of RAEs differs based on the level of play. The authors found no RAEs at the amateur level, whereas they recorded evident birth asymmetries among youth players competing at higher levels. Similar results were also found in England (59), Portuguese (60), and German (61) youth soccer, where weaker RAEs were found at the lowest level of play. In this study, the higher prevalence of RAEs magnitudes among national teams displaying higher FIFA points may be attributed to the highest level of domestic play, which likely intensity selection pressures and, in turn, contribute to the amplification of RAEs (44). Moreover, research has also presented a higher talent pool size is associated with an increased likelihood of selecting relatively older players over their younger counterparts (62). For example, Figueiredo et al. (60) found that RAEs were prevalent in young Portuguese international soccer players but were not pronounced in young Portuguese international futsal players. In a similar vein, a recent investigation conducted by Bennett et al. (63) on Australian soccer specifically aimed at investigating how the member federation size influences RAEs prevalence, they reported that an increase in 760 affiliated players led to a 1% higher selection probability for those born in the first 6 months of a chronological age group. As such, findings from our study which correlated higher national population to higher RAEs magnitudes may be attributed to the fact that a larger population dispose of a larger talent pool size to select from for their youth national representatives, thus causing increased competition for the few available positions in the line-up and reiterating the presence of relative age (dis)advantages.

The focus put on current performance standards is related to the practical and theoretically well-sounding assumption that the most promising youth players are the ones able to outperform their peers (2, 10, 55). Indeed, on a shorter timeframe, this linear and deterministic approach assures early successes (i.e., players' skill improvement, and rise in performance level), and guarantees an increase in players' values both on and off the field (i.e., matches results and market value) (8, 9, 55). Accordingly, the achievements of youth teams (i.e., national and/or international trophies; players signing professional contracts) are celebrated in newspapers and social media alike, to demonstrate soccer governing bodies are investing for the future, and players are on the right developmental pathway (64–66). However, results from our study showed performance outcomes in international tournaments appear associated with national teams' RAEs magnitude, therefore showing how lining up early born players may be required to finish the championship in the top positions, corroborating previous findings in the area (33–35). These results indicate that by emphasising youth soccer success, practitioners continue to reiterate inequalities in opportunities to develop. This eventually undermines the pool of available talent to select from at the senior level by giving the best developmental and competitive opportunities only to players able to perform at the highest levels, while removing low performers from the system, without considering any possible interindividual variations in players' developmental status and their potential implications for accurate decision-making (6, 10). Indeed, as presented by Fürst (6), athlete selection differs from talent selection as "not everyone who demonstrates potential for future excellence will be selected (or even considered talented) due to factors such as biases and practical constraints, for instance, the availability of players or the coach's limited knowledge about certain individuals" (p.81). In the case of national team selections, practical constraints may be even more amplificated, as head coaches can select a maximum of 20 players for the next matches and/or tournaments (i.e., increased selection competition and pressures), whereby only the ones with the required functional attributes and performance standards will be given the chances to represent their country at the international stage, and this could eventually build on RAEs prevalence. Moreover, as presented by Morganti et al. (67) due to limited social visibility, not all players can be seen and considered by their respective national team head coaches.

Results from Part 2 of the study further explored the complex relationship between relative age (dis)advantages and senior career

achievements. These findings confirmed previous research that underlined RAEs at early developmental stages continue to persist and influence performance at both youth and senior stages, although they decline with increasing age (18, 45–47, 59, 68). For example, McAuley and colleagues (45) have recently presented that in Northern Irish soccer, despite no RAEs being found at the senior level, 50% of Northern Irish players selected at the U17 level that were subsequently selected for the senior team were from BQ1, compared to the only 14% born in BQ4, thus revealing possible long-term effects of relative age (dis)advantages, also confirmed in other studies (68, 69). Specifically, Heilmann et al. (68) recorded the presence of RAEs in German third-division professional soccer. The authors revealed these were observed due to the cohort of young players (born after 1998), whose birthdates were significantly skewed toward favouring BQ1s, in contrast, they recorded no asymmetries in the cohort of older players (born before 1998). These results confirm past research, which suggested the beginning of a youth career in soccer is affected by RAEs (70).

However, transient effects of relative age (i.e., decrement of its magnitude at older ages) need to be further investigated as in some cases they appear as the result of RAEs reversal (18, 37, 71, 72). More in detail, Figueiredo et al. (73) explained RAEs as the difference between observed and expected distribution. In the case of senior professional soccer, the expected distribution is represented by the BQ distribution of the younger categories (46). As such, in the context of this study, the U17 European players population represents the expected values. Importantly, when comparing the Senior European BQ distribution to the U17 European BQ distribution, the mitigation of RAEs is explained by the augment in the percentages of players from BQ4. Accordingly, later born players may display the highest likelihood of completing the youth-to-senior transition (18, 46). Researchers attributed several motivations for RAEs reversal, known as the "underdog hypothesis", whereby relatively younger individuals may improve their psychological, technical, and tactical skills to overcome age disadvantages, ultimately developing the required character to compete at the senior level (74). A recent study conducted by Andronikos et al. (75) which aimed at investigating factors contributing to the youth-to-senior transition, indicated factors such as personal resources (i.e., technical attributes, coping strategies, physical condition, self-expectations) and the ability to think positively in any situation as strong and positive predictors of adjustment to senior sport. In line with this, Bolckmans and colleagues (71) in their retrospective study on youth international Belgian soccer players, reported self-confidence [defined as "showing faith in one's skills, the courage to meet difficult situations, and the pleasure one has in playing soccer" (p.4)] was the personality construct that most defined future career outcomes. Those in BQ4s were more likely to score higher in self-confidence than BQ1s, and recorded the highest proportion of players developing into professionals. More in detail, McCarthy et al. (76) showed that initial age advantages experienced by earlier born players (i.e., more time to practice and compete and cognitive and psychosocial skills), cause low levels of early challenges (i.e., higher performance standards), and act as push factors, pushing them to the next developmental stage. However, the authors reported early advantages correlated to an external focus, whereby these players were motivated by winning, being recognised as talented, and gaining selection for a national program. On the other side of the same coin, relatively younger players, due to age-related differences, experience high levels of early challenges that authors displayed correlated to an internal focus, whereby these players were motivated by enjoyment and personal development. Therefore, these two different pathways may help define and characterise players' journeys within the soccer system. For example, experiencing and overcoming early challenges may help develop the right coping mechanisms for future challenges (76).

The breadth of relative age (dis)advantages means that there is an inherent risk within talent identification and development processes. A risk matrix developed by Baker et al. (10) presented how practitioners' tendency to overlook potential in favour of performance outcomes may cause, on one side, the recurrence of false positive errors, consisting of the promotion of players displaying a high level of performance but low long-term potential. On the other side, such a vision causes the reiteration of false negative errors, demoting players from the talent system when performing below given standards despite high long-term potential. Accordingly, soccer systems invest large sums of money, time, and resources (i.e., personnel and structures) (2, 77) in players who will miss the youth-to-senior transition, as already shown by longitudinal research on players' careers (14, 17). Indeed, a recent study by Barth et al. (78) showed how youth performance can only explain 2.2% of the variance in senior performance. As such, this suggests how celebrating youth success and increasing youth performance levels and standards do not linearly lead to an increase in future senior performance. Therefore, soccer systems should not celebrate early results as they can only explain a little part of the developmental journey and are not correlated to future achievements. Indeed, results from our study suggested early successes are achieved through the reiteration of selection biases derived from athlete selection procedures favoured over talent selection ones (6).

Practical implications and future directions

Many of the discussion points raised so far are not novel, and yet their continued presence in sporting systems is undeniable. This perpetuation of RAEs comes in many forms, from a focus on athlete selection rather than talent selection, an overemphasis on youth success, and the overshadowing of harm caused by systemic (dis)advantages for athletes (79). In this final section, we aim to cast out a thread that goes beyond the repeated calls for more research, for better sporting systems, and for holistic approaches to talent identification and development. Understandably, these calls are becoming hollow as they echo through a Special Issue featuring 40 years of research on RAEs. To break from this echo chamber, we need to radically consider

the role that we play, the *practical implications* for those in a position to make change, and forge a path forward together.

While the depth and breadth of conversation needed to unpack why athlete selection and talent selection are not the same thing is beyond the scope of this paper, it is worth briefly reiterating the complexity of "talent". Blurry terminology and poor theory/conceptualisation, coupled with flawed evaluation methods due to periods of variation and instability in maturation and development, has weakened the predictive capacity of talent identification and forecasting initiatives (80, 81). Furthermore, the ease and convenience of using athlete selection makes the push for talent selection all the more difficult; even using the word "talent" has become controversial (80). If selection is at the crux of the issue, what would happen if we removed this need to select teams at youth levels?

When we overemphasise the importance of youth performances, it is often for capitalistic gain within the existing system (55): to win tournaments and championships for prestige and money, despite research repeatedly demonstrating that this does little to prepare athletes for future senior performance. If the perceived need to comply with the provision of teams at international tournaments (and to win them) were removed, then a greater focus on the long-term development of talent could be enacted. This deeper, sociocultural pressure through economics and youth tournament success is incredibly difficult to overcome, and it appears that research into its ineffectiveness will not be enough to create a shift in philosophy and perspective.

While sporting systems remain wedded to athlete selection, the magnitude of RAEs may allow for some regulation of the effects within selected teams. Asking youth performance teams to report the magnitude of RAEs as a benchmarking exercise may explicitly call out selection biases in the hopes of counteracting them, although this may not be enough given the long-term effects of RAEs even when they do not appear in senior performance teams [e.g., 45]. There is also a risk that using RAEs magnitude as a target could mean it stops being an effective measure of relative age effects [Goodhart's Law; as cited in Mattson et al. (82)], where teams begin to target athlete selection based on the benchmarking and not talent selection, moving further away from the intentions of the program.

Let us imagine that such a feat has been achieved, that selection for youth performance teams is no longer necessary. How would we "find the best talent" in the pool of participants? A robust approach to holistic, care-full development of young people distributed through a broader network of talent development environments could focus on the development of factors that do contribute to elite senior performance: overcoming challenges, building self-confidence and "personal resources" linked to a successful progression through the pathway. Again, this recommendation has been seen across multiple areas of athlete development and most recently explored as a dual-pathway approach termed by Till and colleagues (83) as "wide and emergent—narrow and focussed". Not without its challenges, a broader system means even greater difficulty when identifying talent, with a need for strong alignment of what is considered talent across sports, environments and many coaches, creating organised chaos at best (83).

From an organisational perspective, it is worth presenting systemic strategies and proposals that past research has reported and advanced to lower inequalities in selection procedures and opportunities to develop (84). For instance, Boucher and Harley (85) suggested shortening age group categories to 9 months. Hurley et al. (40) proposed the relative age fair cycle system to rotate cut-off dates, whereby players can experience being both the oldest and the youngest in their given cohort throughout their developmental process. Kelly et al. (86) suggested a more flexible chronological approach, which offers relatively older and younger players the opportunities to play up and down their respective age groups (42). Similarly, Helsen et al. (87) introduced a new age-grouping method targeted at levelling the playing field (i.e., mitigating somatic and physical fitness variations in youth soccer), reallocating youth players according to their median birth date calculated between their chronological and estimated developmental birth dates. Moreover, to remove pre-defined selection time points and chronological age groups, Kelly and colleagues (86) proposed the birthday-banding methodology, where young athletes move to the next birthdate group on their birthday. Further research presented that giving additional support to relatively younger players (developmental training camps exclusively opened to later-born players, less emphasis on results, and equal playing time at the earliest developmental stages) coupled with a dynamic grouping strategy (i.e., variating the cut-off date between 1 January and 1 July annually) could correspond to a significant decrease in RAEs presence (88).

Accordingly, investigating youth soccer clubs' RAEs magnitudes through a quantitative approach is needed to continue raising questions and debates on relative age (dis)advantages in a sport system that emphasises selection over development to propose eventual solution mechanisms (79). Moreover, to obtain a more comprehensive understanding of RAEs influence on performance outcomes and career achievements, studies should also focus on players' metrics like playing time (i.e., starting players vs. substitutes), match impact (i.e., goals and assists scored, and match grades), and performance statistics (i.e., physical and technical match outputs). However, deepening our knowledge of RAEs from outside of the system has not been enough to eradicate them, so a greater qualitative exploration of the mechanisms that perpetuate their presence in sporting systems from practitioners' and coaches' perspectives must persist. The entanglement of unique aims related to both youth players' selections and their developmental outcomes via examination of terminology and discourses around talent (identification, selection, and development), with conventional standards and cultural and socio-economic backgrounds (i.e., what entails to be a talented youth player), needs continue investigation to create more equitable talent pathways. Furthermore, considering the limited available studies to explore the effects of possible RAEs solutions, future research should also investigate their eventual positive short- (i.e., increased equality in selection procedures and competition across birth quarters) and long-term (i.e., continued soccer participation and career outcomes) effects.

Limitations

When interpreting the results of this study, it is important to consider its limitations. First, only being part of the respective U17 or Senior National Team roster was required to be included in this study. However, some players could have played considerably more games than others (e.g., regular starts and substitutes). Accordingly, appearances and/or impact on the UEFA European Championship could be variables included to obtain a greater understanding of how relative age (dis)advantages define selection decisions and national teams' performance outcomes. Second, this study did not consider the duration of youth players' careers and investigated relative age (dis)advantage without considering players' past (i.e., retrospective) and future (i.e., prospective) career trajectories. Involving a longitudinal research design would have contributed to gaining a better insightful knowledge of how RAEs interact with players' progression through the system. Third, playing time and playing positions were not included as variables in this study. Including playing time when studying RAEs in soccer is important to examine the influence of players' participation levels on RAEs outcomes, whereas playing positions would guarantee a better understanding of who is more vulnerable to this selection bias. Fourth, the observed relationships between national teams' RAEs magnitudes and their FIFA points and national population may result from differences in national youth development soccer systems (i.e., promoted practices, pay-to-play model, spatial distribution of sport-specific facilities, regular ways of being and doing things) and soccer popularity.

Conclusions

The increased adult involvement in youth soccer, coupled with the recent habit of celebrating under-age teams' achievements in newspapers and social media alike, has resulted in professionalised TID and TD practices, indirectly causing the promotion of early identification and specialisation procedures, which often lead to several selection biases (i.e., RAEs), thus calling for further exploration on the area of birth advantages in soccer. This study highlighted the focus on youth results and the competition for selection (i.e., national population and FIFA ranking points) interact with the reiteration of RAEs (dis)advantages in soccer. Specifically, success at the UEFA U17 European Soccer Championship is associated with national teams' RAEs magnitudes. Furthermore, it showed that youth-level RAEs define players' journeys within the soccer system. Considering RAEs resulting from talent identification and development procedures, future research should aim to use a mixed-method approach. Indeed, quantitative studies are required to assess and evaluate relative age (dis)advantages, whereas qualitative studies are needed to comprehend the root causes of RAEs by investigating the terminology and discourses around talent (identification, selection, and development), conventional standards (i.e., what entails to be a talented youth player), and cultural and socio-economic backgrounds.

Data availability statement

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

Author contributions

GM: Conceptualization, Data curation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing. AK: Conceptualization, Methodology, Writing – review & editing. AL: Writing – original draft, Writing – review & editing. PB: Methodology, Writing – review & editing. EP: Funding acquisition, Writing – review & editing. CF: Writing – review & editing. MP: Writing – review & editing. GB: Writing – review & editing. BR: Conceptualization, Data curation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing.

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Unveiling pathways: exploring chronological and maturational biases in a Spanish professional soccer academy

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This brief research report aimed to analyze the prevalence of asymmetries in players' date of birth, the influence of relative age affects (RAEs) and maturation on players' participation, and the potential maturity biases in performance indicators in a Spanish professional male soccer academy. Maturity status was determined as the percentage of predicted adult height (% PAH). RAEs are strongly represented in the sample as 77% of players were born in the first semester of the year. Relatively older players do not appear to receive significantly more playing minutes, while more mature players showed a higher percentage of playing time in U13 and U14, with no differences in U15 and U16. In other performance indicators, more mature players do not have an advantage when it comes to being considered "promising players", training and competing with higher chronological age groups and being selected by state teams. Finally, individual maturity level within the team does not appear to be relevant to the club's proposal to continue in the academy. Our results show a strong overrepresentation of players born in the first semester of the year, indicating the presence of RAEs. However, this bias does not translate into significant differences in competitive performance, such as playing time. Conversely, individual maturity status demonstrates a transient effect on playing time in younger age groups (U13 and U14). These findings underscore the importance of understanding the interplay between RAEs and maturity biases in talent identification and development in the highly competitive framework of a professional soccer academy.

KEYWORDS

relative age effects, maturation, football, youth athlete, talent development

1 Introduction

Traditionally, the process of talent identification and development in soccer comprises two key stages: (i) talent identification (TID) (i.e., the selection of players who have the potential to develop into elite soccer players), and (ii) talent development (TD) (i.e., the generation of a suitable learning environment for players to develop their full potential) (1). However, this process can be more nuanced, involving additional steps that may overlap or evolve depending on the context (2, 3). The complex process of recognizing, developing, and progressing youth soccer players through elite academies to

professional soccer players has been improved over the last decade and there has been an increasing emphasis on the use of science-based development systems that offer a more holistic approach to TID and TD (4). However, this process is still very much linked to the subjective perception of the professional decision makers (i.e., academy scouts, coaches, coordinators and directors) (5) and in soccer, has been characterized by chronological and maturity biases in TID and TD (6).

In this context of recognizing and developing talent, it has been widely reported in the literature that growth-related biological changes and differences in players' date of birth in relation to a cut-off date—also known as relative age effects (RAEs)—are causal factors in the overrepresentation of players who are either relatively older and/or more mature (MM) in elite soccer academies (7–9). In any case, these players are often characterized by a temporary improvement in anthropometric (e.g., stature and body mass) and physical performance parameters (e.g., power, strength, speed) compared to late-maturing and/or late-born players (10) who are often less physically developed (11). This can result in a (un)conscious decrease in their competitive playing opportunities, jeopardizing continuity in elite soccer academies and, consequently, at the expense of the pursuit of short-term performance, hindering their long-term development prospects (12).

However, current evidence from elite soccer academies examining the combined impact of RAEs and biological maturation on competitive participation, evaluation, and retention decisions remains limited. Most existing studies either focus on the distribution of RAEs and maturation within elite academies (13, 14) or investigate impact on physical performance (15–18). While some research addresses how RAEs alone influences player development trajectories (19), no studies, to our knowledge, explore the combined effects of RAEs and maturation on player competitive participation, evaluation, and retention.

The present study offers a novel contribution by analyzing the interaction between RAEs and biological maturation through unique access to internal data from a professional soccer academy. This data provides insights into player participation, growth, and development in a high-performance environment that are difficult to obtain due to the proprietary nature of such information. By examining these variables together, our study sheds light on how developmental and competitive dynamics interact in shaping talent management decisions in a professional academy.

Indeed, the present study was conducted directly by the Research, Development, and Innovation Department of the academy of a professional club within the Spanish First Division League in the 2022–2023 season (La Liga EA Sports) with the main aim to investigate how present chronological and maturational biases were in TID and TD. For this purpose, it was analyzed: (i) the prevalence of asymmetries in players' date of birth; (ii) the influence of chronological age and maturation on players' competitive participation and; (iii) the potential physical and maturity biases in: (a) the consideration as a "promising players" (i.e., rated by the club with higher projection to become professionals), (b) the call-up for state teams and (c) proposal of continuity/release within the club (i.e., whether the players continue their development in the academy or not).

2 Material and methods

2.1 Sample

The present study was conducted in the academy of a professional club of the Spanish First Division League in the 2022–2023 season (LaLiga EA Sports). A total of 80 male soccer players were categorized according to their chronological age (U-13, $n = 21$; U-14, $n = 18$; U-15, $n = 22$; U-16, $n = 19$). Parents and players signed agreements for the use of their data for internal and external research purposes of the club. Additionally, parents completed a form including the parents' height. The present study was approved by Catholic University of Valencia Research Ethics Committee (UCV/2019–2020/149) in accordance with the Declaration of Helsinki.

2.2 Data collection and procedures

2.2.1 Chronological and relative age

The youth academy leagues within the Spanish Soccer Federation are currently organized according to the players' chronological year (cut-off date of January 1st). One member for the Research, Development and Innovation Department of the club collected information on the birth date of each player and grouped according to (i) the birth quarter: Birth Quarter 1 (Q1), January to March; Q2, April to June; Q3, July to September; and Q4, October to December; (ii) the semester: first semester, January to June; and second semester, July to December.

2.2.2 Anthropometric characteristics

Anthropometric characteristics were collected at three points in time during the 2022–2023 season: measurement 1, in September 2022; measurement 2, in January 2023; and measurement 3, in June 2023. All three measurements were applied to all players within the same week in each of the measurement time points. The players were tested 30 min before starting the training session under standardized conditions ($18 \pm 2°$ C) at the club's sports facilities by an expert from the club's Health & Performance Department. Standing and sitting height were measured with a Seca 213 stadiometer ("Physical distancing for health", Hamburg, Germany) with an accuracy of 0.1 cm according to the ISAK protocol (International Society for the Advancement of Kinanthropometry) (20). Body weight was determined with a Tanita BC-602 scale (Tanita Europe B.V., Amsterdam, Netherlands) with an accuracy of 0.1 kg, with the players wearing their training clothes (socks, t-shirt, and shorts) (21). Height and weight were measured twice. If height and body mass differed by more than 0.4 cm or 0.4 kg respectively, a third measurement was taken, and the mean value was calculated (22).

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2.2.3 Maturity status

The Percentage of Predicted Adult Height (%PAH), measured with the Khamis-Roche (KR) method, has been shown to be a reliable tool for assessing the maturation status of soccer players (23). This method is based on the use of a predictive equation that requires precise anthropometric measurements, including the standing height (cm/in) and body mass (Kg/lb) of the soccer player, as well as the standing height (cm/in) of both parents (24). A formula is applied, considering the reference coefficients provided by Khamis and Roche: %PAH = $\beta 0 + [\beta 1 +$ standing height (cm/in)$] + [\beta 2 \times$ weight (lb/kg)$] + [\beta 3 \times$ mean standing height of both parents (cm/in)$]$ (24). In this formula, $\beta 1$, $\beta 2$, and $\beta 3$ are the coefficients established in the reference table provided by Khamis and Roche, while $\beta 0$ is the smoothed regression coefficient for boys and girls within the KR method (24). The obtained results are compared with the reference table to estimate the %PAH in which the subject falls (25). As the height of parents was provided by themselves, a correction adjustment for overestimation has been carried out according to the criteria by Epstein et al. (26).

To determine the maturation stage of each team's players, they were classified into two maturity groups—Less Mature (LM) and MM—based on the %PAH measured at the beginning of the season (Table 1). This classification was conducted using the median %PAH value within each specific age group as the cut-off point. Players with %PAH values below the median were classified as LM, while those above were categorized as MM. This method ensures relative comparisons of biological maturity within each age group, resulting in two groups of equal size. For instance, in the U14 category, the %PAH ranged from 87.98% to 95.02%, with a median cut-off of 90.2%, classifying nine players as LM and nine as MM.

Research has consistently shown that elite academy players tend to exhibit greater biological maturity compared to their non-elite counterparts (7). In line with previous research (27), grouping players by their relative maturity within each age group —rather than applying absolute classifications such as "early" or "late" maturers based on the general population—provides a contextually relevant framework that reflects the competitive dynamics of professional academy teams and supports a more nuanced analysis of the relationship between maturity and performance.

2.2.4 Players' performance indicators

Players' performance indicators were defined according to the number of participations in competition, their consideration as "promising players", the call-up for state teams and proposal of continuity/release within the club. Participation in regular competition in 2022–2023 season was assessed by the coaching staff weekly, based on the total minutes played in official competitions by each player according to their chronological age team. Participation was expressed as a percentage (%) of the total minutes in which the player was available (i.e., had no injuries or could not compete for non-sporting causes). For example, a player who played 45 out of 90 min (total time) in five games

TABLE 1 Anthropometrics characteristics and playing time depending on birth quarter in different age groups.

Age group	Q1				Q2				Q3				Q4				Height		Weight		PT	
	n	H (cm)	W (Kg)	PT (%)	*n*	H (cm)	W (Kg)	PT (%)	*n*	H (cm)	W (Kg)	PT (%)	*n*	H (cm)	W (Kg)	PT (%)	*F*	*p*	*F*	*p*	F	*p*
U-13$_{(n=21)}$	10	157.5 (±6.2)	44.5 (±6.9)	67.5 (±17.1)	5	150.1 (±8.0)	39.0 (±3.9)	69.1 (±12.1)	0	–	–	–	6	148.4 (±1.0)	40.5 (±3.8)	53.6 (±7.0)	5.571	**.013**	1.930	.174	1.282	.301
U-14$_{(n=18)}$	6	160.1 (±7.0)	48.8 (±8.6)	58.0 (±20.0)	8	164.3 (±9.2)	51.0 (±9.1)	65.2 (±19.0)	2	158.9 (±0.6)	46.6 (±5.3)	63.2 (±34.4)	2	160.8 (±14.1)	48.6 (±14.3)	60.7 (±1.1)	0.380	.769	0.156	.924	0.149	.929
U-15$_{(n=22)}$	9	169.8 (±8.9)	60.4 (±8.9)	67.5 (±19.0)	10	168.3 (±7.3)	60.0 (±6.3)	64.5 (±18.6)	3	166.7 (±11.0)	57.8 (±8.6)	84.2 (±19.7)	–	–	–	–	0.165	.849	0.127	.881	1.282	.301
U-16$_{(n=19)}$	10	174.0 (±5.0)	65.5 (±7.2)	71.9 (±21.6)	3	171.8 (±5.1)	62.5 (±6.9)	65.0 (±8.7)	4	178.0 (±7.3)	70.8 (±3.3)	52.3 (±13.2)	2	170.2 (±12.1)	58.5 (±8.7)	97.2 (±1.8)	0.923	.454	1.764	.197	2.898	.070

Q, Birth Quarter; *n*, number of player per group; H, Height; W, Weight; PT, Playing time; *F*: Anova Value, *p*: significance *p*-value.
Mean and SD (between parenthesis) values.
Bold values denote statistical significance at the $p < .05$ level.

would be given a percentage of 50% of playing time. Moreover, within the academy, players identified as having high potential to become professionals were classified as "promising players". This classification was based on a structured qualitative assessment carried out by the academy's performance department in line with the club's philosophy. Players were assessed on four key dimensions: (i) technical, (ii) tactical, (iii) physical and (iv) psychological using an A, B, C or D standardized scale. Based on these assessments, players were categorized into four levels: A ("Promising player"—high chance to become professional), B (moderate chance), C (low chance) and D (no chance). There was no set limit on the number of players in each category. Many of these promising players were training and competing with older age groups.

Every call-up of a player to the state soccer team for official matches or tournaments were registered by the person responsible at the academy and integrated into a database maintained by the club specifically for this purpose. Additionally, at the end of the 2022–2023 season, the decision to retain or release each player was based on a proposal made by different academy professionals, following a thorough qualitative assessment. This recommendation was officially recorded by the academy director, independent of the player's own decision to stay or leave the club. This measure is significant as it reflects the club's long-term investment strategy and ensures that players who remain in the system have been identified as promising based on multiple professional perspectives.

2.2.5 Statistical analysis

The examination of birth quarter distribution (Q1, Q2, Q3, and Q4) in conjunction with player maturation levels (LM and MM) was carried out using a frequency table. This involved adjusting through chi-square goodness-of-fit tests to assess homogeneity and an analysis of differences between expected and observed frequencies. For the birth quarter, we adopted the assumption of 25% for each birth quarter, consistent with previous studies (28) and the Spanish population census data for individuals born between 2007 and 2010 (Instituto Nacional de Estadística, INE). As the chi-square test alone does not reveal the magnitude and direction of the relationship, therefore, a odds ratio (OR) analysis and 95% confidence intervals (CIs) were included, comparing the results between Q1 and Q4. The OR indicates the probability of membership; a result of 1.0 suggests equal group membership probability, while 2.0 indicates double the probability of one group compared to the other (29). Regarding maturation, cut off values of 50% within the chronological age group were used to determine whether players were relatively LM or MM compared to their peers (30).

Considering that the Kolmogorov–Smirnov and Levene tests indicated normal distribution and homogeneity of variance ($ps < .05$) for the *Playing minutes* variable, group comparisons based on relative age (Q) were conducted using ANOVAs. Comparison between the two maturation groups were analyzed through independent samples *t*-test. Effect sizes were reported using Cohen's *d*, classified as small ($d = 0.2$), medium ($d = 0.5$), and large ($d \geq 0.8$) (31).

Correlation between the athlete's %PAH and minutes played was assessed using Pearson correlation. Correlation coefficients below 0.2 were considered very low, between 0.21 and 0.40 were categorized as low, between 0.41 and 0.60 as moderate, from 0.61 to 0.8 as high, and above 0.8 as very high (32). All statistical analyses were performed using IBM SPSS Statistics software (Version 25.0, Chicago, IL, USA).

3 Results

3.1 Relative age effect and maturation

The results of Birth Quarter (Q) distribution in the total sample are depicted in Table 1 and Figure 1 (total sample), and Figure 2 (RAEs per age group). RAEs were observed in this soccer academy [χ^2 (3, $N = 80$) = 24.100; $p < .001$], showing a 77% of players born in the first semester, and obtaining an OR = 3.5, IC (1.34–9.14) when comparing players born in Q1 with those born in Q4. In terms of age group results, the U13 and U15 groups did not include players born in Q3 or Q4, respectively. In the U14 group, no significant differences were noted according to birth quarter [U14: χ^2 (3, $N = 18$) = 6.000; $p = .112$; OR = 3.0, IC (0.40–22.71)]. However, the U16 group showed significant differences favoring players born in Q1 [U16: χ^2 (3, $N = 19$) = 8.158; $p = .043$; OR = 5.0, IC (0.64–39.06)].

When presenting the results regarding the distribution of maturation across birth quarters, the data showed that players born in the first two quarters of the year were predominantly MM compared to those born in the last two quarters of the year (Figure 3). Conversely, there was a higher proportion of LM players among those born in the third and fourth quarters. These results suggest an uneven distribution of maturation across the year, with players born earlier being more biologically advanced. Statistical analysis supports this conclusion [χ^2 (3, $N = 80$) = 9.945, $p = .019$], indicating a significant association between birth quarter and maturity status.

3.2 Relative age effects, maturation and playing time

Regarding the influence of relative age on players' individual performance indicators, our results indicate that playing time was not influenced by the birth quarter [$F(3, 76) = 0.098$, $p = .961$] in none of the age groups (Table 1).

Analyzing the distribution of minutes based on players' maturation, Table 2 and Figure 4 reveals that MM players ($M = 68.6$, $SD = 16.9$) played more percentage of minutes than their LM counterparts ($M = 63.3$, $SD = 19.4$), although these differences did not reach statistical significance [$t(78) = -1.29$; $p = .199$], due to the high variability within each group and sample size. However, upon closer examination of distinct age categories, it was found that the youngest players (U13 and U14), classified as LM, experienced over 12% less playing time compared to their MM counterparts. The disparities in the U13 group were statistically significant [$t(19) = -2.36$; $p = .029$]. Indeed, moderate significant correlations between maturation and playing minutes were observed both in the U13 and U14 categories [U13: $r(21) = .545$, $p = .011$; U14: $r(18) = .573$, $p = .013$],

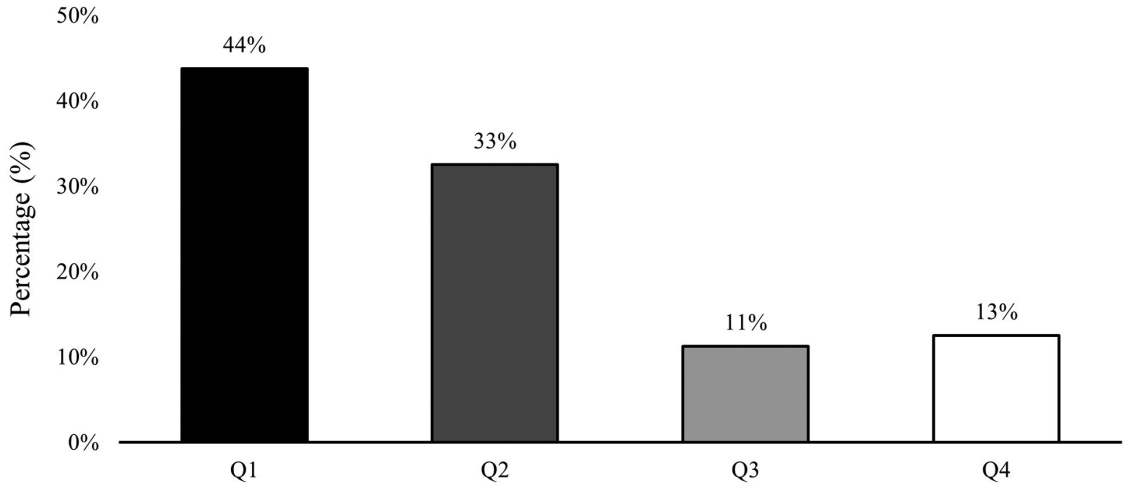


FIGURE 1
Distribution of players by birth quarter in the academy. Q, Birth Quarter.

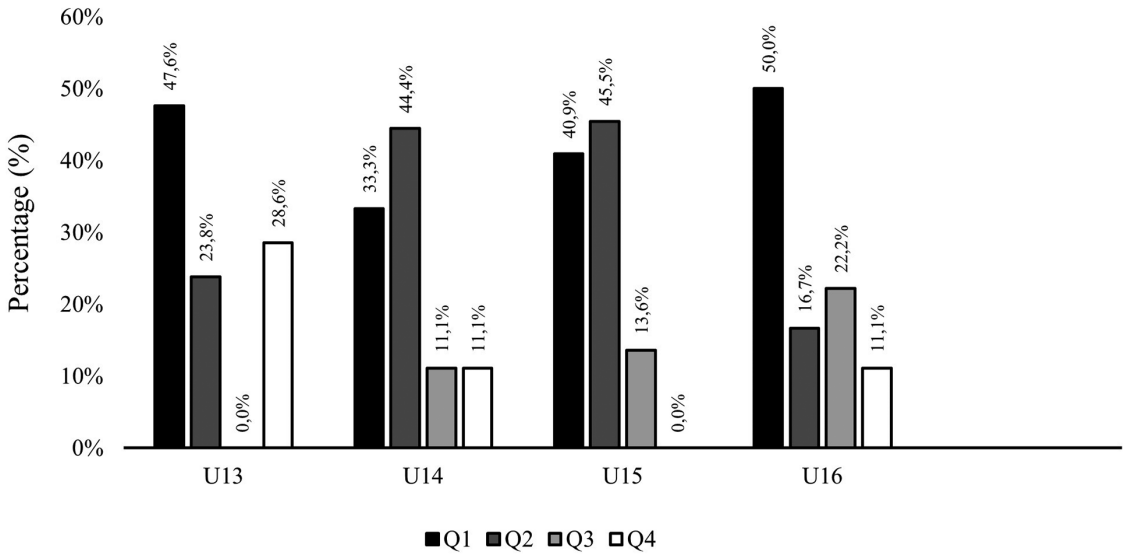


FIGURE 2
Distribution of players by birth quarter across the age groups. Q, Birth Quarter.

whereas the older groups did not exhibit significant correlations [U15: $r(22) = -.142$, $p = .527$; U16: $r(19) = -.107$, $p = .664$]. The interaction between birth quarter and maturity level did not yield significant results, indicating that the effect of birth quarter on playing time does not vary according to players' maturity status [$F(3, 72) = 0.248$, $p = .862$].

3.3 Relative age effects, maturation and anthropometric parameters

RAEs analysis revealed no significant differences ($ps > .05$) in anthropometric variables when comparing birth quarters across the different age groups (Table 1). However, MM players showed higher anthropometric parameters (height and weight) than their LM teammates, with significant differences ($ps < .05$) in the U13, U14 and U15 groups (Table 2).

3.4 Relative age effects, maturation and players' projection

As shown in Table 3, the analysis of RAEs revealed significant differences in player continuity ($p < .001$) whereas these differences did not reach statistical significance for promising and promoted

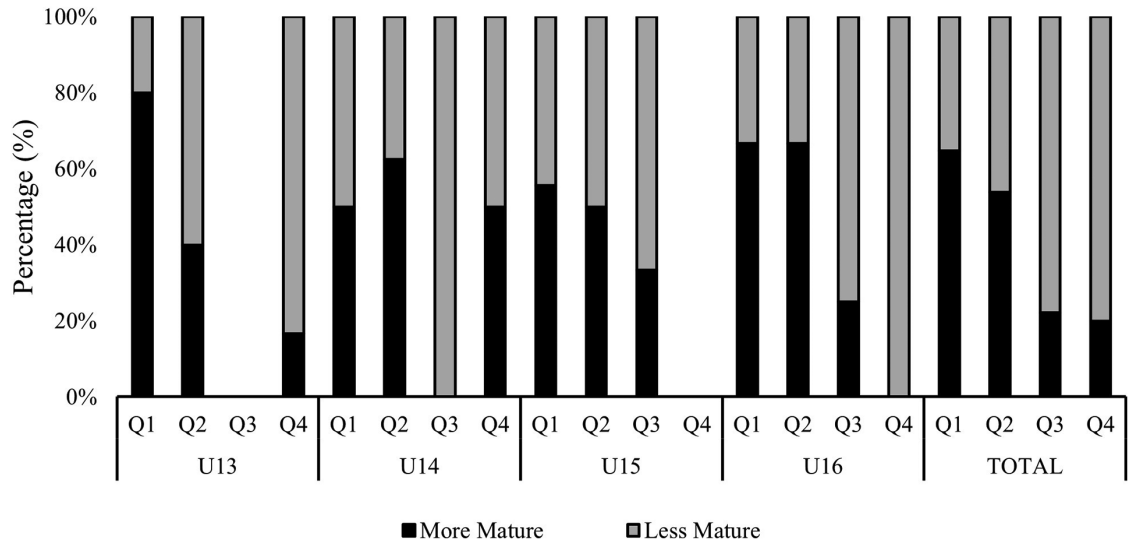


FIGURE 3
Distribution of maturation status by birth quarter across the age groups. Q, Birth Quarter.

players (both *ps* = .062). This pattern is consistent with the greater representation of players born in the first two quarters of the year in the sample. Given this distributional bias, it is expected that similar trends will emerge for these variables as the overrepresentation of players born early influences the observed results.

Regarding the maturation analysis, 47.8% of the players who were offered the opportunity to continue within the club belonged to the LM group, while 52.2% belonged to the MM group, though this difference was not statistically significant, [$\chi^2(1, N = 71) = 0.127$; $p = .722$]. Among the players considered as more promising within the club, 44.4% belonged to the LM group while 55.6% were included in the MM group. Similarly, from the group of players promoted to older teams within the club, 42.1% belonged to the LM group and 57.9% to the MM group. In none of these previous comparison significant differences were found [χ^2 (1, $N = 18$) = 0.222; $p = .637$ and χ^2 (1, $N = 19$) = 0.474; $p = .491$, respectively]. Finally, regarding the players selected for the state team, 40.0% of them were LM players, while the remaining 60.0% belonged to the MM group, although again these differences did not reach statistical significance [χ^2 (1, $N = 10$) = 0.400; $p = .527$].

4 Discussion

This study aimed to analyze: (i) the prevalence of asymmetries in players' date of birth; (ii) the influence of chronological age and maturation in players' competitive participation and (iii) the potential physical and maturity biases in: (a) the proposal of continuity/release within a professional club, (b) the consideration as a "promising players" and (c) the call-up for state soccer teams.

RAEs are strongly represented in the sample examined in this study, which is consistent with previous studies on elite youth soccer academies (9, 16, 19, 33–37). Specifically, 77% of the sample analyzed were born in the first semester of the year. Furthermore, as expected, players born in the first semester were mostly MM, while those born in the second semester had considerable higher proportion of LM players (78% in Q3, 80% in Q4). In this context, when considering the influence of RAEs on players' individual performance indicators, it was found that players born in the first semester of the year received slightly more playing time, with no significant differences between quarters, which is consistent with previous research in Spanish elite soccer academies (38).

In terms of player maturity, the MM players received slightly more playing time than their LM counterparts, although there were no significant differences, as when looking at the whole sample, which is in line with more recent approaches (27, 39).

Similarly, the interaction between maturity and RAEs were not significant, suggesting that maturity status does not differentially impact playing time based on players' born in the different birthquarters. This outcome may reflect the academy's prioritization of competitive balance over physical maturity or relative age. In fact, the lack of significant differences in the percentage of playing time between early and late maturing players is in line with the recommendations of previous authors suggesting that playing decisions should not be based on physical and momentary performance parameters, but also on other performance indications such as technical skills, motor coordination or tactical understanding (40). However, upon further examination within each age category, a moderate correlation between maturity status and playing time was observed in U13 and U14, with MM players showing a higher percentage of minutes played, while there was no correlation in

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TABLE 2 Anthropometrics characteristics and playing time depending on the maturation in different age groups.

Age group	Less mature						More mature						Height		Weight		%PAH		PT	
	%PAH	*n*	H (cm)	W (Kg)	%PAH	PT (%)	*n*	H (cm)	W (Kg)	%PAH	PT (%)		*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
U-13$_{(n=21)}$	82.54–89.87	10	148.2 (±4.5)	38.9 (±3.7)	83.8 (±0.9)	56.7 (±9.4)	11	157.6 (±5.8)	44.9 (±6.1)	87.5 (±1.3)	70.5 (±16.1)		−4.08	**<.001**	−2.68	**.015**	−7.56	**<.001**	−2.36	**.029**
U-14$_{(n=18)}$	87.98–95.02	9	155.7 (±3.8)	42.8 (±4.9)	89.1 (±0.8)	56.4 (±18.7)	9	168.1 (±6.3)	56.1 (±5.4)	92.9 (±1.7)	67.8 (±17.7)		−5.06	**<.001**	−5.49	**<.001**	−5.79	**<.001**	−1.32	.206
U-15$_{(n=22)}$	88.46–97.40	11	164.9 (±9.0)	56.0 (±6.4)	93.6 (±2.0)	69.3 (±17.9)	11	172.5 (±5.2)	63.7 (±6.5)	96.5 (±0.5)	67.5 (±21.1)		−2.40	**.029**	−2.84	**.010**	−4.70	**<.001**	0.21	.836
U-16$_{(n=19)}$	95.82–99.10	10	172.6 (±8.3)	63.9 (±8.8)	96.7 (±0.8)	70.3 (±26.9)	9	175.4 (±3.3)	66.8 (±5.3)	98.2 (±0.5)	65.5 (±14.6)		−0.96	.351	−0.87	.394	−4.89	**<.001**	0.19	.855

%PAH, Percentage of Predicted Adult Height; *n*, number of player per group; H, Height; W, Weight; PT, Playing time; *t*, *t*-Student; *p*, significance *p*-value; "Less Mature" (<50%), "More Mature" group (>50%).
Bold values denote statistical significance at the $p < .05$ level.

U15 and U16. This result may be evident in the U13 and U14 groups as the differences in maturity levels are higher in this age period (41). Players with early maturity levels have shown in previous studies better aerobic capacity, speed, strength and power than their late maturity counterparts (42, 43). In fact, studies in youth soccer have shown that late-maturing players are consistently excluded as the age- and sport-specific demands increase, especially in this critical phase of adolescence (44).

Nevertheless, our results suggest that MM players do not have a significant statistical advantage in performance/projection indicators such as promotion to higher chronological age categories, being classified as "promising players" within the academy, or selection for state soccer teams. However, it is important to interpret these findings with caution, as the number of players classified as "promising" ($n = 18$), promoted to higher age groups ($n = 19$), or selected for the state team ($n = 10$) was relatively small. Furthermore, in all cases, MM players within their age group were more represented. The lack of significant differences might be explained by this small sample, as well as other contextual factors within the academy's selection processes which prioritize game understanding and technical-tactical skills over anthropometrics and physical performance. This is important to consider as growth and maturation have been shown to influence coaches' and decision makers' perceptions of ability/potential and performance (45), with early maturing players in elite academies being perceived as more capable (6) and with greater potential (46), which may also lead to them being promoted in the academy and called up by their state or national team (47). Finally, in the same vein, it seems that the level of maturity has not been very influential on the club's proposal to remain in the academy. This is an important factor, as physical advantages related to age and/or maturation during adolescence are highly transitory and tend to disappear or even reverse in adulthood, where technical, tactical and cognitive skills -that are prevalent among talented players in the academy- play a key role (10).

We believe that these results are promising for advancing TID and and TD practices, especially as they suggest that it is possible to mitigate the typical effects of RAEs and maturational biases on performance outcomes in a high competitive environment. This may be because the academy has deliberately designed its development criteria to prioritize long-term potential over immediate physical advantage, reducing the biases associated with age and maturity. In addition, awareness-raising activities have been implemented to actively minimize this bias and ensure a fairer and more informed development process. This approach, in line with the club's philosophy, emphasizes the holistic development of players by prioritizing technical and tactical skills and understanding of the game over short-term physical attributes.

There are some limitations that need to be considered in the present brief research report. Our study offers concise and focused findings, reflecting the specific context of a Research, Development, and Innovation Department of the academy of a professional club. Only one team was analyzed for each level of competition, so possible conclusions should be taken with

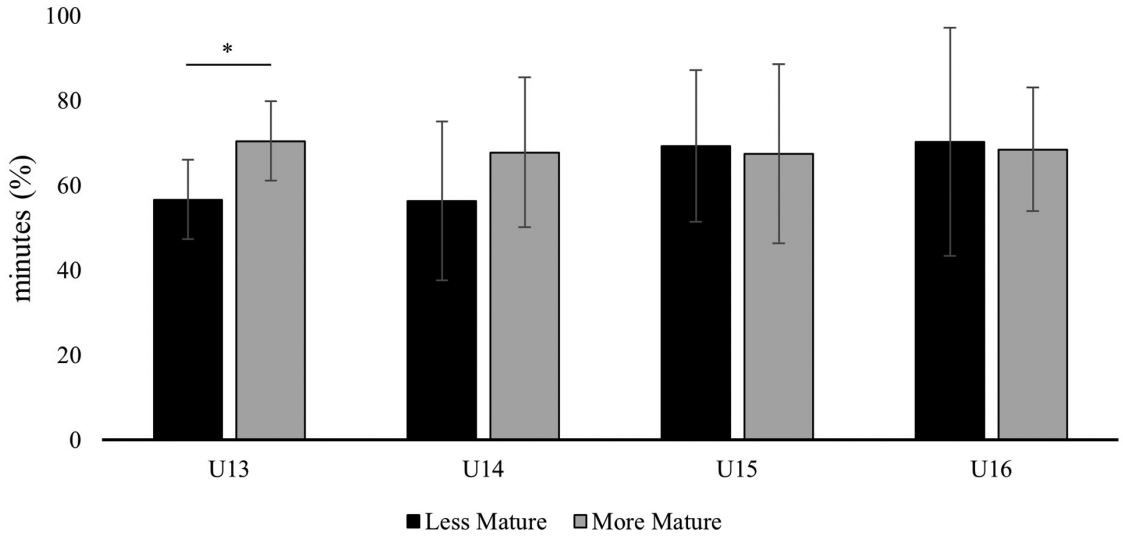


FIGURE 4
Distribution of playing time by maturation status across age groups. *$p < .05$.

TABLE 3 Players' projection based on maturation and RAEs.

	Less mature		More mature		χ^2	p	Q1		Q2		Q3		Q4		χ^2	p
	n	%	*n*	%			*n*	%	*n*	%	*n*	%	*n*	%		
Player continuity	34	47.9	37	52.1	0.127	.722	32	45.1	22	31.0	7	9.9	10	14.0	22.352	**<.001**
Promising players	8	44.4	10	55.6	0.222	.637	9	50.0	5	27.8	2	11.1	2	11.1	7.333	.062
Promoted players	8	42.1	11	57.9	0.474	.491	9	47.4	6	31.6	2	10.5	2	10.5	7.316	.062

χ^2, Chi-square; *n*, number of player per group; *p*, significance *p*-value.
Bold values denote statistical significance at the $p < .05$ level.

caution as variables could be influenced by contextual factors. While it presents initial data and specific advancements, it is inherently limited in terms of the generalizability of the results due to the limited sample size. Another important limitation is that the maturity was assessed indirectly, To increase accuracy, future research should incorporate direct and validated methods of assessing biological maturation whenever possible, such as radiographic analysis (e.g., x-rays), growth velocity measurements, ultrasound imaging, dual-energy x-ray absorptiometry (DXA), or magnetic resonance imaging (MRI) (48). The use of these direct techniques could provide a more accurate understanding of the maturation process and its potential influence on the variables under investigation compared to indirect approaches (49). Finally, it must be considered that "promising players", who were estimated with higher prognosis of becoming a professional, have been evaluated by the club's professionals with a subjective nature according to the club's philosophy. For these reasons, future studies should consider increasing the sample size and studying how age, maturation, and physical biases may cross-sectionally and longitudinally influence participation and selection process in other professional soccer academies. The methodological strengths of this study should also be highlighted. Specifically, access to a professional soccer academy. This access allowed for a comprehensive assessment of potential chronological and maturational biases in various performance indicators and provided valuable insight into TID and TD in soccer.

5 Summary

RAEs are strongly represented in the sample, as 77% of players were born in the first semester of the year. Relatively older players do not appear to receive significantly more playing minutes, while MM players show a higher percentage of playing time at U13 and U14, with no differences at U15 and U16. In other performance indicators, MM players have no advantage when it comes to being considered "promising players", training and competing with higher chronological age groups, and being selected by state teams. Finally, individual birth date and maturity level within the team do not appear to be relevant to the club's proposal to continue in the academy. Individual differences in date of birth and biological maturation pose numerous challenges for both players and professional decision-makers at elite soccer academies. It is therefore crucial to understand how these

differences can influence TID and player development within the very demanding competitive framework of the professional soccer academies.

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 Catholic University of Valencia Research Ethics Committee (UCV/2019 - 2020/149). 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

SPG: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SMG: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. FHO: Conceptualization, Formal Analysis, Methodology, Supervision, Validation, Visualization, Writing – review & editing. HJG: Data curation, Formal Analysis, Methodology, Software, Validation, Visualization, Writing – review & editing. RBL: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, 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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Relative Age Effects and contextual factors in male Spanish youth football: a 10-year cross sectional analysis of U12 to U16 players

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Introduction: The Relative Age Effects (RAEs) are complex, multifactorial phenomena influenced by individual (e.g., maturity status), task-related (e.g., field position or competitive level), and environmental (e.g., coaches' expectations) factors. This cross-sectional study aimed to investigate the relationship between RAEs and the maturity status, field position, competitive level and coaches' expectations within a sample of 1,120 young male Spanish football players [mean age: 13.72 ± 1.40 years; weight: 54.09 ± 11.85 kg; height: 162.11 ± 11.38 cm; years from peak height velocity (PHV): −0.22 ± 1.44], across tree age categories (U12, U14 and U16).

Methods: Data was collected over 10 years (2014–2024), considering the maturity status, estimated using the Mirwald et al. (2002) formula. Physical performance was assessed through tests for strength (1RM), power, speed (30-m sprint), agility (*T*-test), jumping (CMJ), and aerobic endurance (estimated VO_{2max}). Players' field positions and coaches' efficacy expectations about their players were also collected.

Results: A Chi-square (χ^2) analysis revealed a skewed distribution across birth quartiles within age categories ($p < 0.05$). Pearsons' correlation and linear regression analyses showed significant relationship between relative age and maturity status ($r = 0.91$; $R^2 = 0.84$). The RAEs were more pronounced at higher competitive levels, while the distribution bias in playing positions was comparable to the overall sample, with the exception of goalkeepers in the U12-14 categories. ANOVA results tend to a higher physical performance and coaches' efficacy expectations for players with higher RA in the U14 and U16 categories.

Conclusion: This study confirms the presence of strong RAEs over the past decade in youth football players from U12 to U16. Individual and environmental factors, such as advanced maturity status, the intensified selection processes at higher competitive levels, an increased physical performance and higher coaches' efficacy expectations, may contribute to RAEs in a complex and interdependent manner.

KEYWORDS

soccer, maturation, team sports, physical performance, sports performance

1 Introduction

The practice of organizing athletes into annual age categories is a widely adopted approach in youth sports, designed to mitigate disparities in physical and cognitive development throughout childhood and adolescence (1). By grouping athletes based on their birth year, this method aims to create a more level playing field by aligning athletes of similar chronological ages. However, this age-based organization inadvertently introduces structural disadvantages known as Relative Age Effects (RAEs) (2). The term relative age (RA) refers to the differences in chronological age among young players born in different months of the same year (3). For instance, a player born in January and another born in December of the same year have an RA difference of nearly twelve months. The consequences of these RA differences among players within the same selection year are referred to as RAEs, which often leads to an overrepresentation of athletes born in the initial months of the year in sports (1, 2, 4). RAEs have been extensively documented across multiple sports, with particularly high prevalence in sports like ice hockey, basketball, and football (soccer), where physical size and strength play a significant role in performance (1).

The impact of RAEs is multifaceted, as player selection processes must consider various factors, including physical, technical, and tactical performance (among others), which influence the likelihood of selection and progression in competitive sports. RAEs may vary not only across different sports or disciplines but also by gender, field positions and competitive levels in which players participate (1, 5). According to Wattie et al. (2), the factors influencing RAEs can be categorized as (1) individual, meaning those related to the person; (2) task-related, referring to the specific roles and demands of the sport; and (3) environmental, pertaining to external factors beyond the athlete. Among the individual factors that may influence RAEs, one example is the athlete's maturity status. The RAEs in sports, and specifically in football, have been suggested to be primarily linked to differences in physiological growth and maturation among young athletes (6), as those born earlier in the year tend to exhibit physical advantages, which in turn can be misinterpreted as indicators of talent (7). These developmental differences can perpetuate a biased view of players' athletic potential, especially in high-contact and high-competition sports like football, where relatively older athletes or those with an advanced maturity status are more likely to be favoured in selection processes. Biological maturation refers to the process leading to adulthood, while the term "status" refers to the current stage or level of progress within the maturation process (6, 8). When the maturity status is controlled, the impact of RAEs on physical performance can decrease, suggesting that the observed effect may be due, at least in part, to maturation differences rather than chronological age alone (9, 10). In other words, the maturity status appears to have a greater impact on the physical performance of young players than RA (11, 12). A youth born in the earlier months of the year is more likely to be advanced in his maturation, in line with his higher RA (11), but it is possible to find a relative younger player with an advanced maturity status or a relative older player being less mature than his mates (6). This distinction highlights the need to treat RAEs and biological maturation as interrelated but independent constructs, as the advantages observed in relatively older players (1) may be attributed to their advanced maturity status rather than their RA alone (13), and (2) are temporal, as late matures can achieve the same or even higher performance than their early maturing peers once maturational processes become equalized (6, 14).

Among the task-related factors, the specific demands of each playing position may influence the selection of players with different RA. It has been suggested that the distribution of players across field positions could also be shaped by the RAEs, as coaches may tend to prefer more physically mature athletes for positions that require specific physical skills (4, 5, 15). However, the impact of RA on field position assignment remains a subject of debate, as no conclusive evidence has been found to support differences in RA across various playing positions, or which specific positions are more influenced by the RAEs (4, 15, 16).

The competitive level may be considered another task-related factor influencing RAEs, as the demands of the sport itself can vary depending on the level of competition, increasing the physical, technical, and tactical requirements placed on athletes as the competitive tier or performance category rises. The magnitude of the RAEs can be considerably higher in sports with high physical demands, particularly at the national or Olympic levels, where selection pressure tends to increase the prevalence of this phenomenon (17, 18). Moreover, previous research suggests that this effect is more prominent in higher-level teams, where selection pressure and performance demands are greater, and it tends to be smaller or non-existent in lower-level teams (16, 17, 19, 20). In football specifically, players born in the first quartiles of the year (Q1) are more likely to be selected for higher-level teams compared to those born in later quartiles (Q4), as observed in multiple population-based studies conducted internationally (21–23). However, it seems that the impact of RAEs tends to diminish as players progress to higher age categories, particularly during the transition to senior levels (24). While the RAEs significantly influence short-term performance in youth and junior categories, it often reverses in senior categories, due to factors such as the maturation of athletes, which equalizes the physical and anthropometric advantages of relatively older players; the increasing importance of technical, tactical, strategic, and psychological skills over physical attributes in advanced competition; and the resilience developed by relatively younger players who overcome RAEs-related challenges (6, 24). This phenomenon aligns with the underdog effect, which posits that relatively younger or late-maturing players develop superior psychological and technical skills due to the greater challenges they face during their development (6).

Thirdly, environmental factors such as the age category or coaches' expectations regarding their players' performance may also influence the RAEs. The age category is an environmental factor influencing RAEs, as it represents an externally imposed structure that organizes athletes by age, shaping opportunities for participation, selection, and development within the sport system.

It is this structure, which groups young football players into one-year cohorts, that generates the differences in RA mentioned earlier. On the other hand, the role of social agents, such as coaches and parents, has also been identified as an environmental factor reinforcing the RAEs, as they tend to mistakenly associate physical maturity with superior athletic skills. This phenomenon has been partially explained by the Matthew Effect, the Pygmalion Effect, and the Galatea Effect, where expectations and beliefs influence athletes' performance and opportunities (10, 25). In this context, coaches' efficacy expectations have been studied as a mechanism that can consolidate the competitive advantage of players born in the first months of the year or with greater physical maturity, thereby increasing their chances of reaching higher competitive levels. From this perspective, coaches have shown higher efficacy expectations for players born in the early months of the year, even when the maturity status was controlled (10). This suggests that coaches' beliefs may partly contribute to making the RAEs more pronounced and persistent, as they may provide more opportunities to players with higher RA due to a perceived expectation of greater performance (25, 26).

The aim of this study was to analyse the impact of RAEs in a representative sample of young football players (U12, U14, and U16 categories) by examining how environmental factors (e.g., age category or coaches' expectations), task-related factors (e.g., competitive level or field position distribution) and individual factors (e.g., the player's maturity status) influence its manifestation. Additionally, the study aimed to assess the relationship between RAEs and specific physical performance metrics (e.g., speed, endurance, and strength) to quantify how RAEs may affect athletic capabilities. This comprehensive approach seeks to enhance the understanding of the mechanisms underlying RAEs and its implications for talent identification and development in youth football, providing evidence to support equitable sports policies and foster balanced development opportunities for young athletes.

2 Materials and methods

2.1 Participants

This study utilized data collected over the past 10 years (2014–2024) on various factors potentially associated with the RAEs in young male Spanish football players within the U12 (11.59 ± 0.58 years), U14 (13.27 ± 0.61 years), and U16 (15.16 ± 0.58 years) categories, representing different teams from five youth football academies. Each age category consists of two one-year cohorts. Players within the same age category can be classified as "first-year" (1st) players (the youngest within the category) or "second-year" (2nd) players (the oldest within the category). This categorization structure allows competition between players spanning two age groups. To appreciate the contextual factors, data collected for this study included individual constraints [e.g., maturity status, by the *maturity offset* (−0.22 ± 1.44 years from/to the PHV)], task-related constraints (e.g., field position distribution), and environmental constraints (e.g., competitive level and coaches' efficacy expectations). A total of 1,120 young football players aged 11–16 years, recruited from different teams and academies, were included in the study. Descriptive data for the sample are provided in Table 1. All players, along with their parents or legal guardians, signed an informed consent form detailing the study's purpose, in accordance with the Declaration of Helsinki.

2.2 Procedures

To gain a broader understanding of how various factors influence the RAEs in a large sample of young football players, data were collected over a 10-year period (2014–2024) as part of academies regular testing procedures. In light of this, these data were gathered at different periods throughout the season and analysed using a cross-sectional study design. Due to methodological changes in data collection within these academies, the variables gathered each year may have varied. The most commonly collected variables included the players' RA and maturity status (100% of the cases), competitive level (70%), playing position (90%), and physical performance (60%–90%), as well as the coaches' efficacy expectations (60%–80%) regarding their players.

2.2.1 Relative age

The designated "cut-off" date used to organize young football players into 1-year age categories [i.e., U12(1st)] varies by country; in Spain, this date is set for January 1st. To examine RAEs, players were classified into four birth-month quartiles: Q1 (January to March), Q2 (April to June), Q3 (July to September), and Q4 (October to December). In this system, Q1 includes players with the oldest RA in their category, while Q4 includes the youngest.

2.2.2 Maturity status

Anthropometrical data (body weight and height, leg length and sitting height) was measured using a digital body composition monitor (Tanita Bc 601 Ltd., Japan ± 0.1 kg) and a fixed stadiometer (SECA Ltd., Germany ± 0.1 cm). The decimal age (1) was obtained as:

(1) Decimal Age = (Date of valuation—Date of birth)/365,25

Each player's maturity status was determined by estimating the years from/to Peak Height Velocity (PHV) (2), using the formula by Mirwald et al. (27):

(2) Maturity Offset (boys) = −9.236 + [0.0002708 * (Leg length * Sitting height)] + [0.001663 * (Chronological age * Leg length)] + [0.007216 * (Chronological age * Sitting height)] + [0.02292 * (Weight/Height * 100)]

Estimating the number of years before or after PHV (27) is the most widely used approach to assess somatic maturation in the sports field, with over 1,000 citations of this method from 2002–2023 (28). PHV marks a key period of accelerated growth

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TABLE 1 Descriptive data for the participants.

Variable	U12 (1st)		U12 (2nd)		U14 (1st)		U14 (2nd)		U16 (1st)		U16 (2nd)	
	n	M ± SD	*n*	M ± SD	*n*	M ± SD	*n*	M ± SD	*n*	M ± SD	*n*	M ± SD
Height (cm)	40	143.88 ± 4.94	110	147.16 ± 7.29	261	156.40 ± 7.84	275	163.09 ± 8.46	263	169.64 ± 7.87	166	171.83 ± 7.15
Weight (kg)	40	37.67 ± 6.39	110	41.77 ± 6.73	261	47.39 ± 7.92	275	53.52 ± 9.38	263	61.40 ± 9.11	166	66.10 ± 7.95
1RM (kg)	*nd*	*nd*	*nd*	*nd*	85	59.41 ± 16.15	73	72.22 ± 17.59	51	101.22 ± 20. 03	3	102.00 ± 27.51
PPO (W·kg^{-1})	*nd*	*nd*	*nd*	*nd*	85	584.50 ± 178.05	73	728.11 ± 247.60	51	1,030.57 ± 269.122	3	1,097.17 ± 533.04
CMJ (cm)	40	27.32 ± 4.25	109	28.09 ± 4.72	87	28.88 ± 4.91	98	30.85 ± 5.65	109	33.48 ± 4.72	114	36.33 ± 5.02
30-m sprint (s)	26	5.18 ± 0.19	85	5.23 ± 0.34	205	4.91 ± 0.31	229	4.75 ± 0.32	231	4.51 ± 0.26	127	4.41 ± 0.20
T-test (s)	26	10.18 ± 0.44	85	10.03 ± 0.67	172	9.41 ± 0.56	169	9.13 ± 0.66	157	8.86 ± 0.53	98	8.73 ± 0.45
EVO2max (ml·kg·min^{-1})	40	43.81 ± 2.56	95	42.74 ± 2.75	135	44.96 ± 2.97	155	45.38 ± 3.30	160	47.23 ± 3.98	116	48.48 ± 5.15

1RM, one repetition maximum; PPO, peak power output; CMJ, counter movement jump; EVO2max, estimated maximal oxygen uptake; and, No Data.

in stature during adolescence, generally occurring around age 14 in boys and 12 in girls.

2.2.2.1 Competitive level

In Spain, there are three competitive levels (CL) for the U14 and U16 age categories, with CL 1 representing the highest level and CL 3 the lowest. For the U12 category, due to the players' young age, no competitive levels are established to avoid creating a promotion/relegation system that could negatively impact the behavioural or psychological development of young players at such an early stage. Of the sample included in the study, 12% of the players belonged to CL1, 44% to CL2, and 44% to CL3.

2.2.3 Field position

Various scientific publications have categorized football players by playing position, using different specific roles or categories. However, because teams may use varying tactical systems (which involve different on-field positions) and because younger age categories tend to involve less specialization in specific roles, this study categorized players based on their field line position: goalkeepers (GK); defenders (DEF), including central and lateral defenders; midfielders (MF), including defensive and offensive central midfielders, and midfielders playing near the flanks; and forwards (FOR), including central forwards, second strikers, and wingers.

2.2.4 Physical performance

Maximal Strength: Maximal strength was assessed through a half-squat one-repetition maximum (1RM) estimation by analyzing movement velocity using a linear encoder (T-Force System, Ergotech, Murcia, Spain) with a 3RM load, and with high validity and reliability ($R^2 = 0.98$; CV = 0.3%) (29).

Power: To assess lower-limb power, the estimation of peak power output (PPO) was conducted. Players performed three half-squats at maximal speed using 60% of their one-repetition maximum (1RM) load. Participants were verbally encouraged to exert maximum effort to ensure they achieved the highest possible movement velocity.

Linear Speed: Players completed two trials of a 30-meter linear sprint, starting from a stationary position, with times recorded at the 5-meter and 30-meter marks using photoelectric cells (Witty System, Microgate, Bolzano, Italy). Players were encouraged to sprint at their maximum speed. The best attempt (lower time) was recorded for further analysis.

Change of Direction: Players performed two trials of a modified *T*-test (30) which incorporated only forward movements to better align with common football actions and omitting the "touching the cone" requirement (31). Completion time for the *T*-test was recorded using a single start-stop photoelectric cell (Witty System, Microgate, Bolzano, Italy) placed at the point where the test starts and finishes. Players were instructed to run at maximal velocity, and the fastest trial was selected for subsequent analysis.

Jump Capacity: Players performed two trials of the Countermovement Jump test (CMJ) keeping the hands on the hips throughout the test (32). Jump height was measured using a

contact platform (Globus Ergotester®, Italy), with the highest jump recorded for subsequent analysis.

Aerobic Endurance: Maximal oxygen uptake (VO_{2max}) was estimated using an intermittent endurance test (30–15 IFT) (33), chosen for its higher specificity to the physical demands of the sport. This estimation was calculated using the following formula (3):

(3) Esimated $VO_{2max} = 28.3 - (2.15 \times \text{Gender}) - (0.741 \times \text{Age}) - (0.0357 \times \text{Weight}) + (0.0586 \times \text{Age} \times \text{vIFT}) + (1.03 \times \text{vIFT})$

The validity and reliability of this method for estimating aerobic capacity using the 30–15 IFT test have been widely demonstrated and have been proposed as appropriate and extremely useful for team sports (34).

2.2.5 Coaches' efficacy expectations

To assess coaches' efficacy expectations, coaches were asked to rate their confidence in each player's capability to perform specific physical performance tests, adhering to Bandura's (35) guidelines and employing the same questionnaire utilized in Peña-González et al. (10). The questionnaire was always administered to the coaches immediately prior to the assessment of the players. An example question presented to the coaches was: "Indicate your level of confidence in your player's performance on an indirect Repetition Maximum test for the squat exercise, a test designed to assess maximal strength in the squat movement," thereby capturing the coach's expectations regarding the player's performance on this specific test (10, 35). Additionally, coaches were asked to evaluate their confidence in each player's overall football-playing ability. This single item, referred to as Football Performance Expectations (FP-Exp), assesses the coaches' confidence in their players' comprehensive performance, encompassing physical, technical, and tactical skills. Literature supports the use of single-item measures to evaluate both individual and collective efficacy in performance contexts (36). Each item was rated on a Likert scale from 1 ("no confidence") to 5 ("maximum confidence"). Previous research by Peña-González et al. (10) identified a single factor among items related to physical performance tests, with a Cronbach's alpha of 0.87, indicating good internal reliability. This factor, termed Physical Performance Expectations (PP-Exp), is similarly applied in the present study.

2.3 Statistical analisys

The RAEs, as well as the comparison of physical performance and efficacy expectations among players from different Q, was presented by one-year cohorts [e.g., U12(1st), U12(2nd)]. In contrast, the distribution by competitive levels and specific field positions was shown by age categories (U12, U14, and U16), following the structure of competition at these ages. A Chi-square test (χ^2) was employed to assess a potential skew in the distribution of players among Q by age categories, CLs, and field positions. The relationship between players' chronological age and maturity status was assessed using a simple linear regression analysis for each age category, where both variables were expressed as continuous variables in decimal format. Pearson's correlation coefficient (r) was included to report the relationship between age and maturity status and it was interpreted as: trivial (<0.09), small (0.10–0.29), moderate (0.30–0.49), high (0.50–0.69), very high (0.70–0.89) and almost perfect (>0.90) (37). The coefficient of determination (R^2) of the linear regression was also included to show the common variance between age and maturity status. A one-way analysis of variance (ANOVA) was conducted to examine differences in physical performance and coaches' efficacy expectations across birth quartiles for each age category. Where significant differences were identified, *post-hoc* Bonferroni tests were applied to assess pairwise comparisons. To complement these analyses, effect sizes (ES) between Q1 and Q4 players were calculated using Hedges' g (38), with interpretation as follows: $g > 0.8$ (large effect), 0.5–0.8 (moderate effect), 0.2–0.5 (small effect), and <0.2 (trivial effect). All statistical analyses were performed using custom spreadsheets developed in Microsoft Excel (Microsoft, Seattle, USA) and JASP software (version 0.13, JASP, Amsterdam, Netherlands). Data were analysed with a threshold for statistical significance set at $p < .05$.

3 Results

3.1 Environmental factors: RA distribution across age categories and coaches' efficacy expectations

The χ^2 test revealed a skewed distribution of players born in different Q of the year across the three age categories (Figure 1).

No systematic differences were found in coaches' efficacy expectations for players from different birth quartiles in the U12 category (Table 2). Significant differences were found among Q in PP-Exp (favouring early born players) in U14(1st) and U16(1st), while differences in FP-Exp were found in U14(2nd).

3.2 Task-related factors: competitive levels and field positions

The χ^2 analysis showed an even greater participation of players born in Q1 and a lower participation of those born in Q4 at the highest competitive level (CL1) (Table 3), using the general distribution of players by birth Q in each age category —already shown to be skewed in favour of Q1 (Figure 1)—as the expected distribution. In CL3, the skewness in birth Q distribution was reduced, though not significantly. Furthermore, there was no consistent increase or decrease in the RAEs by specific positions compared to the initially skewed distribution by category used as the expected distribution, except for the GK position (Table 4). For GKs, a reduction in the RAEs was observed in U12, with a decrease

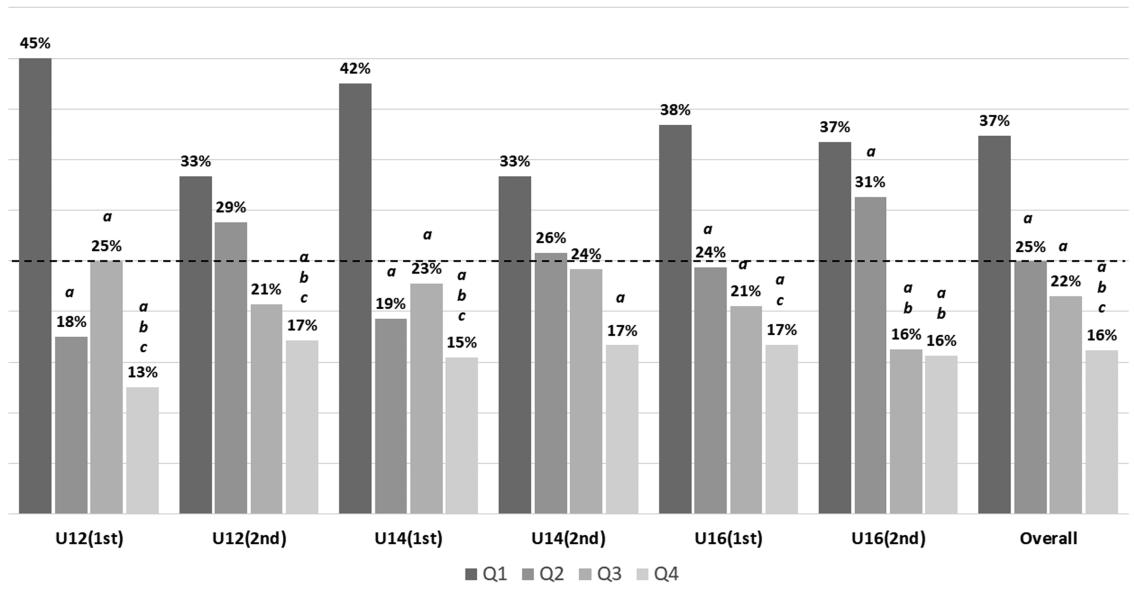


FIGURE 1
Player's distribution across birth quartiles for each age category and the overall sample. [a]Significant difference with Q1; [b]Significant difference with Q2; [c]Significant difference with Q3. 25% expected distribution.

in the percentage of players from Q1 (−6.3%) and an increase in players from Q4 (12.7%), as well as in U14, where an increase in Q4 players was noted (7.5%). This trend did not appear significant in U16 or across the total sample.

3.3 Individual factors: maturity status and physical performance

Pearson's correlation and linear regression analyses showed a significant relationship between age and maturity status for the U12 ($r = 0.34$ and 0.39; $R^2 = 0.11$ and 0.09; $p = 0.03$ and <0.01, for the 1st and 2nd year of this category, respectively), U14 ($r = 0.48$ and 0.39; $u^2 = 0.23$ and 0.15; $p < 0.01$) and U16 categories ($r = 0.52$ and 0.44; $R^2 = 0.27$ and 0.19; $p < 0.01$), as well as for the overall sample ($r = 0.91$; $R^2 = 0.84$; $p < 0.01$) (Figure 2).

The ANOVA revealed no differences in weight, height, or physical performance variables between players from different quartiles in the U12 category (Table 5). Some differences in anthropometric and physical performance variables between players from different Q in U14 and U16 categories are shown in Table 4. Q1 players were taller in U14 (1st and 2nd) and heavier in U14(1st). Q1 players in U14 were also faster in the 30-m sprint and *T*-test both in 1st and 2nd ages, while they had better results in 1RM, PPO and CMJ only in the U14(2nd). For the U16 category, differences among Q were shown for height and *T*-test in the 1st age of the category, while for weight and 30-m sprint in the 2nd age.

4 Discussion

The aim of this study was to analyse the impact of RAEs in a representative sample of young football players in the U12, U14, and U16 categories, considering how environmental factors (e.g., age category or coaches' expectations), task-related factors (e.g., competitive level or field positions) and individual factors (e.g., the player's maturity status) influence the manifestation of RAEs. The findings of this study corroborate the prevalence of the RAEs across youth soccer categories, with significant implications for player development and talent identification. Our results align with existing literature, which demonstrates that players born earlier in the competitive year (typically those in Q1) tend to be overrepresented in youth football (39), particularly in higher competitive levels but without higher prevalence in particular positions on the field.

4.1 Environmental factors: age categories and coaches' efficacy expectations

Upon reviewing previous research, the findings regarding which age categories exhibit a more pronounced RAEs remain inconclusive. While it has been argued that this effect may increase during adolescence due to its interaction with maturity status, there is no unified criterion in the literature to establish that certain age categories are more susceptible to the RAEs than others (40). In this study, although we do not

TABLE 2 Coaches' efficacy expectations of U12, U14 and U16 football players across the 4 birth quartiles (Q1, Q2, Q3 and Q4).

Variable	Q1	Q2	Q3	Q4	F (*p*)	ES (Q1-Q4)
U12 (1st)						
CMJ-Exp	3.72 ± 0.75	3.57 ± 0.54	3.50 ± 0.53	3.20 ± 0.84	0.83 (0.49)	0.65 (−0.36; 1.66)
30-m-Exp	3.94 ± 0.80	3.57 ± 0.79	3.80 ± 0.92	3.20 ± 0.84	1.17 (0.34)	0.88 (−0.14; 1.91)
T-test-Exp	3.72 ± 0.90	3.86 ± 0.90	3.70 ± 0.95	3.20 ± 0.84	0.58 (0.64)	0.56 (−0.44; 1.57)
EVO_{2max}-Exp	3.83 ± 0.86	3.86 ± 1.07	4.00 ± 1.05	3.20 ± 1.10	0.78 (0.51)	0.67 (−0.34; 1.68)
PP-Exp	3.81 ± 0.73	3.71 ± 0.73	3.75 ± 0.73	3.20 ± 0.82	0.91 (0.45)	0.79 (−0.23; 1.80)
FP-Exp	4.44 ± 0.86	4.29 ± 0.95	4.30 ± 0.68	4.40 ± 0.55	0.11 (0.96)	0.05 (−0.94, 1.04)
U12 (2nd)						
CMJ-Exp	3.71 ± 0.93	3.70 ± 0.70	3.47 ± 0.96	3.63 ± 1.07	0.33 (0.80)	0.08 (−0.48; 0.64)
30-m-Exp	3.86 ± 0.88	3.67 ± 0.76	3.53 ± 1.02	3.32 ± 1.16	1.51 (0.22)	0.54 (−0.03, 1.11)
T-test-Exp	3.80 ± 0.90	3.63 ± 0.77	3.58 ± 0.96	3.53 ± 0.96	0.50 (0.69)	0.36 (−0.20; 0.92)
EVO_{2max}-Exp	3.69 ± 1.11	3.50 ± 0.90	3.42 ± 1.07	3.47 ± 1.12	0.35 (0.79)	0.19 (−0.37; 0.75)
PP-Exp	3.76 ± 0.83	3.63 ± 0.69	3.50 ± 0.89	3.49 ± 0.99	0.64 (0.59)	0.30 (−0.26; 0.86)
FP-Exp	3.66 ± 0.91	3.70 ± 0.75	3.47 ± 1.02	3.58 ± 1.12	0.26 (0.85)	0.08 (−0.48; 0.64)
U14 (1st)						
1RM-Exp	3.79 ± 0.86	3.19 ± 0.87	3.29 ± 1.01	3.25 ± 0.70	2.39 (0.08)	0.64 (−0.16; 1.43)
PPO-Exp	3.90 ± 0.82	3.14 ± 0.73[a]	3.29 ± 1.01	3.38 ± 0.52	4.04 (0.01)*	0.66 (−0.14; 1.46)
CMJ-Exp	3.95 ± 0.88	3.40 ± 0.83	4.00 ± 0.82	3.33 ± 1.21	2.31 (0.08)	0.65 (0.07; 1.23)
30-m-Exp	3.80 ± 0.88	3.56 ± 1.11	3.38 ± 0.81	3.07 ± 1.07	3.25 (0.02)*	0.79 (0.20; 1.38)
T-test-Exp	3.99 ± 0.87	3.56 ± 0.81	3.50 ± 0.93[a]	3.14 ± 1.03[a]	5.23 (<0.01)*	0.94 (0.06, 1.82)
EVO_{2max}-Exp	3.83 ± 0.93	3.67 ± 0.90	3.79 ± 0.92	3.33 ± 1.21	0.53 (0.67)	0.51 (0–36; 1.37)
PP-Exp	3.88 ± 0.76	3.44 ± 0.75[a]	3.51 ± 0.82	3.21 ± 0.87[a]	4.71 (<0.01)*	0.85 (0.26; 1.44)
FP-Exp	4.15 ± 0.94	3.86 ± 0.80	4.02 ± 0.86	3.79 ± 1.05	1.13 (0.34)	0.37 (−0.21; 0.95)
U14 (2nd)						
1RM-Exp	3.96 ± 1.04	3.56 ± 0.71	3.50 ± 0.79	4.33 ± 0.82	2.19 (0.10)	−0.36 (−1.24; 0.53)
PPO-Exp	4.00 ± 1.02	3.44 ± 0.86	3.67 ± 0.84	4.67 ± 0.82[b]	3.22 (0.03)*	−0.66 (−1.56; 0.24)
CMJ-Exp	3.21 ± 0.79	3.33 ± 1.16	3.82 ± 0.85	3.44 ± 1.03	1.55 (0.21)	−0.25 (−0.92; 0.42)
30-m-Exp	3.85 ± 1.18	3.69 ± 0.95	3.40 ± 1.08	3.59 ± 1.22	1.25 (0.30)	0.22 (−0.29; 0.72)
T-test-Exp	3.89 ± 1.03	3.74 ± 1.02	3.58 ± 1.13	3.55 ± 1.10	0.87 (0.46)	0.32 (−0.19; 0.83)
EVO_{2max}-Exp	3.32 ± 0.89	3.29 ± 1.06	3.96 ± 0.90	3.19 ± 0.83	2.94 (0.04)*	0.15 (−0.52; 0.81)
PP-Exp	3.78 ± 0.97	3.56 ± 0.80	3.62 ± 0.83	3.60 ± 1.05	0.51 (0.68)	0.18 (−0.33; 0.69)
FP-Exp	4.17 ± 0.96	3.67 ± 1.22	4.05 ± 1.04	3.46 ± 0.96	3.23 (0.02)*	0.73 (0.21; 1.25)
U16 (1st)						
CMJ-Exp	3.39 ± 0.89	3.39 ± 1.04	3.73 ± 0.47	2.69 ± 0.86[c]	3.11 (0.03)*	0.78 (0.07; 1.48)
30-m-Exp	3.53 ± 0.90	0.32 ± 0.95	3.30 ± 0.82	2.86 ± 0.86	2.14 (0.10)	0.74 (0.14; 1.35)
T-test-Exp	3.51 ± 0.95	3.44 ± 1.04	3.44 ± 0.51	2.79 ± 0.80[a]	2.55 (0.06)	0.77 (0.17; 1.38)
EVO_{2max}-Exp	3.57 ± 0.99	3.44 ± 1.15	3.73 ± 0.65	2.92 ± 1.04	1.57 (0.21)	0.63 (−0.06; 1.33)
PP-Exp	3.53 ± 0.73	3.48 ± 0.82	3.46 ± 0.44	2.86 ± 0.77[a]	3.46 (0.02)*	0.90 (0.28; 1.51)
FP-Exp	3.65 ± 0.69	3.68 ± 0.99	3.44 ± 0.73	3.07 ± 1.39	1.91 (0.13)	0.65 (0.05; 1.25)
U16 (2nd)						
CMJ-Exp	4.19 ± 0.75	3.75 ± 0.87	3.83 ± 0.75	3.86 ± 0.38	0.92 (0.44)	0.48 (−0.42; 1.38)
30-m-Exp	4.06 ± 0.77	3.42 ± 0.90	3.33 ± 1.03	3.71 ± 0.49	1.94 (0.14)	0.48 (−0.42;1.38)
T-test-Exp	3.88 ± 0.81	3.33 ± 0.99	3.67 ± 0.82	4.00 ± 0.82	1.22 (0.32)	−0.14 (1–03; 0.75)
EVO_{2max}-Exp	3.81 ± 0.91	3.67 ± 0.89	4.00 ± 0.89	3.71 ± 0.49	0.23 (0.88)	0.12 (−0.77; 1.01)
PP-Exp	3.99 ± 0.64	3.54 ± 0.82	3.71 ± 0.83	3.82 ± 0.35	0.98 (0.41)	0.29 (−0.61; 1.18)
FP-Exp	4.13 ± 0.62	4.00 ± 0.85	4.00 ± 0.89	4.00 ± 1.00	0.08 (0.97)	0.17 (−0.72; 1.06)

Q, birth quartile; ES, effect size; Exp, expectations.
[a]Statistically different from Q1.
[b]Statistically different from Q2.
[c]Statistically different from Q3.
*$p < .05$.

statistically analyze differences in the distribution of players across Q between the age categories examined, the observed trend appears to be consistent across all categories. Specifically, we found a clear overrepresentation of players born in Q1 and a notable underrepresentation of those born in Q4.

To further explore the impact of environmental variables on RAEs, we examined the efficacy expectations of coaches, which revealed a tendency to rate relatively older players more favourably in terms of physical performance potential. These expectations may contribute to the amplification of the RAEs in higher-level

TABLE 3 Observed frequencies and increments (in percentage) for each birth quartile (Q) by competitive level (CL), according to the expected distribution.

Competitive level	Q1	Δ	Q2	Δ	Q3	Δ	Q4	Δ
ED_{U14}	**38.3%**		**22.7%**		**22.5%**		**16.4%**	
CL1	41.9%	3.6%	20.9%	−1.8%	27.9%	5.4%	9.3%[a,b,c]	−7.1%
CL2	42.6%	4.3%	26.5%	3.8%	20.0%	−2.5%	11.0%	−5.4%
CL3	35.5%	−2.8%	23.7%	1.0%	21.1%	−1.4%	19.7%	3.3%
ED_{U16}	**37.5%**		**26.6%**		**19.5%**		**16.4%**	
CL1	53.3%	15.8%	30.0%[a]	3.4%	10.0%[a,b]	−9.5%	6.7%[a,b,c]	−9.7%
CL2	48.1%	10.6%	22.6%	−4.0%	18.9%	−0.6%	10.4%[a,b]	−6.0%
CL3	33.3%	−4.2%	24.1%	−2.5%	20.4%	0.9%	22.2%	5.8%
ED_{TOT}	**37.4%**		**24.6%**		**21.9%**		**16.2%**	
CL1	46.6%	9.2%	24.7%	0.1%	20.5%	−1.3%	8.2%[a,b,c]	−8.0%
CL2	44.8%	7.5%	24.9%	0.3%	19.5%	−2.4%	10.7%	−5.4%
CL3	34.6%	−2.7%	23.8%	−0.7%	20.8%	−1.1%	20.8%	4.6%

ED, expected distribution; CL, competitive level.
[a]Statistically different from Q1.
[b]Statistically different from Q2.
[c]Statistically different from Q3.

TABLE 4 Observed frequencies and increments (in percentage) for each birth quartile (Q) by field positions (FP), according to the expected distribution for each category.

Field position	Q1	Δ	Q2	Δ	Q3	Δ	Q4	Δ
ED_{U12}	**34.1%**		**25.1%**		**25.7%**		**15.1%**	
GK	27.8%	−6.3%	33.3%	8.2%	11.1%[a,b]	−14.6%	27.8%[a,b,c]	12.7%
DEF	38.3%	4.2%	25.5%	0.4%	19.2%	−6.5%	17.0%	1.9%
MF	34.2%	0.1%	21.1%	−4.1%	31.6%	5.9%	13.2%	−1.9%
FOR	40.4%	6.3%	25.5%	0.4%	21.3%	−4.4%	12.8%	−2.3%
ED_{U14}	**38.3%**		**22.7%**		**22.5%**		**16.4%**	
GK	40.2%	1.9%	18.5%	−4.2%	17.4%	−5.1%	23.9%[b,c]	7.5%
DEF	34.3%	−4.0%	26.6%	3.9%	23.1%	0.6%	16.1%	−0.3%
MF	42.1%	3.8%	22.4%	−0.3%	24.3%	1.8%	11.2%	−5.2%
FOR	37.7%	−0.6%	23.9%	1.1%	23.1%	0.6%	15.4%	−1.0%
ED_{U16}	**37.5%**		**26.6%**		**19.5%**		**16.4%**	
GK	29.3%	−8.3%	26.8%	0.2%	23.2%	3.7%	20.7%	4.3%
DEF	47.5%	10.0%	22.1%	−4.5%	17.2%	−2.3%	13.1%	−3.3%
MF	34.9%	−2.6%	27.9%	1.3%	25.6%	6.1%	11.6%	−4.8%
FOR	35.0%	−2.6%	31.1%	4.5%	16.5%	−3.0%	17.5%	1.1%
ED_{TOT}	**37.4%**		**24.6%**		**21.9%**		**16.2%**	
GK	34.4%	−3.0%	23.4%	−1.1%	19.3%	−2.6%	22.9%	6.7%
DEF	40.1%	2.7%	24.7%	0.1%	20.2%	−1.7%	15.1%	−1.1%
MF	38.1%	0.7%	24.2%	−0.3%	26.0%	4.1%	11.7%	−4.5%
FOR	37.1%	−0.2%	26.8%	2.2%	20.4%	−1.5%	15.7%	−0.5%

ED, expected distribution; CL, competitive level.
[a]Statistically different from Q1.
[b]Statistically different from Q2.
[c]Statistically different from Q3.

teams, as they likely influence selection decisions and training opportunities. Additionally, our physical performance data supported these claims, showing that relative older players, overrepresented in higher competitive levels, tend to outperformed their counterparts in physical performance tests. However, as Peña-González et al. (20) highlighted, it is necessary to determine whether players with greater RA reach higher CLs due to physical superiority prior to the selection process or if being selected for these more competitive environments leads to improved physical performance. Relatively older players, once selected, may benefit from superior training quality and intensity available at higher levels, suggesting that the RAEs becomes self-reinforcing in competitive contexts as early-born players gain access to better resources and support. To this end, it is worth considering that in this study, players with a higher RA did not exhibit better physical performance outcomes or higher efficacy expectations from coaches in the U12 category, where competitive levels do not exist, and thus, the selection process is less rigorous.

The study's findings on young football coaches' efficacy expectations reveal a nuanced impact of the RAEs on coaches'

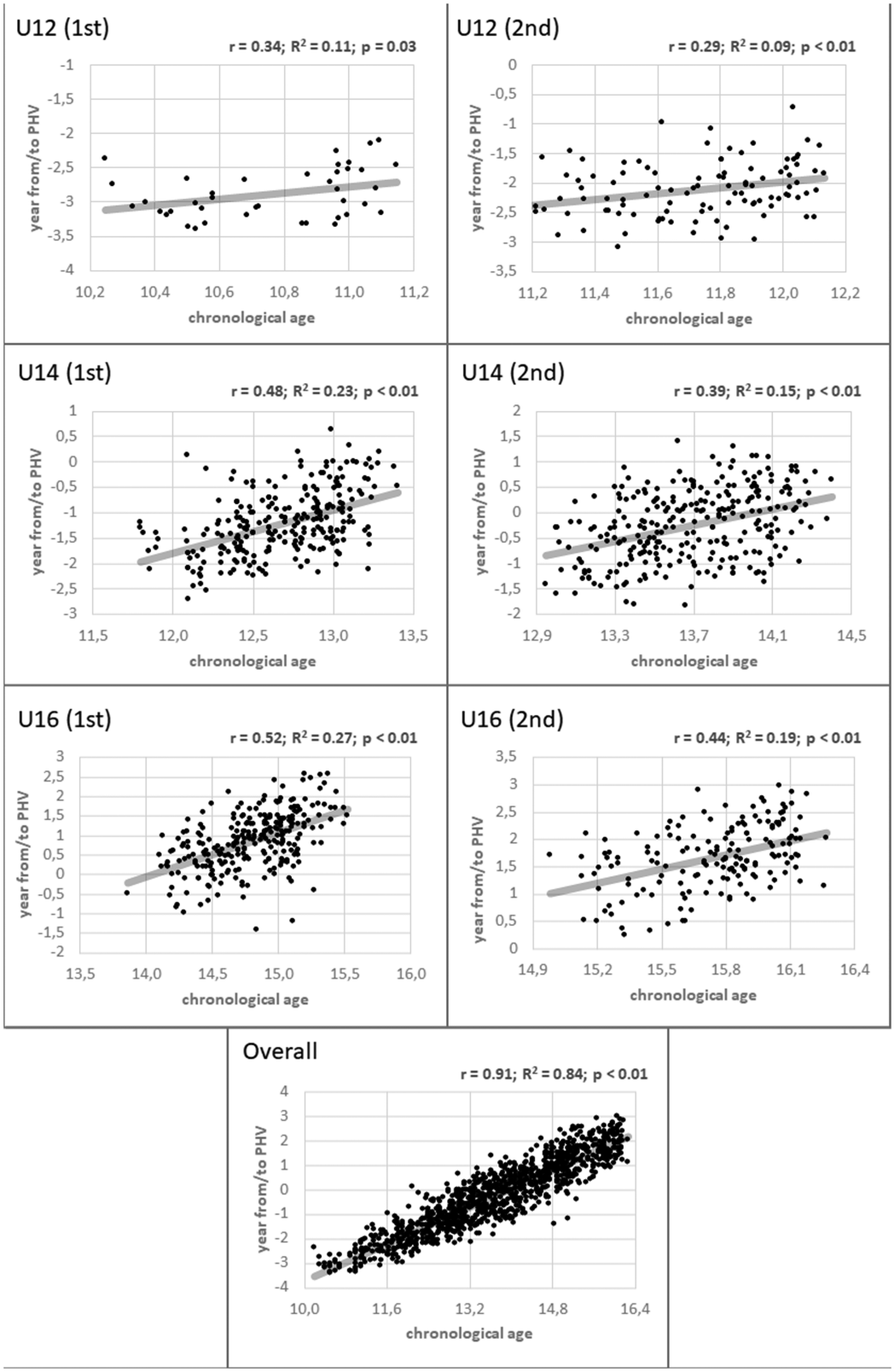


FIGURE 2
Linear regression analysis of chronological age (expressed in decimal age to reflect relative age) and maturity status by age category. *r*: Pearson's correlation coefficient; R^2: Coefficient of determination.

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TABLE 5 Anthropometric and physical performance variables of U12, U14 and U16 football players across the 4 birth quartiles (Q1, Q2, Q3 and Q4).

Variable	Q1	Q2	Q3	Q4	F (*p*)	ES (Q1-Q4)
U12 (1st)						
Height (cm)	145.30 ± 5.99	142.46 ± 3.11	142.02 ± 4.54	144.44 ± 1.72	1.20 (*0.32*)	0.15 (−0.84; 1.14)
Weight (kg)	38.41 ± 7.26	35.99 ± 2.36	35.38 ± 4.27	41.92 ± 9.04	1.46 (*0.24*)	−0.44 (−1.44; 0.56)
CMJ (cm)	27.83 ± 3.67	26.34 ± 4.70	27.75 ± 3.85	26.02 ± 6.87	0.38 (*0.77*)	0.39 (−0.61; 1.39)
30-m sprint (s)	5.16 ± 0.20	5.26 ± 0.20	5.13 ± 0.17	5.25 ± 0.23	0.57 (*0.64*)	−0.42 (−1.67; 0.84)
T-test (s)	10.09 ± 0.38	10.54 ± 0.61	10.14 ± 0.40	10.14 ± 0.55	1.11 (*0.37*)	−0.12 (−1.36; 1.13)
EVO_{2max} (ml·kg·min^{-1})	44.44 ± 2.79	43.96 ± 3.06	43.88 ± 1.39	41.18 ± 1.48	2.35 (*0.09*)	1.21 (0.16; 2.26)
U12 (2nd)						
Height (cm)	148.61 ± 6.27	146.24 ± 8.76	147.06 ± 6.75	145.95 ± 7.24	0.82 (*0.48*)	0.40 (−0.16; 0.95)
Weight (kg)	41.88 ± 5.54	41.54 ± 8.22	40.80 ± 6.10	43.07 ± 7.17	0.41 (*0.75*)	−0.19 (−0.75; 0.36)
CMJ (cm)	28.82 ± 4.75	28.77 ± 4.10	27.92 ± 4.95	25.77 ± 4.88	2.11 (*0.10*)	0.63 (0.06; 1.19)
30-m sprint (s)	5.18 ± 0.31	5.17 ± 0.30	5.28 ± 0.27	5.36 ± 0.45	1.49 (*0.22*)	−0.49 (−1.10; 0.12)
T-test (s)	9.98 ± 0.66	9.93 ± 0.59	9.93 ± 0.72	10.36 ± 0.71	1.69 (*0.18*)	−0.55 (−1.17; 0.06)
EVO_{2max} (ml·kg·min^{-1})	43.04 ± 2.98	42.87 ± 1.88	42.39 ± 2.74	42.44 ± 3.41	0.33 (*0.81*)	0.19 (−0.41; 0.78)
U14 (1st)						
Height (cm)	159.28 ± 7.62	154.81 ± 7.21[a]	154.93 ± 7.43[a]	153.35 ± 7.69[a]	8.87 (*<0.01*)*	0.77 (0.39; 1.14)
Weight (kg)	49.56 ± 7.99	46.79 ± 8.15	46.12 ± 6.89[a]	44.55 ± 7.84[a]	5.17 (*<0.01*)*	0.62 (0.25; 1.00)
1RM (kg)	62.37 ± 17.42	59.29 ± 16.58	56.20 ± 12.17	55.33 ± 18.13	0.84 (*0.48*)	0.39 (−0.34; 1.13)
PPO (W·kg^{-1})	603.62 ± 172.51	566.64 ± 189.83	591.80 ± 175.94	535.62 ± 193.67	0.43 (*0.73*)	0.38 (−0.36; 1.11)
CMJ (cm)	29.57 ± 5.49	29.50 ± 4.19	28.09 ± 3.74	26.18 ± 4.90	1.46 (*0.23*)	0.62 (−0.11; 1.35)
30-m sprint (s)	4.81 ± 0.29	4.89 ± 0.28	5.00 ± 0.27[a]	5.03 ± 0.37[a]	6.37 (*<0.01*)*	−0.69 (−1.12; −0.26)
T-test (s)	9.30 ± 0.53	9.35 ± 0.51	9.55 ± 0.53	9.68 ± 0.73[a]	3.58 (*0.02*)*	−0.66 (−1.18; −0.14)
EVO_{2max} (ml·kg·min^{-1})	44.97 ± 2.92	45.18 ± 3.69	44.89 ± 2.94	44.83 ± 2.68	0.06 (*0.98*)	0.05 (−0.42; 0.52)
U14 (2nd)						
Height (cm)	165.04 ± 8.85	162.99 ± 8.57	161.41 ± 7.55	161.53 ± 8.03	3.09 (*0.03*)*	0.40 (0.05; 0.75)
Weight (kg)	54.88 ± 9.19	53.10 ± 9.70	52.30 ± 8.87	53.05 ± 9.86	1.09 (*0.35*)	0.19 (−0.16; 0.54)
1RM (kg)	74.48 ± 19.90	73.68 ± 14.72	66.37 ± 13.68	75. 17 ± 24.57	0.96 (*0.96*)	−0.03 (−0.91; 0.85)
PPO (W·kg^{-1})	797.66 ± 253.52	665.34 ± 261.77	638.05 ± 141.88	876.85 ± 321.94	2.94 (*0.04*)*	−0.29 (−1.17; 0.59)
CMJ (cm)	32.63 ± 4.99	31.04 ± 5.64	31.25 ± 6.33	27.52 ± 4.46[a]	3.15 (*0.03*)*	1.05 (0.40; 1.70)
30-m sprint (s)	4.65 ± 0.30	4.77 ± 0.29	4.77 ± 0.31	4.88 ± 0.37[a]	5.13 (*<0.01*)*	−0.70 (−1.10; −0.30)
T-test (s)	8.93 ± 0.55	9.08 ± 0.65	9.17 ± 0.59	9.62 ± 0.82[a,b,c]	6.73 (*<0.01*)*	−1.06 (−1.57; −0.55)
EVO_{2max} (ml·kg·min^{-1})	46.24 ± 3.24	45.27 ± 3.00	44.67 ± 3.24	44.91 ± 3.78	1.87 (*0.14*)	0.38 (−0.09; 0.85)
U16 (1st)						
Height (cm)	171.95 ± 7.65	168.58 ± 7.49[a]	168.84 ± 7.66	166.86 ± 7.99[a]	5.58 (*<0.01*)*	0.65 (0.29; 1.01)
Weight (kg)	62.70 ± 8.67	61.04 ± 9.33	60.65 ± 9.10	59.83 ± 9.68	1.27 (*0.28*)	0.32 (−0.04; 0.67)
CMJ (cm)	33.60 ± 4.20	33.92 ± 4.89	34.14 ± 6.19	31.97 ± 4.33	0.84 (*0.47*)	0.38 (−0.16; 0.92)
30-m sprint (s)	4.48 ± 0.22	4.51 ± 0.26	4.49 ± 0.28	4.59 ± 0.28	1.94 (*0.12*)	−0.45 (−0.83; −0.07)
T-test (s)	8.70 ± 0.52	8.92 ± 0.47	8.84 ± 0.50	9.37 ± 0.38[a,b,c]	9.94 (*<0.01*)*	−1.34 (−1.87; −0.81)
EVO_{2max} (ml·kg·min^{-1})	47.59 ± 4.45	47.56 ± 3.80	47.25 ± 3.34	46.21 ± 3.93	0.99 (*0.40*)	0.32 (−0.11; 0.75)
U16 (2nd)						
Height (cm)	173.13 ± 6.54	171.59 ± 7.16	171.63 ± 9.54	169.49 ± 5.04	1.65 (*0.18*)	0.59 (0.12; 1.05)
Weight (kg)	67.36 ± 8.06	67.06 ± 8.05	65.37 ± 7.85	61.95 ± 6.40[a,b]	3.34 (*0.02*)*	0.70 (0.23; 1.17)
CMJ (cm)	37.89 ± 4.70	35.40 ± 5.31	36.30 ± 5.56	35.11 ± 4.23	2.13 (*0.10*)	0.61 (0.08; 1.13)
30-m sprint (s)	4.35 ± 0.17	4.42 ± 0.24	4.48 ± 0.16	4.49 ± 0.19	3.36 (*0.02*)*	−0.79 (−1.35; −0.23)
T-test (s)	8.62 ± 0.42	8.89 ± 0.47	8.67 ± 0.46	8.78 ± 0.39	2.15 (*0.10*)	−0.38 (−0.97; 0.21)
EVO_{2max} (ml·kg·min^{-1})	49.31 ± 4.77	48.99 ± 5.92	47.30 ± 4.58	46.05 ± 4.61	2.02 (*0.12*)	0.68 (0.09; 1.27)

Q, birth quartile; ES, effect size.
[a]Statistically different from Q1.
[b]Statistically different from Q2.
[c]Statistically different from Q3.
*$p < .05$.

perceptions of player abilities, particularly in the U14 and U16 age categories, where the selection process becomes more pronounced due to the implementation of different competitive levels. In alignment with previous research by Peña-González et al. (10), it was found that coaches tend to have higher expectations for relatively older players, reflecting a bias favouring those born earlier in the selection year (10), further amplifying the RAEs. Such biases may stem from the perception that relatively older players possess more advanced physical or cognitive maturity, even when actual performance differences are minimal (41). This

is consistent with Hancock et al.'s (26) theoretical framework, which suggests that the Pygmalion effect—the tendency for coaches' expectations to shape athlete performance—can reinforce RAEs by amplifying the advantages of early-born players through differential treatment and support (25). Coaches often interpret physical maturity as an indicator of superior potential, impacting their selection choices and leading to preferential treatment of early-born players. Our findings reinforce this notion, as the significant differences in coaches' efficacy expectations between Q1 and Q4 players in specific physical tests, particularly in the U14 category, suggest that these perceptions play a critical role in the selection and advancement of early-born athletes, often at the expense of their younger peers. This is especially relevant in the U14 category, as it marks the beginning of a more rigorous selection process due to the introduction of different competitive levels and the emergence of the greatest physical differences, as players are around the PHV stage. Moreover, this raises a broader concern regarding talent development: youth football coaches should not only consider the age group to which players belong but also their relative age when setting expectations and assessing talent. A key question is whether coaches evaluate relatively younger players based on expectations aligned with their own stage of development or in comparison to their relatively older peers within the same age category. Given that these biases can influence training opportunities and long-term development trajectories, coach education programs should emphasize the importance of assessing players based on their individual maturation patterns rather than solely on their chronological age. Addressing these biases through structured awareness and intervention strategies could foster a more inclusive approach to talent identification, where players' potential is evaluated independently of RA, as advocated by previous research aiming to support equitable youth sports development.

4.2 Task-related factors: competitive level and field positions

In addition to the overrepresentation of relatively older players, our study suggests that the RAEs is influenced by the competitive level in which young players participate, as higher-level teams consistently showed a more prevalent RAEs. This supports Romann et al. (17), who found that selection pressures in youth football tend to reinforce the RAEs, with a preference for athletes who demonstrate early physical and cognitive advantages, often perceived as indicators of talent (17). Expanding on our findings, the stronger RAEs observed in higher-level teams aligns with Peña-González et al. (20), who report a clear preference for young players born in the first half of the year, with early-born players making up 80.6% of high-level teams compared to only 58.5% in teams at the lowest competitive level (20). This pattern suggests that selection pressure in more competitive leagues amplifies the RAEs, likely due to coaches' inclination to associate physical and cognitive maturity with performance potential, which favours relatively older players. Findings from Götze and Hoppe (19) further reinforce this relationship, showing that RAEs is markedly more pronounced in higher leagues, especially in elite male teams, where competition intensity is greatest (19). This evidence underscores how selection pressures in top-tier competitions intensify the RAEs, further consolidating the advantages of early-born athletes in elite contexts. This supports prior research by Gutierrez Diaz Del Campo et al. (16), which demonstrated that heightened competition increases the RAEs, further favouring early-born players (16). Additionally, Peña-González et al. (20) found that while significant physical performance differences existed between competitive levels, they were not attributed solely to RA. Instead, players from higher levels outperformed those from lower levels in strength, speed, and agility tests, independent of RAEs factors. These findings suggest that the advantage of early-born players in higher levels may be reinforced by greater training quality and intensity rather than by innate physical advantages alone. Consequently, as early-born players receive superior training resources and coaching support, the RAEs becomes self-reinforcing in competitive contexts.

This study also examined the distribution of players across field positions, revealing non-significant differences in birth quartile distribution across positions compared to the expected distribution within each category, except for a reduction in RAEs among goalkeepers in the younger U12 and U14 categories. Although it has been hypothesized that certain field positions may require specific physical attributes, potentially favouring the selection of relatively older players (5), prior studies have shown no consistent RAEs differences across positions (16). However, our findings of a diminished RAEs in goalkeepers align with prior research, which often reports a less pronounced RAEs in the goalkeeper position compared to others, such as defender or forward, where older players tend to be overrepresented (42, 43). For example, Figueiredo et al. (42) observed a minimal or absent RAEs in goalkeepers within various age categories of elite Brazilian players, and similarly, Pérez-González et al. (43) found a significant RAEs in goalkeepers in only one out of four international U19 tournaments. Peña-González et al. (20) also reported a significant RAEs across all field positions (>67%) except goalkeeper (47%) when comparing halves of the birth year. These combined findings suggest that, while RAEs generally influences player selection in all field positions, the goalkeeper role may be less impacted by RA advantages, likely due to lower physical maturation demands relative to other positions (20). Similarly, the study by Romann and Fuchslocher (18) on young Swiss football players identified a stronger RAEs in defensive positions and a relatively lower effect among goalkeepers. This finding supports the hypothesis that, in positions requiring specific physical attributes, coaches may be predisposed to select relatively older players (18). It suggests that the physical development of defensive players enables them to fulfil roles demanding immediate physical performance, whereas goalkeepers—particularly at younger ages—can succeed without the same physical advantages, thereby reducing the RA bias in this position (18).

4.3 Individual factors: maturity status and physical performance

The findings of this study provide valuable insights into the interaction between maturation and the RAEs in youth football, while also underscoring their independence as constructs operating at distinct stages of the developmental process. The Pearson's correlation and linear regression analyses revealed a strong relationship between player's age and maturity status, particularly in the U14 and U16 categories. However, it is crucial to highlight that RAEs and maturity status, although correlated, are not interchangeable concepts. In this regard, these results are consistent with previous studies suggesting that RA advantages often align with advanced maturity status, potentially providing early-born players with additional physical and cognitive benefits that increase their likelihood of selection in competitive youth sports (1). Nevertheless, cases exist where relatively younger players demonstrate advanced maturation or relatively older players are less biologically mature than their peers (6). These distinctions underscore the complexity of the relationship between RAEs and maturity status and highlight the need to view them as interrelated but distinct factors influencing athlete development. It is important to note that differences in physical performance between players with varying RAs are not solely due to birth timing but are primarily linked to differences in the maturity status among them (12). Thus, players with a lower RA who exhibit advanced maturation also have a greater likelihood of selection (44), although this phenomenon is less common. Studies that control for the effect of maturity on performance outcomes have shown that when maturation impact is adjusted, the differences between players of different RA disappear (9, 10). This reinforces the idea that maturity status is a crucial factor in shaping selection and development opportunities for young athletes, more than just the RA (11, 12). This is particularly interesting in the process of talent identification and selection, where, despite a strong relationship between player's age and maturity status ($r = 0.91$; $R^2 = 0.84$), identifying outliers—cases where age and maturity status are not aligned (players with different chronological and biological ages)—may represent future success stories. By implementing training programs tailored to their maturation rather than their chronological age, these players can be effectively developed.

Differences in physical performance were observed between Q1 and Q4 players in the U14 and U16 categories. As previously suggested, these differences could be linked to the more advanced maturation of players in Q1. The greatest differences in physical performance among players with different RAs are observed in the U14 category, around the age at PHV, and where presumably larger disparities exist between players with advanced maturity status and their peers with later maturation (13, 45). Additionally, differences in speed-related variables (i.e., sprint or change of direction speed tests) are evident in the first year of the U14 category, while differences in variables related to strength among players of different quartiles emerge in the second year of this category [U14(2nd)]. This aligns with previous literature, which highlights greater increases in speed prior to PHV and more significant gains in strength once PHV is reached or surpassed, typically around the age of 14 (45–47). The findings of this study also support certain long-term development models based on maturation status, such as the YPDM (47), which emphasizes that different physical qualities develop at varying rates throughout maturation, with neural and mechanical factors playing a key role in the enhancement of speed and strength. These findings also emphasize the importance of considering the maturity status in talent identification and development processes, as relatively younger and late-maturing players may be overlooked despite their potential. Integrating maturity assessments into youth football selection could help mitigate the impact of the RAEs, promoting a fairer and more comprehensive approach to player development.

The study is not without limitations. The selected sample for this study comes from various research projects, with data collected at different points in time over the past 10 years. To mitigate this potential limitation, all assessments were conducted by the same research team using consistent materials and procedures. However, this temporal variability may still introduce inconsistencies in the data due to potential changes in selection practices and developmental trends within youth football. Additionally, a potential limitation is the possibility that some players may appear more than once in the dataset, given the longitudinal data collection over 10 years. Nevertheless, the high variability of clubs and academies involved reduces the likelihood of duplicate players, and any potential overlap does not affect the cross-sectional nature of the analyses, which treat each data point as an independent representation of the player at a specific stage of their development. Another consideration is that Tables 3, 4 present information by competitive categories, which include two-year selection groups (e.g., U14 1st and 2nd year). This could imply a loss of information by not displaying the data according to single-year categories. Although competitive categories allow players from both birth years to compete together, clubs and academies often structure their teams with players from a single birth year [e.g., only 14(1st) players competing at the highest competitive level and 14(2nd) players competing at the lower level]. Therefore, if the analysis were conducted by birth year instead of by full competitive category, it would reveal the absence of players of a specific age in certain competitive levels. The estimation of PHV in this study was conducted using the original formula by Mirwald et al. (27). While this may represent a limitation of the study, as newer formulas and corrections (e.g., Moore's correction to the Mirwald equation) have been developed in recent years (48), some of the data analyzed were collected several years ago, at a time when PHV was commonly estimated using Mirwald's formula, which was the most widely used method at that time. Regarding coaches' efficacy expectations, another limitation is that only the efficacy expectations of each coach for their own players were assessed. This means that variations in individual coaches' perceptions could lead to differences in evaluations between teams. This limitation is somewhat mitigated by including only qualified coaches with over five years of experience in youth football. Additionally, given that our sample was specific to Spanish youth

football, results may differ in other cultural contexts or sports systems with varying selection pressures and competitive structures.

In terms of practical implications, addressing the RAEs require a multi-faceted approach, as recommended by Romann et al. (17). Strategies such as adjusting selection procedures, implementing birth-date banding or bio-banding, and delaying age-based competition until post-maturation could help balance developmental opportunities (49, 50). Additionally, fostering the inclusion of teams composed solely of players born in the second half of the year or late-maturing players—as parallel teams to higher-level competitive teams within the academy—could provide appropriate training stimuli tailored to their characteristics, rather than leading to early dropout from the sport. This approach could increase participation of these players in the short term, thereby acutely reducing the RAEs, while also offering the potential to identify future talent once growth and maturation processes have levelled among players. By emphasizing long-term athlete development over early success, sports organizations can foster a more equitable environment, allowing late-born athletes and those with delayed maturation to realize their potential without the disadvantage posed by early selection biases. Furthermore, considering the previously mentioned underdog hypothesis and the long-term benefits that relatively younger individuals may develop, it is worth exploring whether players should be challenged by training and competing with older individuals as part of their development. A more flexible and dynamic youth development pathway, in which players have opportunities to train and compete across various age groups, could be beneficial for all athletes.

Our study confirms that RAEs remain a significant factor in youth football, particularly within competitive structures that favor early physical and cognitive advantages. By analyzing a representative sample across different age categories (U12, U14, and U16) recruited over a 10-year period, our findings provide a comprehensive perspective on how environmental (age category, coaches' expectations), task-related (competitive level, field position), and individual (maturity status, physical performance) factors contribute to RAEs. The consistent overrepresentation of early-born players, especially in higher competitive levels, highlights that selection processes continue to favor those with early physical advantages, reinforcing systemic biases in talent identification. Coaches' expectations further amplify this effect, as they often perceive relatively older players as having greater potential, influencing their selection and development opportunities. However, our study reinforces that RAEs and maturity status, though related, are distinct constructs, emphasizing the need for talent identification models that prioritize biological rather than chronological age. Educating coaches to recognize and address these biases is also crucial in fostering a more inclusive talent development framework that prioritizes long-term potential over short-term success.

Data availability statement

The data supporting this research will be available upon request via email to the corresponding author from the time of publication and for the following three years, provided that a reasonable justification.

Ethics statement

The studies involving humans were approved by Oficina de Investigación Responsable (Miguel Hernández University). 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

IP-G: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. GF-J: Data curation, Formal Analysis, Investigation, Resources, Writing – original draft. IC-G: Data curation, Formal Analysis, Investigation, Resources, Writing – original draft. MM-R: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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A survival analysis of dropout among French swimmers

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This study examines the dropout rates among French swimmers based on performance levels, sex, and relative age. Using data from 160,861 swimmers under the age of 21, we analyzed the distribution of birth quarters and dropout rates across performance levels. Chi-squared tests were conducted to confirm the significant effect of birth quarter on performance. Kaplan–Meier Survival (KMS) curves were used to evaluate and interpret the impact of sex and relative age on dropout trends. The results show that dropout peaks occur at 13.16 years for girls and 17.50 years for boys. Analyzing by age year, at 13 years, the top 10% of female swimmers exhibit a dropout rate of 8.7% (9.9% for males), while the bottom 10% show a much higher rate of 78.1% (69.3% for males). By 17 years, the dropout rate rises to 39.6% (28.6% for males) for the top 10% and 91.7% (83.4% for males) for the bottom 10%. KMS curves, stratified by age, reveal similar dropout trends for both sexes below the age of 13. However, after this age, the dropout rate increases more sharply among females, reaching a maximum difference of 4.8% at 17.9 years. Disparities in dropout rates based on birth quarters are most pronounced at 12.7 years for girls (10%) and at 14.7 years for boys (8.1%). This study underscores the significant influence of sex, relative age, and performance level on dropout rates among French swimmers. Higher performance levels are associated with lower dropout rates, and female swimmers display consistently higher dropout rates than their male counterparts.

KEYWORDS

dropout, swimming, youth sports, talent identification, Kaplan–Meier analysis, athlete retention

Introduction

Dropout in youth sports is defined as the termination of participation in a specific sport, without necessarily ceasing participation in all sports (1). It represents a critical challenge in the development of young athletes, with wide-reaching implications for both the individual and the broader sports ecosystem. Dropout is often linked to factors such as loss of interest, boredom, attraction to other activities, conflicts with coaches, injury frequency, stagnation in performance, and a lack of enjoyment (2, 3). Conversely, sustained participation is frequently associated with positive parental support, intrinsic satisfaction from the sport, and rewards derived from success (3). However, excessive pressure during adolescence can lead to disengagement (4), further complicating the

retention dynamics in youth sports. While these general factors have been widely documented, the interplay of sex, performance level, and the Relative Age Effect (RAE) in explaining dropout patterns remains underexplored, particularly in the context of competitive swimming.

The concept of RAE has been widely studied in team sports, revealing an overrepresentation of athletes born early in the selection year due to developmental advantages (1). However, its impact on individual sports like swimming remains underexplored, particularly in the context of dropout. This study addresses this gap by analyzing dropout rates among French swimmers with respect to sex, performance level, and birth quarters. Investigating these factors is crucial, as dropout trends differ significantly between boys and girls, often peaking during puberty (5), and are influenced by performance pressures and relative age disadvantages.

The present study is grounded in three key hypotheses to address this gap. First, we hypothesize that dropout rates will differ between male and female swimmers, with female athletes experiencing higher dropout rates at an earlier age. This hypothesis is supported by prior studies highlighting gender disparities in youth sports participation, as well as the unique pressures often faced by female athletes during adolescence. Second, we anticipate that RAE, a phenomenon in which athletes born earlier in the selection year gain a relative advantage in physical and cognitive maturity compared to their peers born later, will play a role in dropout patterns. Specifically, swimmers born in the first quarters of the year are expected to have lower dropout rates than those born in later quarters, as the advantages conferred by RAE have been shown to impact both performance and selection in youth sports. Finally, performance level is hypothesized to significantly influence dropout rates, with higher-performing swimmers—those in the top deciles of performance—being more likely to persist compared to lower-performing swimmers. This aligns with previous findings suggesting that success in competition fosters continued engagement, creating a virtuous cycle of commitment and achievement.

While several studies have examined dropout rates in youth sports, most rely on descriptive statistics rather than more robust methods such as survival analyses. Kaplan–Meier Survival (KMS) analyses and Cox regression models, traditionally used in medical research, offer a powerful framework for investigating dropout rates. These methods account for censored data, enabling a more nuanced understanding of persistence over time. For example, in a study of Flemish gymnasts, only 17.6% of athletes remained in the high-performance pathway for more than five years, with an average survival time of 2.5 years (6). Similarly, survival analyses applied to Canadian female soccer players revealed that only 23.3% persisted over a seven-year period, with disparities in survival times based on birth quarters (7). Such findings underscore the utility of survival analyses in identifying dropout patterns across various sports.

The concept of RAE adds another layer of complexity to youth sports retention. RAE, which reflects the advantage of being relatively older within an age group, has been shown to influence performance and participation in a wide range of sports. For instance, Canadian female soccer players born in the first quarter of the year demonstrated longer survival times in the sport compared to those born later in the year (7). However, the extent to which RAE influences dropout varies by sport and context. In swimming, RAE has been shown to impact young French swimmers regardless of sex or competitive level (8). This suggests that while RAE is a relevant factor, its interaction with other variables, such as performance level and sex, warrants further investigation.

Swimming provides a unique context to study dropout and RAE because it is both highly competitive and performance-oriented, with objective and standardized metrics for success. Prior research among Australian swimmers identified factors such as age, level of competition, and proximity to urban centers as significant predictors of dropout, whereas sex and relative age appeared less influential (1). However, no study to date has examined dropout in French swimmers using an integrative approach that simultaneously considers sex, RAE, and performance level. The present study seeks to fill this gap by investigating dropout patterns among French male and female swimmers, with a particular focus on the 50 m freestyle event—the most widely contested swimming event. By examining the interplay of sex, performance levels, and birth quarters, this study aims to provide novel insights into the mechanisms underlying dropout in swimming. Understanding these dynamics is essential for identifying at-risk athletes and developing targeted interventions for coaches, policymakers, and sports federations to foster long-term engagement in the sport.

Materials & methods

Data collection

The database from the French Swimming Federation provides all French participation in all types of competitions (local to international) from 2002–2020 in all individual events (50 m, 100 m, 200 m, 400 m, 800 m, 1,500 m Freestyle, 50 m, 100 m, 200 m Breaststroke, Backstroke and Butterfly). For each swimmer, birthdate, performance time and competition are available. All performances took place in 50-meter pools, which is the official Olympic standard length. Only swimmers who started competition before the age of 18 and competed at least two seasons were considered. Swimmers (50.8% females) were divided into age categories. According to the French Swimming Federation, the female age categories are as follows: Kids: under 10 years old, Youth: between 11 and 13 years old, Junior: between 14 and 16 years old, Senior: over 17 years old. For males, the age categories are shifted up by one year. At each age, swimmers are divided into performance decile, according to their best performance. A performance decile is a method of dividing a ranked dataset into ten equal parts, with Decile 1 representing the top 10% of swimmers (highest performance) and Decile 10 the bottom 10% (lowest performance). Indeed, for our analysis Decile 1 includes the top 10% of swimmers (highest performance), Decile 2 represents the 10%–20% performance

range, Decile 3 covers the 20%–30% range, and so on, ending with Decile 10, which includes the bottom 10% of swimmers (lowest performance). This classification provides a consistent and comparable metric for assessing swimmers' relative performance each year, independent of competition levels or age groups. By using deciles, we can intuitively analyze trends, such as how dropout rates vary across performance levels, allowing us to compare top-performing and bottom-performing swimmers without being limited to specific events or competitions.

Relative age effect

The distribution of the birth quarters (Q1: January–March, Q2: April–June, Q3: July–September, Q4: October–December) was calculated for each decile. Chi-square tests was run for each age category to identify significant differences of birth quarters between performance deciles.

Dropout

Dropout was defined as swimmers disappearing from the database before age 21 or being absent for at least two consecutive seasons before 21. The starting age was the swimmer's first recorded competition. Dropout rates were analyzed by performance decile, event, and sex, using linear regression to test the relationship between decile and dropout rate. The analysis ended in 2020 to avoid the confounding effects of the COVID-19 pandemic, which disrupted sports participation. A two-year absence threshold was chosen to account for temporary absences, such as injuries, ensuring that only permanent dropout was identified. Swimmers competing continuously until 21 or with interruptions of less than two years were not classified as dropouts. We measure the dropout proportion for each performance decile, event and sex. The dropout rate "r" at age "t" will be expressed as a function of the membership of performance decile D at age t-1. At each age, we perform a linear regression between the dropout rate and decile:

$$r = a*D + b$$

We perform a Student test to test the hypothesis that the coefficient "a", representing the additional percentage per decile, is different from 0 at threshold 0.05.

Survival analysis

To study the evolution of the onset of dropout according to sex and birth quarter, KMS curves were estimated. This method was particularly adopted here as it allows to deal with swimmers who started swimming at different times in their life, considering starting age. In this study, KMS curves were plotted according to relative age in order to compare athletes at a similar stage of their career. Kaplan Meier estimates were computed to determine differences in terms of dropout between birth quarter for each sex. To assess the significance of the results, log-rank tests were performed for each considered groups. This test checks whether KMS curves are significantly different from each other.

Results

160 861 athletes who started swimming before the age of 18 are included in this study (49.2% male). Among those who are at least 21 years old and have been practicing for at least two seasons, 79.1% of male and 87.2% of female have dropped out of swimming. Regardless of the age at which the performances are carried out, girls drop out the most at 13 and boys at 17. When we look at the ratio of these frequencies to the population of the age concerned, the dropout rate is higher at 17 for both girls and boys.

The distribution of swimmers by birth quarters within each performance decile is shown in Figure 1 for the 50 m Freestyle male and female event in the 50 m pool at 13 and 17 years old. The birth quarter distribution between Q1 and Q4 for all other events is shown in Supplementary Table S1 in Supplementary File. Swimmers with at least one performance time at 13 and who are more than 15 years old at the last recorded competition are considered here (similarly for 17 years old swimmers, only those with at least one performance time who are older than 19 are included). By conducting a chi-square significance test on all events, females support a significant effect from birth quarter on performance decile from 13–18 years of age (and from 13–19 years of age for males, except in breaststroke; p-value < 0.05).

At age 13 in decile 1, 40.3% of female swimmers are born in Q1 vs. 12.4% in Q4 (Figure 1A), while 47.3% of males are born in Q1 vs. 8.7% in Q4, (Figure 1C). The proportion of Q1 decreases significantly and the proportion of Q4 increases significantly as performance level decreases, from decile 1 to decile 10.

At age 17, the difference is smaller but still present: 29.6% of females belonging to decile 1 are born in Q1 vs. 20.5% in Q4, (Figure 1B) while 34.0% of males are born in Q1 vs. 14.1% in Q4 (Figure 1D).

The evolution of the dropout rate by performance decile for the female and male 50 m Freestyle is presented in Figure 2. Chi-squared tests highlight the significant effect of the performance decile at age t on dropout at $t+1$ in both sexes from age 8 onwards. The dropout rate increases significantly with performance decile. The dropout rates at ages 14 and 18 according to performance deciles 1 and 10 at ages 13 and 17 respectively are presented in Supplementary Table S2 in Supplementary File.

The KMS curves according to sex are presented in Figure 3. 74,922 males and 80,170 females started swimming at 8 years or later. The KMS curves are similar before the age of 14; then, the difference between the two curves becomes significant from the age of 15 onwards (log-rank test: p-value < 0.005): females drop out significantly more than males. The greatest difference

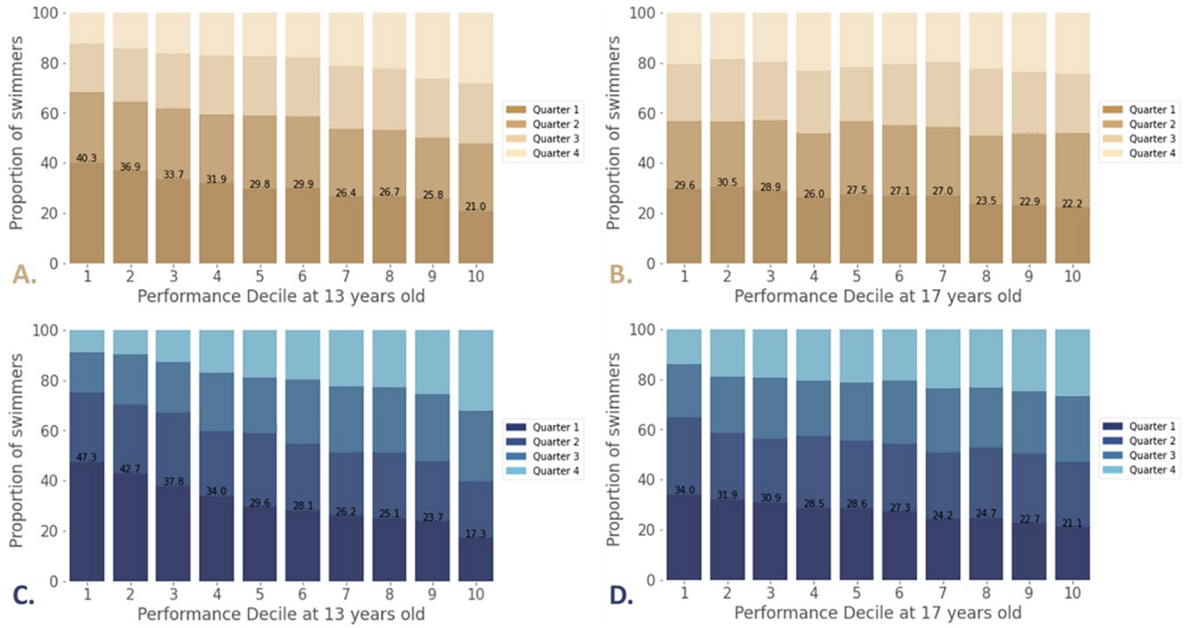


FIGURE 1
Distribution by birth quarter and performance decile of swimmers at 13 (A) and 17 (B) years old in the female 50 m freestyle and of swimmers at 13 (C) and 17 (D) years old in the male 50 m freestyle.

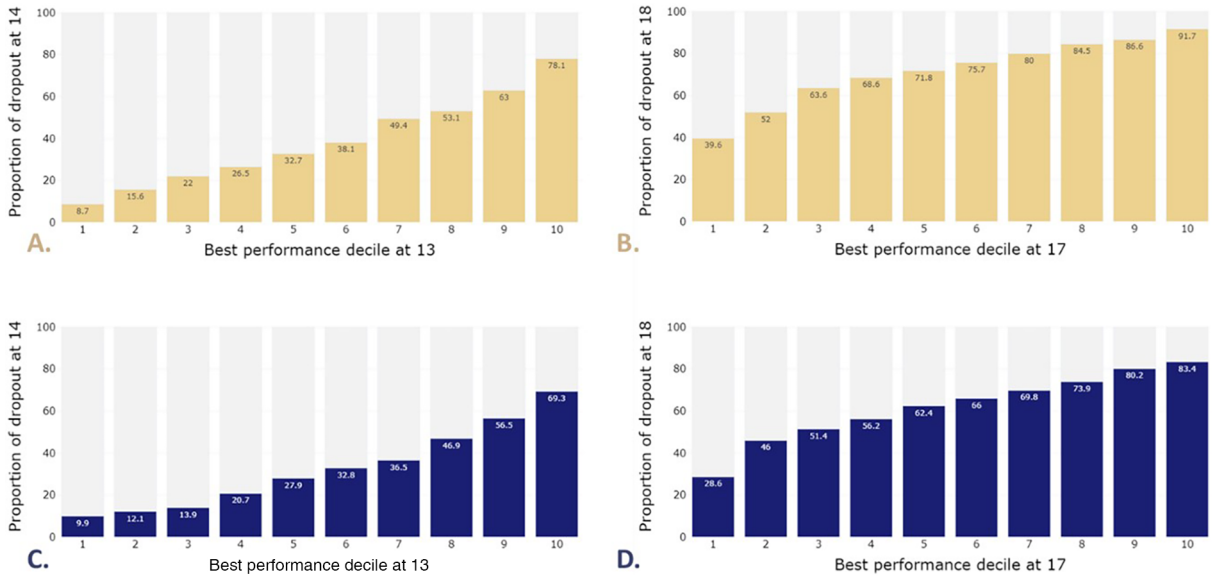


FIGURE 2
Dropout rate at age 14 based on performance deciles at age 13 in the female (A) and male (C) 50 m freestyle in the 50 m Olympic swimming pool. Dropout rate at age 18 based on performance deciles at age 17 in the female (B) and male (D) 50 m Freestyle in the Olympic swimming pool (50 m).

between both sexes occurs at 17.89 years, where females are 4.8% more likely to drop out than males.

The KMS curve for quarter 1 is always above that of the other quarters from age 10 onwards for females (log-rank test: p-value < 0.005, Figure 4A) and from age 13 onwards for males (log-rank test: p-value < 0.005, Figure 4C), while the KMS curve for quarter 4 is always below that of the other quarters. Focusing only on the difference between the quarter 1 and quarter 4, the largest observed difference between the two corresponding KMS curves occurs at 12.71 years old with a 10% difference (Figure 4B) and at 14.67 years old with 8.1% (Figure 4D).

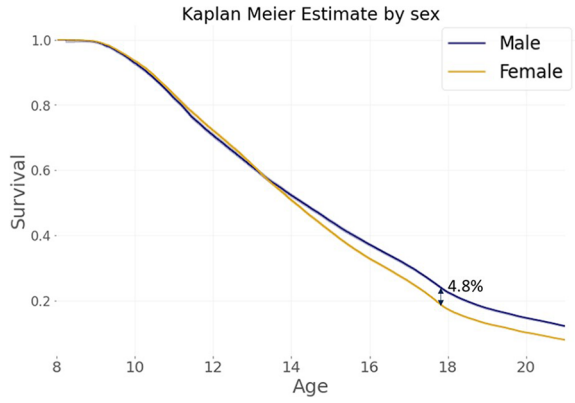


FIGURE 3
KMS curves by sex.

Discussion

This study highlights the impact of sex, birth quarter and performance level on dropout rates for all swimming events among 8–21 years old swimmers. It shows that the dropout rate increases when the level of performance decreases. The Kaplan Meier survival curves show a similar evolution of dropout rates for girls and boys until the age of 13, after which girls tend to drop out significantly more than boys, who face a peak in dropout around the age of 17.

Dropout and birth quarter

A relative age effect is found within the performance deciles, particularly at age 13, for both girls and boys, in accordance with previous study (9). In the top performance decile, the proportion of swimmers born in the first quarter of the year is consistently higher than the proportion born in the last quarter (3). Taking the top 10% of a sample of Australian swimmers (equivalent to our performance decile 1), at ages 13, 14, 15 and 16, the proportion born in Q1 is 56%, 42.9%, 50% and 36.4%, while that born in Q4 is 4%, 8.9%, 8.3% and 14.5% respectively. At 13, 14 and 15, the authors identify a large effect size and a medium one at 16 years of age. Difernand et al. (9) also highlight a relative age effect accentuated by the level of performance in French 50 m Freestyle swimmers. In a study (4), reveal a similar trend in 12–15-year-old 100 m and 200 m breaststrokers, with more Q1 born swimmers in the top 10% than Q4.

Yet, month of birth is not the only birth-related variable that affects dropout. The place of birth also seems to have an influence (6). Brazilian footballers, who were born in the first

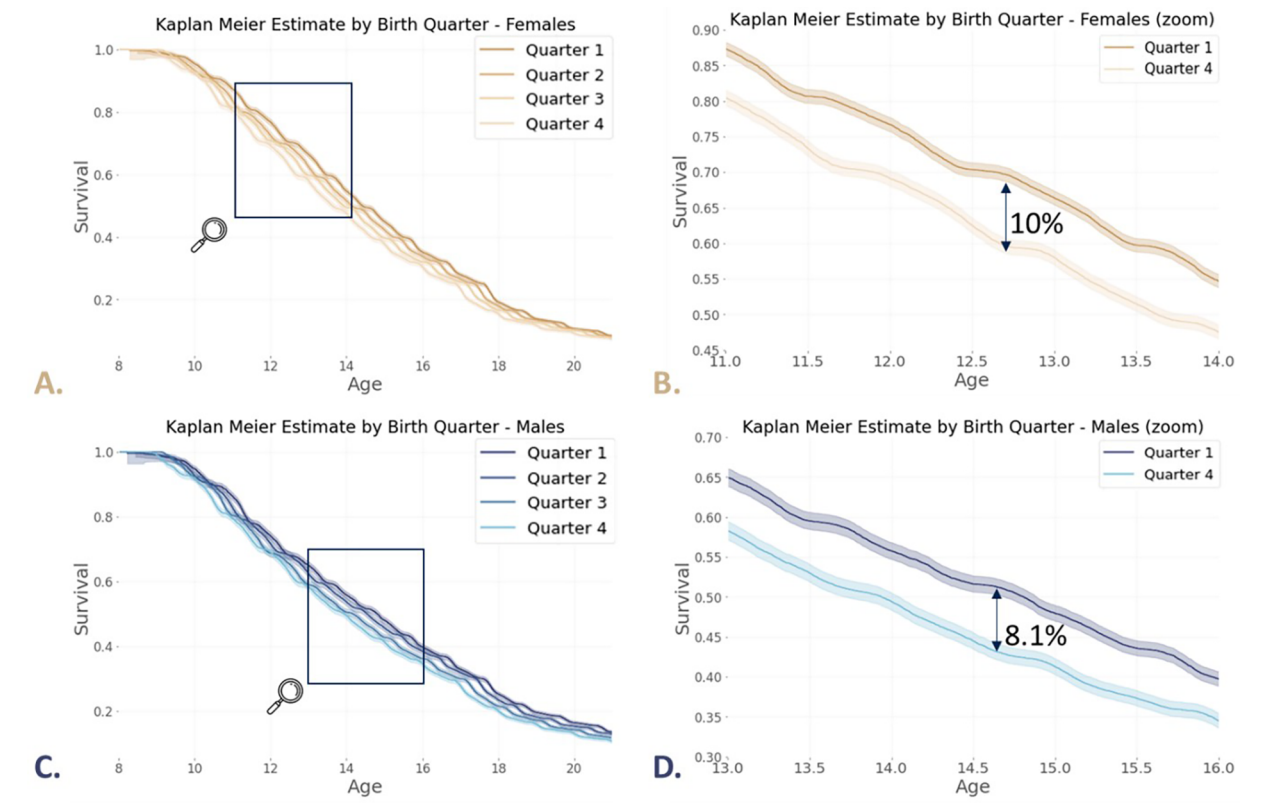


FIGURE 4
(A) KMS curves according to birth quarters for females (B) zoom in on the first and last quarter KMS for females between 11 and 14 years of age (C) KMS curves according to birth quarters for males (D) zoom in on the first and last quarter KMS for males between 13 and 16 years of age.

half of the year in a city with less than 100,000 inhabitants and a human development index (dimensionless composite index between 0 and 1, calculated on the basis of the quality of life of their citizens: health, education, standard of living) above 0.501 are more likely to play in the top teams of the Brazilian football league compared to those whose born in the second semester (6). Good access to health and education facilities may encourage sports participation, especially among young people (6), and human development index may favor the development of sport (7).

Dropout and performance

We find that the dropout rate is lower when performance level increases. It may be due to the coaches paying more attention to the best swimmers of the category, in the quest of future medals. The relationship with the coach and manager and the attention given to young athletes is a determining factor in future success (8). To our knowledge, there is no study yet that has quantified dropout by distinguishing performance levels. However, Rottensteiner (10) and Eystein mentioned stagnation or decline in performance as a major cause of low self-esteem, lack of motivation and dropout (11). Attempting to achieve a higher performance may turn into an obsession and eventually becomes a source of demotivation (11). Lack of success is one of the major factors for withdrawal from sport (12). In addition, the desire to spend more time with friends or practice other activities, with time spent away from sport or school is important (10, 11, 13). In particular, some "dropped-out" swimmers considered competitive swimming as less important than other activities (12), with a high level of burnout within competitive swimming (14). When the return on investment is not as good as hoped for, and the results not as expected, the heavy volume of training and the relationship with the coach tend to be blamed (13). Indeed, swimmers find training intolerable when they are not satisfied with the results.

Dropout age and sex

Our sample of females swimmers present a dropout rate significantly higher than their males' counterparts (87.2% vs. 79.8%), in accordance with previous studies (15). Among the population of French swimmers, females drop out the most at 13 years of age and males at 17, a trend similar to young French footballers (16, 17). This highest probability of dropping out of swimming at age 13 for girls is consistent with the difference in the two survival curves between the first and last quarters, which peaks at 12.71 years. Erlandson et al. (18) investigated growth and maturation in gymnastics, swimming and tennis among 222 athletes, and suggested that puberty could be an explanatory factor. With the menarche, the body changes which may affect negatively the motivation and slow down the sport practice, with the acceptance of a new morphology, the management of menstruations, the appearance of body hair while going to the pool or the difficulty to fit in a swimming suit.

For boys, on the other hand, the maximum dropout difference between the first quarter and the last quarter occurs at 14.61 years of age, almost two years later than for girls. Once again, the connection with the onset of puberty may be questioned. Peak of Height Velocity (PHV), *i.e.,* the time of maximum height growth, generally occurs later in boys (between 13 and 15 years) than in girls (between 11 and 13 years) (19, 20). Also, the fact that the probability of boys dropping out is highest at 17 may be linked to the moment of moving out from high school and therefore to a choice to be made. A study (21) of 169 student athletes in team sports (basketball, baseball, softball, volleyball) and individual sports (tennis, golf, cross country, swimming) revealed that more than half of the students report that it is difficult to match both athletic and academic expectations and that it is not easy to find enough time to study during their sport season.

To our knowledge, the only study using Kaplan Meier survival curves to investigate the dropout of swimmers was conducted by Moulds et al. (22). Among 7,895 female and 6,545 male swimmers, they found that 33% and 35% respectively dropped out after 2 years, while the median time of participation before dropout was 4 years. In a second part of the study, the authors sought to incorporate the notion of competition and considered 758 female swimmers and 603 male swimmers who are involved in competition. Among them, respectively 28% and 35% dropped out after 2 years of practice. The authors revealed that dropout was not associated with sex and birth quarter, unlike in our study. Indeed, by the age of 21, we show that females have significantly dropped out more than males. Other variables are included in the Moulds et al. study, such as socio-economic categories of the swimmer's living area, age category, level of competition, and proximity to a major city. These variables, which are related to the social developmental environment of the young swimmer, are found to be significantly more important and are the strength of this study. Møllerløkken et al. (15), in a meta-analysis showed that girls tend to have a higher dropout rate (26.8%) than boys (21.4%). Vilhjalmsson et al. (23) analyzed the sports habits of more than 3,000 Icelandic 6th, 8th and 10th grade students. They also found a higher dropout rate for girls at 34% and for boys at 29%. Their study showed that girls are less likely to join a sports club and are less physically active. In this study, girls reported practicing physical activity with their mothers or older sisters, while boys preferred practicing sport with their friends.

Strengths & limitations

In swimming, some strokes require a high level of technique and a longer learning time. Swimming a 50 m freestyle is different from swimming a 1,500 m freestyle at 13 years old. Also, the return on investment may be delayed on longer distances, which may explain a higher dropout rate with the event distance. Experience was not taken into account in this study: some swimmers may regularly compete when others

compete only once a year, but this may also be linked to the performance level. Other variables, such as information related to the club, training, school or familial environment, may also be relevant and generate future research. To strengthen the manuscript's impact, we propose actionable recommendations for coaches and policymakers based on our findings. Coaches should implement tailored retention strategies for younger swimmers, focusing on critical dropout ages—around 13 for girls and 17 for boys. Strategies like psychological support, individualized training, and mentorship programs can help sustain motivation and engagement. Policymakers should address the Relative Age Effect (RAE) by restructuring age-group categories or offering development programs for late-born swimmers, fostering inclusivity and long-term retention. Future research should explore interventions to mitigate RAE, investigate psychological and social factors influencing dropout, and analyze how specialization timing or multi-event participation affects retention. These efforts would provide a more holistic understanding of dropout and inform targeted strategies for swimmer retention.

Conclusion

This study highlights the different impacts of sex and performance level on the dropout rate of young French swimmers. Girls drop out more frequently and earlier than boys while dropouts increase when performance level decreases. In that sense, since being highly performing at a young age is not necessarily a factor for success at the senior elite level (24–26), coaches and federation members could use this argument to explain to young athletes that they should not drop out based solely on 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

Our data is provided by the French Swimming Federation. All data are reported anonymously. Data collection complies with the General Data Protection Regulations (RGPD) applied in the European Union. The IRMES scientific committee designed and monitored this study. The ethics panel of CSMF (Conseil Scientifique, Médical et de Formation) from INSEP (Institute National du Sport de l'Expertise et de la Performance) approved the protocol. The Commission Nationale de l'Informatique et des Libertés (governing office supervising data utilization in France, CNIL n° 2223498) approved the use of retrospective data obtained from public sources.

Author contributions

AD: Conceptualization, Formal Analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing, Investigation. AM: Formal Analysis, Methodology, Visualization, Writing – original draft. QD: Methodology, Visualization, Writing – review & editing. RP: Data curation, Project administration, Writing – review & editing. AM: Investigation, Writing – review & editing. KB: Investigation, Writing – review & editing. JA: Methodology, Visualization, Writing – review & editing. J-FT: Supervision, Writing – review & editing. AS: Conceptualization, 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.2025.1509306/full#supplementary-material

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Tell me your date of birth, and I will tell you how good you are in orienteering

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Orienteering is a sport where participants must choose the best route between control points marked on the map, combining it with their displacement capacity. It combines endurance running with mental capacity. As in other sports, age can be a determinant in defining differences among youth runners. In this research, the hypothesis is that older orienteers will show better performance than younger orienteers within the same competitive group, for both girls and boys. Overall, official results of the FEDO (Spanish Federation of Orienteering) in long and middle-distance events, from 2005 to 2023, have been analyzed (sprint format events were excluded). Different categories from ten to twenty years of age for both sexes were included, and each category was divided into two years (1Y, 2Y) and two semesters (1S, 2S) within each year, creating four independent variables from the combination of year and semester (1Y1S, 1Y2S, 2Y1S, and 2Y2S). A total of 7,731 entries were examined, 4,318 were boys and 3,109 were girls. Descriptive statistics were analyzed for each variable, showing the mean and standard deviation. Normal distribution was confirmed for all variables ($p > 0.05$). Results showed a significant performance difference in favor of older orienteers in the youngest categories (U-10, M/F-12, M/F-14, and M-16), with these differences disappearing as age and performance increased (M/F-18 and M/F-20). These findings support the research hypothesis and align with other studies where age-related differences have also been found in other sports.

KEYWORDS

relative age, orienteers, performance, youth, competition, races

Introduction

Orienteering is a sport that involves navigating through unfamiliar terrain using a map and compass to locate specific points in the shortest time possible. Orienteering can take place in various environments such as forests, urban areas or parks, making it a versatile and engaging outdoor activity for people of all ages. Participants must use their navigational skills to choose the best route between control points marked on the map by combining it with their displacement capacity. It combines physical exercise with mental challenges, requiring both physical fitness and strategic thinking.

The popularity and understanding of orienteering have been on the rise globally in recent years, which could potentially influence the emergence of Relative Age Effects (RAEs). Despite the scarcity of comprehensive studies that contribute to the enhancement and peak performance of orienteering athletes, emerging research aims to investigate some of the most crucial aspects of orienteering. For instance, the systematic review by Batista et al. (1) provides an exhaustive overview of studies from recent decades concerning the physiological and cognitive demands of orienteering. Subsequent studies have also focused on evaluating cognitive performance and its correlation with physical performance (2, 3). Others have explored the benefits of orienteering practice in preventing cognitive decline (4), addressed issues related to musculoskeletal injuries and training patterns (5–7), and examined the relationship between various physical abilities, motor coordination skills, and orienteering practice (8, 9). In the realm of nutrition and anthropometry, specific studies are beginning to surface (10). Additionally, investigations into technical errors in orienteering have been conducted (11). Moreover, research on navigation skills (12, 13) and mental rotation skills (14), although not directly specific to orienteering, have significant applicability. These studies underscore gender differences, and one of them (12) even discusses the potential impact of cultural activities (citing the example of orienteering in Nordic countries) on cognitive performance.

However, to identify and clarify the key factors of orienteering performance, the potential predictors of talent, and to determine the best methods of assessment, there is a clear limitation and controversy. Although there are studies, including some very recent ones, they are insufficient, suggesting a need to expand this line of research (15–19). This limitation primarily stems from the nature of orienteering and its conditions during the competition -different terrains, routes, height differences, or the interaction among runners during the race–making the monitorization of the performance a difficult task, with specific field test. Consequently, the results of the competition could be a key factor in tracking the sports talent in orienteering just as it is done in other similarly competitive nature sports (20).

Talent selection processes in orienteering primarily rely on performance in regional and national competitions, where athletes are evaluated for their navigation skills and physical endurance. Additionally, coaches play a crucial role in determining training opportunities, often prioritizing athletes who demonstrate superior performance at an early stage. The number of competitions per season varies, with a structured series of regional and national events allowing athletes to accumulate points and gain deliberate practice (21). Performance in these events often influences future competition levels, as stronger results lead to more advanced participation opportunities. Importantly, orienteering follows a cut-off date of January 1, meaning that athletes born early in the year may have a developmental advantage over those born later.

Accordingly, to form competitive groups within sports organizations, one fundamental criterion commonly employed is the year of birth. While this method is straightforward and often utilized in established systems like education, it poses certain drawbacks for the optimal nurturing of sporting talent. Nonetheless, for a competition to be effective, the performance of orienteers should be compared on an equal basis. An individual born in January is nearly twelve months older than someone born in December of the same year. Consequently, any physical and psychological advantages or disadvantages that may arise could be attributed to this age gap (22). The consequences attributed to those differences have been studied extensively as the Relative Age Effects -RAEs-, being more prominent in younger age groups (23, 24). Additionally, in orienteering, the competitive groups are defined with a range of two years (for children and teenagers) and therefore the aforementioned differences could increase significantly.

Understanding how RAEs influence sports performance requires acknowledging the complexity of identifying factors that contribute to talent development. The process of identifying such factors is inherently multifaceted (25). For instance, first-level influences—such as genetics, training, and physiological factors—play a direct role in shaping talent (26). However, secondary and indirect factors, like the RAE, can also significantly affect the opportunities and developmental pathways of young athletes (27). These secondary influences are particularly relevant in the context of orienteering, where competitive age groupings and environmental conditions may exacerbate disparities.

These consequences can be interpreted as a systematic discrimination and/or unequal opportunities for those individuals born shortly before the cut-off date of the competitive selection year (28). From another perspective, an orienteer might perceive a lack of sporting prowess or ability compared to their peers -within their competitive group- at a particular moment, potentially leading to negative feelings regarding their skills (29). This could result in a misguided belief that they are not achieving the same levels of success as others, diminishing their motivation in sports and increasing the possibilities of dropout (30, 31). As an example of this fact, one could cite scientific literature focusing on Athletics, which indicates that under-18 and under-20 athletes born in the first week of the year are about 2–3.5 times more likely to be included in the top-100 ranking than the athletes born in the last week of the year (28); some authors have investigated this phenomenon, referring to it as the Galatea effect in sport (32). The decisions made by coaches or scouts, as well as the criteria outlined in training programmes, may be influenced by short-term performance, prioritising maturation aspects over the innate potential of the orienteer. This approach can impede the development of long-term sporting talent (33), depriving vulnerable individuals of the deliberate experiences necessary to achieve expert performance (34).

The concept of constituent year effects refers to the impact of an athlete's birth year within a multi-year age category and its influence on competitive outcomes. Unlike the RAE, which examines disparities arising within a single-year age group, constituent year effects focuses on differences that emerge due to an athlete's birth position within a multi-year cohort. Research suggests that athletes born in the earlier years of a multi-year age category may have a competitive advantage over their younger counterparts due to increased physical and cognitive

development during early stages of participation. For instance, studies on elite German youth basketball players indicate that the proportion of athletes per constituent year varies across age categories, with older individuals within the multi-year bands being overrepresented at higher competitive levels (35). Similarly, research on age-group effects in various sports suggests that constituent year effects prevalence can influence both individual development trajectories and overall team performance (36). Additionally, a longitudinal study on French top youth table tennis players found that birth quartiles were significantly associated with performance trajectories, particularly among male athletes under 18, highlighting the long-term impact of early relative age advantages within multi-year competitive structures (37). These findings imply that the structure of age-group classifications in sports can inadvertently benefit athletes born earlier in the designated age bands, potentially creating long-term disparities in skill acquisition, training opportunities, and career progression.

In consequence, it has been observed that RAEs influence coaches' decisions, favouring greater opportunities to add competitive hours (38). This data underscores the notion that older individuals — in the same year — have increased opportunities for skill acquisition within a competitive setting. Moreover, these elevated expectations from coaches or even family members would favour individuals with more advantageous RAEs, a phenomenon known as the Pygmalion effect in sport (32). Thus, the resulting consequences create a feedback loop that perpetuates advantages for those with more beneficial RAEs; this phenomenon is also explored in sports, termed the Matthew Effect (32), which necessitates mitigation from a professional standpoint.

Numerous comprehensive and recent scientific studies have explored the concept of Relative Age Effects (RAEs) in individual sports (39–46). However, when we narrow our focus to orienteering specifically, there is a scarcity of research linking RAEs to this sport. To our knowledge, only one recent study (47) has addressed RAEs in orienteering. Conducted in Sweden, this research presents an intriguing comparative analysis of the impact of RAEs on performance across various sports—Cross-country skiing, Alpine skiing, Athletics, Orienteering, Chess, and E-Sports- It also categorizes participants by age range, but does not consider competitive groups. Another related study (48), although not specific to orienteering and conducted within the context of soccer, associates RAEs with cognitive-attentional functioning. This aspect could be crucial for enhancing performance and identifying talent in orienteering. Despite these contributions, no study to date has demonstrated the relationship between relative age, competitive groupings, and orienteering with a broad sample and rigorous methodology. This gap in the literature sparks interest within the scientific community.

Once a comprehensive overview of the current state of research is provided, further investigation is warranted to ascertain how various variables influence talent development in young orienteers —factors such as age, gender, performance level, and experience—. Therefore, building upon the findings from the literature review mentioned earlier, the initial hypothesis posits that:

Hypothesis (H1). Older orienteers will show better performance than younger orienteers within the same competitive group, both girls and boys.

Materials and methods

A transversal study design was used because this research concerned results from national events in Spain within the different youth categories. Thus, the overall results of the races were analysed. Therefore, the research design was based on an retrospective analysis without interference in the natural context of the events under study. Orienteering has experienced steady growth in Spain, particularly in youth categories, with an increasing number of participants each year. According to FEDO (Spanish Federation of Orienteering) reports, Spain hosts multiple national and regional events annually, with thousands of registered orienteers actively competing across different age groups. Despite being a specialized sport compared to traditional team sports, orienteering has gained recognition as an important discipline in outdoor and endurance sports.

Sample

All data originated from the official results of the FEDO in long and middle distance events from 2005 (the first year in which data is available through electronic control systems) to 2023 were included, that is, 19 seasons. The races in sprint format (urban) were excluded from the analysis.

All the results analysed correspond to races belonging to the national league in young categories, included Under 10 (9–10 years old, boys and girls competing together). The categories or competitive groups included are (M = male, F = female): M/F12 (<12 years old), M/F14 (13–14 years old), M/F16 (15–16 years old), M/F18 (17–18 years old) and M/F20 (19–20 years old). A total of 7,731 entries were examined, 304 were boys and girls in U-10; 4,318 of which were boys and 3,109 were girls (Table 1), representing the whole context analysed (100%). In order to avoid bias in the research the same individual could register different entries for different seasons. However, those orienteers who competed in competition group above their chronological age were excluded from the analysis ($n = 23$). Thus, this registry of the data contributes to a greater understanding of the cases, due to the same orienteer being able to provide data related not only with its first year but also with its second year of the next season. FEDO was informed of the aim of the study and gave its consent for the publication of the data, anonymously, after signing a confidentiality agreement with the University of Alicante.

Procedure

Firstly, we identified both year (1Y or 2Y) within the competitive group and relative age semester (S1 = January–June; S2= July–December) as an independent variable for all the

TABLE 1 Frequency of participation according to sex, competitive group and relative age semester.

Competitive group	Girls (n = 3,109)					Boys (n = 4,318)					U-10 (n = 304)
	F12	F14	F16	F18	F20	M12	M14	M16	M18	M20	
2Y1S	184	289	196	90	62	235	367	285	140	103	103
2Y2S	145	243	181	79	45	199	317	281	129	95	91
1Y1S	140	241	257	148	89	192	333	328	218	140	60
1Y2S	111	209	215	124	61	151	276	291	178	128	50

M/F 12 (< 12 years old), M/F 14 (13–14 years old), M/F 16 (15–16 years old), M/F 18 (17–18 years old) and M/F 20 (19–20 years old); 1Y1S, first year within competitive category and first relative-age semester; 1Y2S, first year in competitive group and second relative-age semester; 2Y1S, second year and first relative-age semester; 2Y2S, second year and semester.

orienteers that participated, in at least one race, in the National Federation League of orienteering in Spain during the past 19 seasons 2005–2023 in the categories indicated above (Table 1). Therefore, four independent variables were used from the combination of the year and the semester: *1Y1S* = First season within competitive category and first relative-age semester; *1Y2S* = First season in competitive group and second relative-age semester; *2Y1S* = Second season and first relative-age semester; *2Y2S* = Second season and semester.

Secondly, the performance indicator—PI—was calculated in all the races. This indicator, used in other sports with the same monitoring and control difficulties (49), is calculated from the results in competition, which are obtained through a chip-timing system that allows to check an overall time for each individual with a high level of precision. PI is expressed from 0 to 100.00 points, with 100.00 being the score for the best time of the race and, therefore, the best performance. The rest of the orienteers' performances were calculated as a proportional part of that mentioned best time [PI = (Best Time × Personal Time^{-1}) × 100]. An exception is set for the results in the Spanish championships, as the score for the best performance increases by 5% (105 points for the best performance).

Finally, a dependent variable was calculated from the PI as the average of all PI achieved by the individual over long and middle distance races during that season.

Statistical analysis

The analysis of the data was carried out using SPSS® by IBM® software which was released in version 28 and with Microsoft Excel® for Mac in its 16.83 version. Descriptive statistics were analysed for each variable, showing the mean and standard deviation. In the different analyses, normality test was applied to the continuous variables (Shapiro–Wilk for $n < 50$ or Kolmogorov–Smirnov for $n > 50$). As a result, a normal distribution was shown for all variables ($p > .05$). In consequence, Anova 1-way and *post-hoc* test was applied. Since the homocedestacity criterion was not met, the statistical test *Games-Howell* was considered. Using Microsoft Excel software, the effect size was calculated (50). The effect size results (ω^2) were classified into small results (0.01–0.06), medium results (>0.06–0.14), and large results (>0.14) (51). The level of significance was established in .05 in all cases except for the correction of Bonferroni ($p < .008$) in the *post-hoc* peer comparison.

Results

First, based on the relative age semester (Table 2), it was observed that for each competitive group, the best results were obtained by both, male and female orienteers born in S1 (January–June). Secondly, as a result, Anova 1-way test results indicated that, based on the performance differences depending on the specific year and semester of birth (Table 2), statistical differences ($p < .001$) were observed in the youngest categories, this is, M-12, M-14 and M-16 (Figure 1) and U-10, F-12 and F-14 (Figure 2).

The Games-Howell statisticians of the *post-hoc* analysis (considering Bonferroni correction to avoid type II error; $p < .0083$) showed differences in favour of the older group (G1 = 2Y1S) compared to the younger group (G4 = 1Y2S) in all competitive groups that showed differences in Anova (U-10, M/F-12, M/F-14 and M-16). Specifically in males, M-14 presented differences among all its competitive groups except for G1 over the second largest (G2 = 2Y2S). Differences were also shown between G1 over the second younger group (G3 = 1Y1S) and G2 Vs. G4, in M-12 (Table 2, *post-hoc*).

Discussion

The main aim of this research was to investigate possible differences in performance among young orienteers in early orienteering, considering both the year of birth and the relative age semester. The most relevant result of this research showed a significant performance difference in favor of older orienteers within the same competitive group in the youngest categories (U-10, M/F-12, M/F-14 and M-16), disappearing these differences as age and performance increases (47, 52). These findings support the research hypothesis put forward in this study (H1 is accepted).

While this investigation focuses on the impact of competitive grouping based on chronological age criteria rather than directly examining RAEs, the findings align with those of other studies where differences have been found in other sports (23, 47, 49). Evidently, both RAEs and competitive grouping, as documented in previous literature (22, 29), play significant roles in shaping the opportunities for athletes to attain the highest levels of sports talent development (32). These authors proposed a socio-psychological framework to understand the broader implications

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TABLE 2 ANOVA-1 way test for performance in orienteering races according to the different groups (average ± standard deviation).

Sex	Competitive group	Older → Younger				F-ANOVA (sig.)	ES (ω^2)	*post-hoc*: Games-Howell (Effect Size, ω^2)							
		G1	G2	G3	G4			1vs2	1vs3 Sig. (ES)	1vs4 Sig. (ES)	2vs3 Sig. (ES)	2vs4 Sig. (ES)	3vs4 Sig. (ES)
Mixed	U-10	64.8 ± 17.2	58.4 ± 19.1	56.8 ± 17.6	52.9 ± 18.6	5,615*	(.044)	—	—	.002 (.043)	—	—	—
Female	F-12	67.3 ± 16.9	62.8 ± 18.0	62.5 ± 15.1	57.6 ± 17.2	7,912*	(.034)	—	—	<.001 (.037)	—	—	—
	F-14	63.9 ± 16.2	60.3 ± 17.1	59.4 ± 17.3	55.4 ± 16.8	10,595*	(.028)	—	—	<.001 (.030)	—	—	—
	F-16	65.4 ± 16.7	65.1 ± 14.4	63.8 ± 15.8	63.0 ± 15.2	1,097	—	—	—	—	—	—	—
	F-18	67.7 ± 17.1	64.2 ± 13.7	66.9 ± 15.9	63.7 ± 14.6	1,737	—	—	—	—	—	—	—
	F-20	69.0 ± 15.7	69.6 ± 15.9	68.0 ± 16.2	66.0 ± 17.4	0,525	—	—	—	—	—	—	—
Male	M-12	66.4 ± 18.8	62.6 ± 18.1	60.7 ± 17.4	55.6 ± 17.7	11,316*	(.038)	—	.008 (.012)	<.001 (.039)	—	.002 (.015)	—
	M-14	62.9 ± 17.2	60.7 ± 15.7	56.7 ± 16.4	52.2 ± 16.4	25,390*	(.054)	—	<.001 (.017)	<.001 (.048)	.008 (.006)	<.001 (.028)	.004 (.008)
	M-16	63.8 ± 16.0	60.5 ± 15.7	59.7 ± 16.3	57.2 ± 14.8	7,992*	(.019)	—	—	<.001 (.020)	—	—	—
	M-18	64.2 ± 15.6	62.3 ± 15.0	65.2 ± 15.2	62.7 ± 14.5	1,355	—	—	—	—	—	—	—
	M-20	70.2 ± 17.8	68.2 ± 16.4	67.6 ± 17.0	65.7 ± 15.2	1,449	—	—	—	—	—	—	—

ES = Effect Size (ω^2); M/F 12 (<12 years old), M/F 14 (13–14 years old), M/F 16 (15–16 years old), M/F 18 (17–18 years old) and M/F 20 (19–20 years old); G1, 2Y1S (second year and first relative-age semester); G2, 2Y2S (second year and second relative-age semester); G3, 1Y1S (first year within competitive category and first relative-age semester); G4, 1Y2S (first year in competitive group and second relative-age semester).
*$p < .001$.

of RAEs, highlighting three interrelated mechanisms: the Pygmalion effect, where greater expectations are placed on relatively older athletes; the Matthew effect, where initial advantages compound over time; and the Galatea effect, where self-perceptions of competence influence performance. These mechanisms suggest that RAEs not only affect physical and technical development but also the social and psychological environment, amplifying disparities between older and younger athletes in the same group. Addressing these underlying mechanisms is crucial to creating equitable talent pathways in orienteering and other sports.

It is true that an athlete who is in his first year (the youngest, 1Y), the following year moves to the second year (2Y), and the cycle gradually balances out from one competitive group to another. However, if the orienteer is born in the second half of the year (and he is under-16 or she is under-14), meaning between July and December, they will consistently encounter significant differences as shown in this study, regardless of gender, thus carrying a heavier burden for their optimal development and potential performance in the future. While statistical differences attributed to competitive grouping were not detected for rest of competitive groups (F-16, M/F-18, M/F-20) in this study, it is noteworthy that, in all categories, 100% of the top performances were achieved by orienteers born in the first semester of the year, as reported in other research (29, 47, 48, 53, 54). Just as it was applied in other studies (55), further studies are needed to determine how the results shown in this research impact the selection processes of national and regional coaches and scouts in orienteering.

Consistent with the preceding paragraph, a notable impact on performance discrepancy within competitive groups was observed, particularly among the youngest cohort of orienteers, aged between 13 and 14, as supported by other recent studies (56). This underscores the significance of factoring in both RAEs and maturation status (57) since this difference could increase by up to four years. Being comparatively older and concurrently at a more advanced stage of maturation confers a significant advantage in performance-related attributes. Furthermore, Hancock et al. (32) emphasized that relatively older athletes often receive more resources, such as coaching attention and competitive opportunities, which perpetuate the RAEs cycle. This allocation of resources may inadvertently marginalize younger athletes, leading to a self-fulfilling prophecy where perceived underperformance among the relatively younger persists across their development. Although RAEs are generally less pronounced in female athletes, some research has identified small effects, particularly in team sports (23, 28, 29, 55, 56, 58, 59), this study cannot support this statement. However, when analysing the results of boys and girls, it is observed that significant differences in the F-16 group disappear in girls, while in boys they continue in M-16 that later disappear, possibly indicating a diminishing impact of growth and maturation processes on sports participation, particularly noticeable in women, occurring two years earlier than in men (60). Therefore, RAEs also affects the female sports context in orienteering, as demonstrated by the review and meta-analysis conducted by Smith et al. (52).

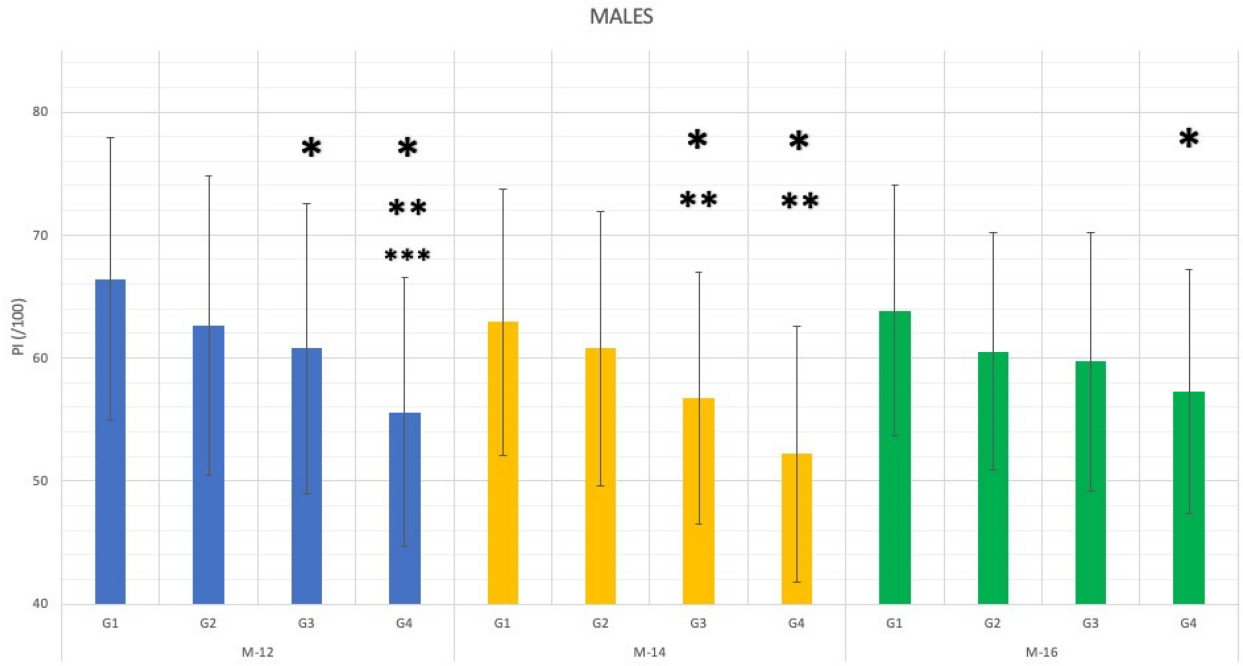


FIGURE 1
Bars graph representing the results of *post-hoc* games-howell test for the performance difference depending on the semester and year of birth of male children orienteers (*$p < .0083$ compared to G1; **$p < .0083$ compared to G2 and ***$p < .0083$ compared to G3).

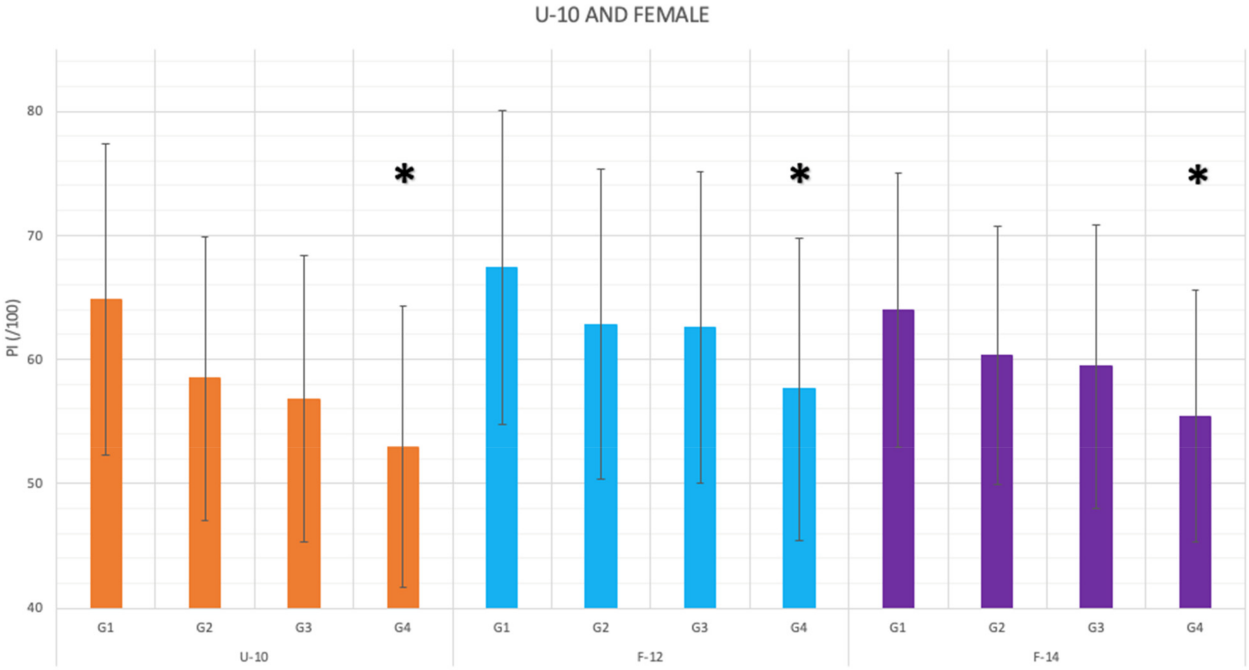


FIGURE 2
Bars graph representing the results of *post-hoc* games-howell test for the performance difference depending on the semester and year of birth of under-10 and female children orienteers (*$p < .0083$ compared to G1).

In alignment with the findings of our research, it is also worth highlighting the study by Jakobsson et al. (47), which bears a striking resemblance to the present research. These authors gathered data from athletes born between 1922 and 2015, spanning various sports, including orienteering ($n = 41{,}164$). The data, in this case divided into four-month periods (tercils: T1, T2, T3), unveiled a significant bias in the distribution of birth dates across all sports, both sexes, and most age groups. In relation to its results specific to orienteering sport, RAEs were identified across various age groups: ≤8, 11–15, 16–20, 21–39, 40–59, and ≤60 years, the effect sizes (V) were 0.25, 0.19, 0.11, 0.17, 0.06, 0.13, and 0.16, respectively, and notably, significant RAEs were evident in all age groups, including boys and girls up to 5 years old ($p < .001$, $V = 0.37$). However, in adults over 60 years, the distribution was nearly equal (approximately 33% per tertile), and an inversed RAE was noticeable in both sexes ($p < 0.05$, $V = 0.14$, ratio T3 = 1.06 for males; $p < 0.05$, $V = 0.19$, ratio T3 = 1.09 for females). Following their study, when considering the entire analyzed sample, RAEs were consistently observed in the majority of individual sports in Sweden, including those that are physically demanding and those requiring cognitive skills. Their findings, which mirror those of the current study, suggest that in most sports, children born earlier often outperform and outrank their later-born counterparts. However, this trend is not evident among adult athletes, where no discernible correlation between birth date and performance exists. Jakobsson et al. (47) concluded that neglecting to address the issue of relative age early on could result in a restricted and arbitrary selection of elite adult athletes, disproportionately favoring those born earlier in the selection year while prematurely excluding potentially talented but younger athletes. Additionally, the lack of intervention could negatively impact public health, as early dropout from organized sports due to RAE disadvantages may lead to lower levels of lifelong physical activity, increasing the risk of sedentary lifestyles and associated health problems such as obesity and cardiovascular diseases. This lends credence to the idea that RAEs and competitive grouping significantly shape the opportunities available for athletes to excel in sports talent development. Consequently, these findings emphasize the importance of considering both RAEs and maturation status when selecting and developing young athletes in orienteering and other sports. These authors also underscore the need for additional studies to comprehend how these findings influence the selection processes employed by national and regional coaches in orienteering and other sports.

Considering the unique characteristics of orienteering sport and the significant role cognitive performance may play, the results obtained by Huertas et al. (48) in a team sport context can be related to our study objectives. The researchers compared attentional functioning, anthropometry, physical fitness, and game intelligence across two age groups (U10 vs. U12) and four birth trimesters (BQ1–BQ4). Their findings revealed a statistically significant RAE ($p < .001$), with approximately 50% of the participants born in the first trimester and 75% in the first half of the year. However, they found no age effect on the functioning of attentional networks. This lack of age effect was attributed to the maturation of attentional networks, which typically reach peak development around nine years of age, and the quality of practice. They noted that athletes in elite teams, due to superior training and competition experiences, have similar daily opportunities for comprehensive development in physical, technical, tactical, and perceptual-cognitive aspects. They further suggested that despite individual baseline differences, elite athletes tend to achieve comparable cognitive benefits. Another possibility they proposed is that relatively younger players, unable to solve game situations by leveraging superior physical abilities, are compelled to enhance their game intelligence and, consequently, their perceptual-cognitive abilities. These insights could be applied to the training and selection of young orienteering athletes. The gap between maturation status and biological age, particularly in physical differences, could be compensated in orienteering learning and training with a focus on technical-tactical and perceptual-cognitive aspects. Additionally, selection or talent identification tests that include cognitive performance assessment, especially for younger competitive groups, could help mitigate the effect of RAEs. Nevertheless, further research is needed on the impact of RAEs and competitive groupings on cognitive performance.

The present study is not without limitations. While the performance indicator used, namely PI, is deemed suitable for assessing performance, especially for tracking purposes, this variable is limited to winner time. Although this approach is better to using the average time of all orienteers (29), winner time is inherently contingent upon the performance of the individual athlete. As outlined in the method section, the dependent variable (individual performance) was calculated as the average value of the performance indicator across competitions for each orienteer within a season. Notably, some orienteers participate in two races, while others partake in four. Additionally, the use of a cross-sectional design and the categorization by birth semesters may limit the depth of the analysis, as this approach may not fully capture seasonal variations and other temporal factors that could influence performance and age distribution. However, this design is common in the relative age effect literature and provides a valuable snapshot for identifying trends and associations at a given point in time. Future studies could benefit from longitudinal approaches to overcome these limitations and examine corrective adjustments, as suggested in prior work (23), offering a more comprehensive understanding of the impact of relative age on orienteering performance over time.

Conclusion

The findings of this study confirm that younger orienteers tend to perform worse within their competitive groups, while older counterparts show enhanced performance. The complex process of talent development is influenced by primary factors like genetics and training (26) and secondary factors such as RAEs (27). This study highlights the impact of competitive grouping in

orienteering, particularly disadvantaging athletes born in the second half of the year.

To promote fairer competition, adjustments in competitive grouping should be considered, especially for young orienteers approaching peak height velocity (60). One potential solution is a refined ranking system within races, segmenting classifications by birth period (e.g., 1Y1S; 1Y2S; 2Y1S; 2Y2S). Alternatively, bio-banding or classification based on biological age (48, 61) could be explored, though adaptation to orienteering would require defining and measuring technical-tactical and cognitive skills. Additionally, reserving spots for younger orienteers may help reduce dropout rates (25, 62, 63) and prevent the loss of potential talent.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: The competition results used in our study are publicly available and were obtained from the following page: https://www.fedo.org/web/archivo-resultados-o-pie. The data regarding the birth dates of federated athletes were provided by the Spanish Orienteering Federation (Federación Española de Orientación, FEDO). These data are not publicly accessible. As such, there are legal restrictions on sharing this dataset, as imposed by the Spanish Orienteering Federation. Designated contact for data inquiries: secretaria.fedo@gmail.com.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

AF: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing. JM: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing, Supervision, Visualization. OØ: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition. JC: Conceptualization, Data curation, Investigation, Methodology, Resources, Software, Writing – original draft, Writing – review & editing. AM: Conceptualization, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing. HE: Conceptualization, Investigation, Methodology, 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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Longitudinal investigations of development in handball and its association with relative age effects

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In this paper, we describe two studies on the association among long-term developmental outcomes and relative age effects. To extend or compliment the cross-sectional work done previously, these studies take different approaches to investigate the association of relative age effects on long-term development. In the first, a retrospective approach is taken, while in the second, developmental data for players over a 4-year period is considered. In study 1 the association between relative age effects and later performance at the adult level is presented. The results show different patterns for females and males. In the second study, development during the national youth development system in handball, over four points in time, are presented. Again, changes over time in birth quartile distribution can be seen. These studies suggest relative age researchers should embrace longitudinal designs. These types of approaches would allow explorations of the association of other variables with the observed relative age effects.

KEYWORDS

talent, within-year effect, between-year effect, sport, bias

1 Introduction

In countries like Germany, where many sports set a cut-off date of January 1st, individuals born on December 31st are the youngest in their year group; a child born the next day (i.e., January 1st) is the oldest in the subsequent year group. Wattie et al.'s (1) model of the mechanisms behind "relative age effects" (RAEs) in sport posits that athletes born closer to the cut-off date used in their sport for age-group selection get developmental advantages due to their relative age compared to younger peers within the same cohort. Such advantages can manifest in increased opportunities for training, competition, and coaching attention (2). Despite the developmental nature of RAEs (3, 4), most research in this area has adopted cross-sectional or quasi-longitudinal approaches (3).

Lately, however, the developmental nature of the phenomena has begun to receive some attention (5). A study by Faber et al. (6), for example, showed that performance trajectories of the top 100 French table tennis players were associated with relative age. To the best of our knowledge no other study has taken a longitudinal approach to investigate these effects.

In this paper, we describe two studies on the association among long-term developmental outcomes and relative age effects. To extend or compliment the cross-sectional work done previously, these studies take different approaches to investigate the association of relative age effects on long-term development. In the first, a retrospective approach is taken, while in the second, developmental data for players over a 4-year period is considered.

2 Study 1—relationships between long-term success of handball and relative age

Previous studies on talent selection camps in German handball have shown classical relative age effects, with an over-representation of athletes born in quartile 1 (7–9). These studies have also shown that relative age effects are smaller in female athletes than in males (7–9). On the surface, these effects appear to decrease or even dimmish over time (e.g., when athletes reach adulthood) (10). However, to the best of our knowledge, no one has tested whether players from these talent camps who make it to the elite levels show the same distributions. Therefore, our primary aim in this study was to test whether this group of "early talents" who made it to the higher levels of performance demonstrated a relative age effect. In general, we expected a decrease in effect with age (3, 4) based on previous studies of handball talents (7–9).

A second aim was to identify players from the same birth years who made it to these higher levels, but were not considered for development at the lower level (i.e., were not participants in junior development programs). No previous studies have explored this type of comparison group, and therefore our analyses here were largely exploratory. For instance, it is possible that if talent is equally distributed over the year, and players from the talent camp are more likely to demonstrate a positive effect, the remaining players could demonstrate a reverse relative age effect with an over-representation in the fourth quartile. This relationship would suggest these "late bloomers" developed later in their career and were still able to make it to the top levels. A third aim of this study involved comparing the birth quartile distributions of early talents with late bloomers.

3 Study 1—methods

3.1 Sample

Birthdates for two groups were collected. First, the German Handball Federation provided the birthdates of participants involved in "talent selections" in 2010 and 2011. In those selections approximately 240 male and 240 female athletes participated each year (11). The players participating at these national talent camps had been previously selected by the twenty regional coaches. They were most often selected by the coaches' eye (12). The selection camps in 2010 and 2011 lasted for 5 days and included a range of tests as well as varying games, the athletes play. During these days national coaches selected players to form the basis for the youth national team.

We then determined league status for these members of this year group for the 2017/2018 season. The second group consisted of players from the same birth years, playing in the first three leagues in the 2017/2018 season, but who did not participate in those talent selection programs. Those players and their birthdates were retrieved from the various official websites of the German female and male handball leagues (http://www.hbl.de, http://www.hbfw.de, http://www.dhb.de/de/wettbewerbe/3–liga/uebersicht/) as well as from official websites (e.g., http://www. handball-world.de/news). From these sources, 108 males and 36 female players were identified.

3.2 Statistical analyses

To test RAEs in this study, birthdates were collected for all male players born from 1994 to 1995 ($n = 542$) and for all females born from 1995 to 1996 ($n = 473$) who either participated in their respective talent selections in 2010 (males with birth year 1994 and female birth year 1995) and 2011 (males with birth year 1995 and female birth year 1996) by the Germany handball federation (junior level) or played at the point of data collection in the highest three leagues (senior level).

At the selection camps, 449 male talents and 444 female talents participated (cf. Table 1). Of these junior participants, 119 male and 110 female players eventually ended up playing in the first to third leagues in German handball during the 2017/2018 season. Additionally, players with the same birth years who were in the first three leagues were identified ($n = 93$ male and 29 female players).

Given that the cut-off date in handball is the first of January, players' birth months were re-coded to reflect his or her birth quartile (January–March = quartile 1, April–June = quartile 2, July–September = quartile 3 and October–December = quartile 4). Because previous research examining the birthdate distribution in Germany has shown roughly equal distributions across the quarters of the year (8), statistical analyses were conducted against this distribution. Chi-square tests were calculated over all leagues, for both sexes. Additionally, we separated "early talents" (i.e., current elite players who were selected as part of the early talent selection process) and "late bloomers" (i.e., current elite players who were not part of the early program). Comparisons of between year groups were not necessary for this sample, because they are only later combined to a 2-year group team.

TABLE 1 Distribution of players at different career points for study 1.

Groups	Male	Female
At talent selection camp (and found in first three leagues in 2017/18 = early talents)	449	444
At talent selection camp and found in first three leagues in 2017/18 = early talents	119	110
NOT at talent selection camp and found in first three leagues in 2017/18 = late bloomers	93	29
Total numbers from both categories	542	473

All analyses were conducted with SPSS 29.0. The alpha-level was set to .05. Effect sizes (Cohen's w) were determined using G*power (13). For each effect size, the 90% confidence interval was calculated based on the noncentral Chi-square files provided online by Michael Smithson (http://www.michaelsmithson.online/stats/CIstuff/CI.html).[1]

4 Study 1—results

As can be seen in Figure 1a, an expected within year distribution was revealed on a descriptive level for female early talents and late bloomers. However, these effects were not significantly different from an equal distribution. For the early talents, a small effect size was found, $\chi^2(3, n = 110) = 4.40$, $p = .22$, $w = .20$, *90% CI* [.00, .32], while for the late bloomers a medium sized effect was noted, $\chi^2(3, n = 29) = 2.59$, $p = .46$, $w = .30$, *90% CI* [.00, .51]. As can be seen in Table 2, these results appear to be driven by the third league, because of the number of players per league although, unfortunately, the small cell sizes do not allow for differentiation between leagues. No significant differences were revealed when comparing the distributions between early talents and late bloomers, $\chi^2(3, n = 139) = 1.27$, $p = .74$, $w = .10$, *90% CI* [.00, .18].

For the male players, different effects were revealed. A significant within-year effect was found for the early talents, $\chi^2(3, n = 119) = 10.18$, $p = .02$, $w = .29$, *90% CI* [.09, .42], as shown in Figure 1b, while a reversed distribution was visible for the late bloomers, although this effect did not reach statistical significance against an equal distribution, $\chi^2(3, n = 93) = 3.56$, $p = .31$, $w = .20$, *90% CI* [.00, .32]. However, comparing both birth quartile distributions, late bloomers differed significantly from early talents, $\chi^2(3, n = 212) = 11.97$, $p < .01$, $w = .24$, *90% CI* [.09, .33].

5 Study 1—discussion

Previous research on German handball talents at the talent selection camps has repeatedly shown small to medium relative age effects (7–9). As expected based on previous findings, the early talent group demonstrated RAEs with small effect sizes (i.e., birth quartile distribution with over-representation of relatively older athletes) (3, 4). As with previous athlete research, females showed smaller relative age effects than males (3, 14).

Interestingly, different distributions were found when comparing male and female samples of late bloomers. In the male sample, the comparison of late bloomers and early talents was statistically significant, indicating differences between these distributions. Descriptively, this difference appeared to be driven by a reverse relative age distribution in the late bloomers, although this main effect was not significant. For the female late bloomers, a different distribution was observed. There were no differences between these late bloomers in comparison to the early talents. In contrast to the male athletes, there was no evidence of a reversed relative age effect. There are several possible explanations for this, but the small sample size of late bloomers ($n = 29$) may have been a contributing factor. Compared with the male athletes ($n = 93$), reaching the higher tiers for females may be more difficult than for males, if they did not make it into the national talent development system. This suggests there is an infrastructure for male players to succeed as late bloomers that is less effective for female athletes (15, 16). Collectively, these distributions could serve as a starting point to contrast the developmental pathways of athletes in German handball in general and between male and female programs in particular.

While this study suggests some intriguing results, there were limitations, including the small female sample noted above. In addition, it would have been interesting to differentiate between the various league levels, but this was not possible due to the small cell sizes between leagues. Future studies might try to develop similar datasets for other sports. Being able to differentiate between league or expertise levels would be helpful for a better understanding of the role relative age effects in the long-term development of athletes. This knowledge might provide us with ideas regarding how relative age effects can be reduced (17).

Overall, this study provides a good first step toward a deeper understanding of relative age effects as a longitudinal phenomenon. However, even within our first study, the developmental path remains a black box, because we did not control for it. For example, an assumption in relative age effect research is that the developmental environment remains constant over time. We explore this assumption in Study 2.

6 Study 2—relative age effects in German youth handball players from the first national talent selection to the junior world championships

The German handball talent development system starts with the first national talent selection camp (16). This group is perceived to include players with the greatest "talent" for future success. Approximately 240 14-year-old female players and 240 15-year-old male players present themselves the first time to the youth national coaches. Of these, around 50 players are chosen by the youth national coaches for a second talent selection, of which approximately 20 are chosen for the youth national team.

These youth national team players then train within the national development system (16). However, to prepare for the international tournaments 2-year groups are combined as one youth national team. The two main international competitions

[1]The SPSS-script provided by Michael Smithson calculates the non-centrality parameter for the non-central distributions under which a particular chi²-value cuts off an area of α% (here: 5%) to the right (λ_{low}) and left (λ_{low}). Based on these calculations, the lower (w_{low}) and upper (w_{upp}) bound of the confidence interval on Cohen's *w* are obtained via the formula w_{low}=sqrt[λ_{low}/N] and w_{upp}=sqrt[λ_{upp}/N], respectively.

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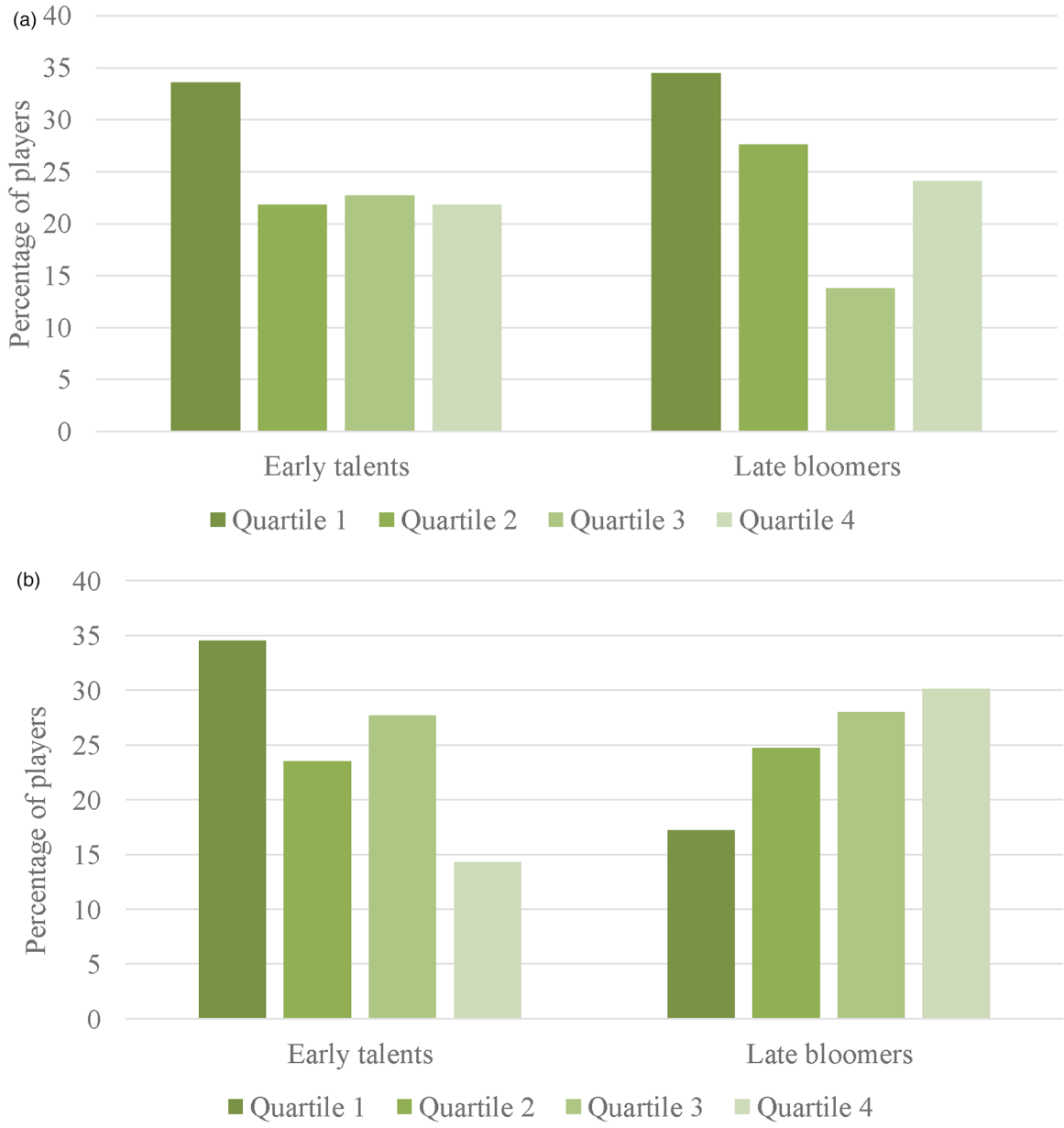


FIGURE 1
(a) Study 1—birth quartile distributions for female early talents and late bloomers. **(b)** Study 1—birth quartile distributions for male early talents and late bloomers.

TABLE 2 Study 1—number of players differentiated by sexes, league level and developmental pathway.

Sex	League	Early talents				Late bloomers			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Female	1	3	7	6	3	2	1	2	0
	2	14	4	5	7	5	3	0	4
	3	20	13	14	14	3	4	2	3
	Total	37	24	25	24	10	8	4	7
Male	1	9	9	6	3	5	4	4	6
	2	12	6	13	8	4	8	3	5
	3	20	13	14	6	7	11	19	17
	Total	41	28	33	17	16	23	26	28

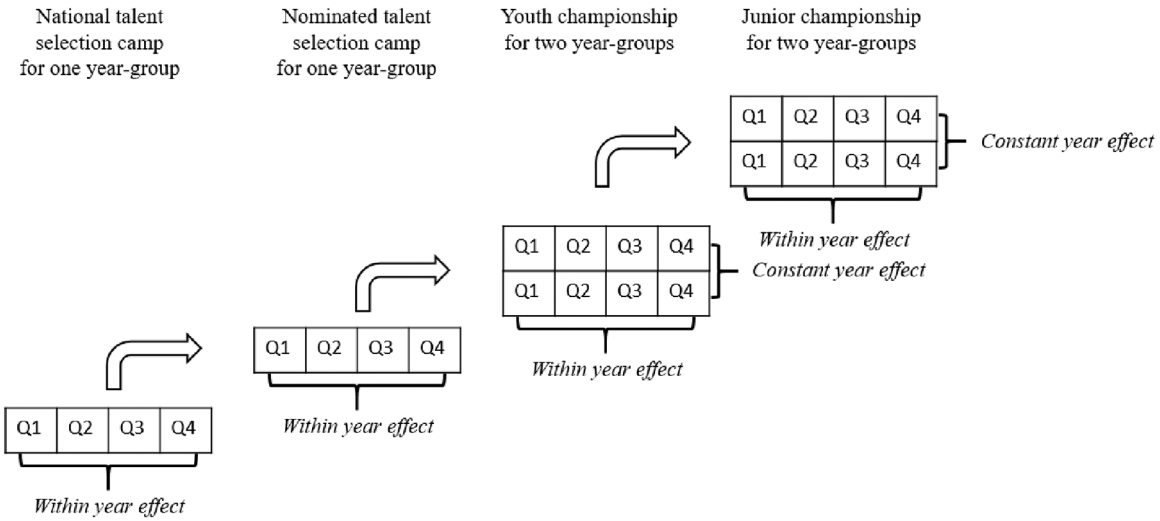


FIGURE 2
Study 2—talent development pathway in German handball with within year effects and constant year effect.

are the Youth World Championships and the Junior World Championships. During this period of approximately 5 years, players not only train in the national development system, they also stay within their clubs. While there is a clear reduction of numbers from the talent selection camps to the youth national team, the number of players remains the same across the international tournaments. However, the team's make-up could still change. Some may remain for the whole period, while others might lose their spot, drop-out from the sport, or move up to the team, if they show strong performances in the club system.

The complicated structure of the German national talent development system suggests there are two age-groupings at play (cf. Figure 2). While the within-year effect (i.e., the classical RAE) can be investigated during all four points of time, a constant year effect can only be explored during tournament phases, when 2-year bands are combined (9). Because the emphasis is typically on international competition, throughout the tournament phase, younger players in this 2-year band have to compete with older players for spots on the roster. These shifting and competing effects highlight the complexity of age-related effects across athlete development. While some previous research has explored the longitudinal nature of with-in year effects [Study 1 as well as (6)], to the best of our knowledge, changes in constant year effects across development have not been examined.

While most studies look only at the beginning and/or the end of this process, the aim of this study was to consider two relative age effects at different points of time during the national talent development period within the German handball federation. In a first step, we report within-year effects during the talent selection period, because only 1 year band is considered here. As with previous research, we expected small to medium effect sizes for the handball talents (7, 10), and smaller effects for the girls as for the boys (14). For tournament phases, we examined within-year effects and constant-year effects among the athletes who remained in the program compared to those had to drop-out or joined at a later age.

6.1 Study 2—methods

6.1.1 Samples

For the present study, birthdates from two samples of young players were taken. First, the German Handball federation provided the birthdates of male athletes born between 1992 and 1997 from their talent development program. Additionally, they provided the data for females in the talent development program born between 1996 and 1999. This information included each athlete's birth date as well as their participation at the first and second talent selection camp, the World youth and World junior championships. These are the four main events during their national talent development career with the German Handball Federation. From the first talent selection camp with 240 participants per birth year, the number of players is reduced to approximately 40 for the second one. For both tournaments, which are played with double year bands, the number of players is reduced to 20 for both birth years together. These are then the players nominated to compete at these international tournaments plus their reserves.

6.1.2 Statistical analyses

Given that the cut-off date in handball is January 1st, players' birth months were re-coded to reflect his or her birth quartile (January–March = quartile 1, April–June = quartile 2, July–September = quartile 3 and October–December = quartile 4) as in study 1. Additionally, we differentiated between athletes in older and younger year groups to test for between-year effects because handball tournaments are played in teams of 2-year bands. As in Study 1 and in line with previous research on birthdate distribution in Germany (8), statistical analyses were conducted

against an equal distribution of births across the year. Chi-square tests were calculated to test for within-year and between-year effects. All analyses were conducted with SPSS 29.0. Effect sizes were determined using the software G*power (13). For each effect size, the 90% confidence interval was calculated based on the noncentral Chi-square files provided online by Michael Smithson (http://www.michaelsmithson.online/stats/CIstuff/CI.html).

6.2 Study 2—results

Males: For the first talent selection, significant within-year effects were revealed for the males, $\chi^2(3, n = 1282) = 164.18$, $p < .001$, $w = 0.36$, *90% CI* [0.31, 0.40]. As expected, the first quartile (37.44%) was over-represented in comparison to the second (27.30%), third (22.70%) and fourth quartiles (12.56%). At the second talent selection camp, a significant within-year effect was observed, $\chi^2(3, n = 279) = 64.53$, $p < .001$, $w = 0.48$, *90% CI* [0.37, 0.57]. Again, the first quartile (43.73%) was over-represented compared to the second (25.45%), third (20.07%) and fourth quartiles (10.75%).

When focusing on the birth-date distributions at the youth and junior world championships (cf. Table 3; Figure 3a), players who played both tournaments (remainders) showed no significant within-year effects, $\chi^2(3, n = 22) = 3.09$, $p = .38$, $w = .37$, *90% CI* [.00, .63], but there was a significant between-year effect, $\chi^2(1, n = 22) = 6.54$, $p = .01$, $w = .55$, *90% CI* [.19, .90]. For those who played the youth tournament, but not the later junior one (drop-outs), neither a significant within-year effect, $\chi^2(3, n = 26) = 6.92$, $p = .07$, $w = .52$, *90% CI* [.00, .78], nor a between-year effect was revealed, $\chi^2(1, n = 26) = 2.46$, $p = .12$, $w = .31$, *90% CI* [.00, .63]. Similarly, no effects were found for players who did not play the earlier youth championship—within-year effect, $\chi^2(3, n = 22) = 2.00$, $p = .57$, $w = .30$, *90% CI* [.00, .53], between-year effect, $\chi^2(1, n = 22) = 0.73$, $p = .39$, $w = .18$, *90% CI* [.00, .53].

Females: For the first talent selection, a significant within-year effect was found for female players, $\chi^2(3, n = 838) = 56.76$, $p < .001$, $w = 0.26$, *90% CI* [0.20, 0.31]. As expected, the first quartile (34.13%) was over-represented in comparison to the second (26.49%), third (23.39%) and fourth quartiles (15.99%). At the second talent selection camp, a significant within-year effects was observed, $\chi^2(3, n = 279 = 17.24$, $p < .001$, $w = 0.30$, *90% CI* [0.16, 0.41]. As expected, the first quartile (35.79%) was over-represented in comparison to the second (23.16%), third (26.32%) and fourth quartiles (14.74%).

When focusing on the birth-date distributions of players at the youth and junior world championships (cf. Table 4; Figure 3b), those who played in both tournaments (remainers) had no significant within-year effects, $\chi^2(3, n = 11) = 1.00$, $p = .80$, $w = .30$, *90% CI* [.00,.54], and no between-year effects, $\chi^2(1, n = 11) = 0.82$, $p = .37$, $w = .27$, *90% CI* [.00, .77]. For those who played in the youth tournament but not the later junior one (drop-outs), neither a significant within-year effect, $\chi^2(3, n = 20) = 2.80$, $p = .42$, $w = .37$, *90% CI* [.00, .64], nor a between-year effect was revealed, $\chi^2(1, n = 20) = 0.20$, $p = .65$, $w = .10$, *90% CI* [.00, .45]. However, for the athletes who played only in the junior world championships, a significant within-year effect was found, $\chi^2(3, n = 19) = 11.95$, $p < .01$, $w = .79$, *90% CI* [.31, 1.11], but no significant between-year effects, $\chi^2(1, n = 19) = 0.47$, $p = .49$, $w = .16$, *90% CI* [.00, .53].

6.3 Study 2—discussion

In a first step, we explored within-year effects during two talent selection camps in German handball. In line with previous research, there were significant, generally medium-sized, within-year effects for female and male athletes (7–9). Also, similar to previous research, the effects sizes for the females were smaller than for the males (7–9).

A more differentiated picture arose for the within-year effects during the tournaments. For the male athletes, three distinct birth quartile patterns emerged. Players who dropped out (i.e., only participated in the first tournament) showed a classical within-year effect, while in the joiners (i.e., those who only participated in the second tournament) the middle two quartiles were over-represented. For the athletes who participated in both tournaments, the first two quartiles were over-represented. These differences in birth quartile distributions might be support for the underdog hypothesis proposed by Smith and Weir (18). The main idea of the underdog hypothesis is that players who were initially disadvantaged by their birth quartile, find a way to compete on the older level during their development and have therefore an advantage at later stages of their development.

However, this pattern was not found for the female athletes. In females the first quartile was over-represented in the joiners and the third quartile was largest for the drop-outs. Of the athletes who played in both tournaments (the remainers), the second quartile was the most frequent one. While the male sample provides a clearer picture, the distributions for the females are more difficult to interpret. Importantly, the small sample sizes in the female analyses need to be treated with caution and future research should try to use bigger sample sizes over an even longer period of time (5).

In contrast to the findings for the within-year effects, similar results were demonstrated for female and males for the between-year effects. The strongest between-year effect can be seen for the remainers. Similar to previous findings on within-year effects, here

TABLE 3 Study 2—comparison of birth quartile distributions of drop-outs (i.e., played the youth tournament but not the later junior one), remainders (i.e., played both tournaments) and joiners (i.e., played the junior tournament but not the earlier youth one) between youth and junior world championships of male German handball talents.

Players development	*N*	Q1	Q2	Q3	Q4	Older	Younger
Drop-outs	26	42.3	30.8	19.2	7.7	65.4	34.6
Remainders	22	31.8	36.4	13.6	18.2	77.3	22.7
Joiners	22	22.7	31.8	31.8	12.6	59.1	40.9

Additionally, the older and younger year groups are presented.

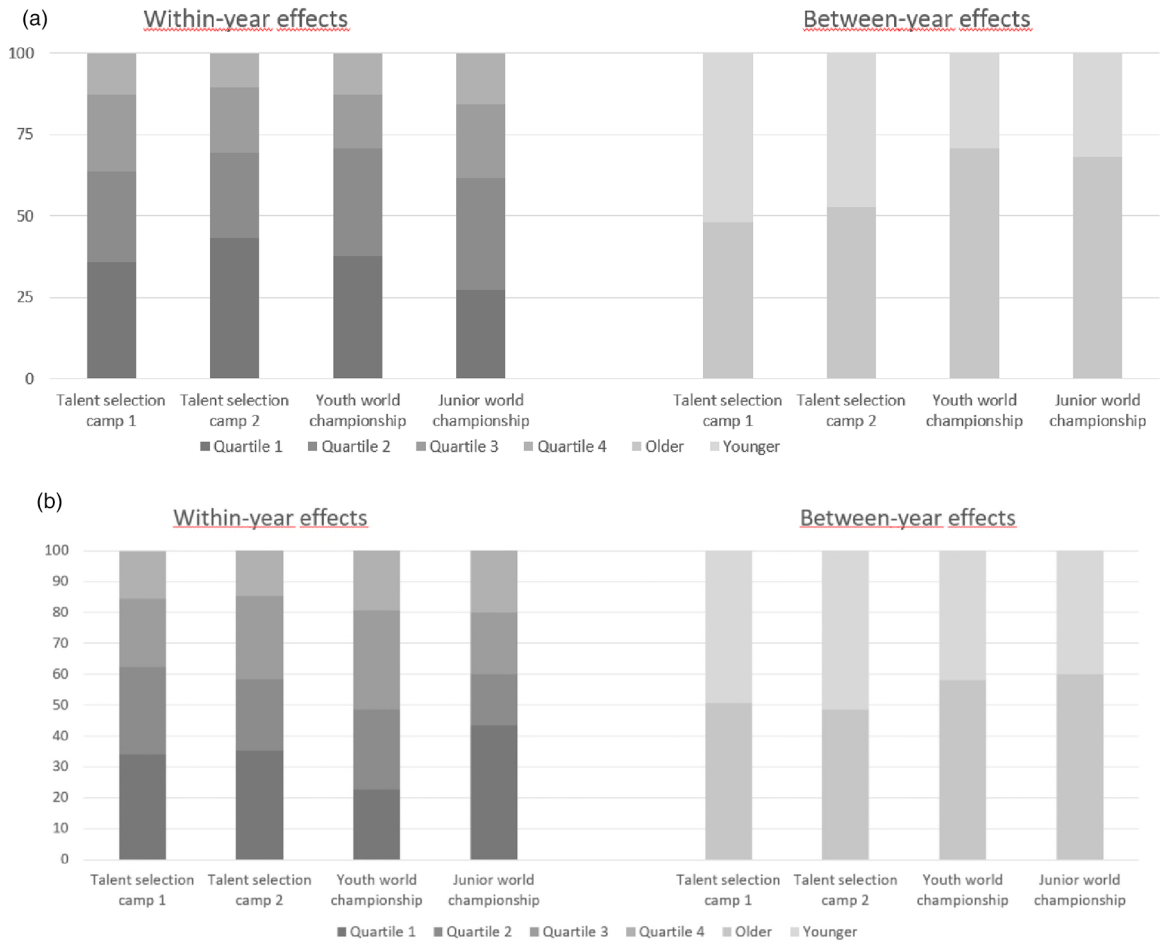


FIGURE 3
(a) Study 2—birth quartile distributions for male players during four different points of time during the national team career. (b) Study 2—Birth quartile distributions for female players during four different points of time during the national team career.

TABLE 4 Study 2—comparison of birth quartile distributions of drop-outs (i.e., played the youth tournament but not the later junior one), remainders (i.e., played both tournaments) and joiners (i.e., played the junior tournament but not the earlier youth one) between youth and junior world championships of female German handball talents.

Players development	*N*	Q1	Q2	Q3	Q4	Older	Younger
Drop-out	20	25.0	20.0	40.0	15.0	55.0	45.0
Remainders	11	18.2	36.4	18.2	27.3	63.6	36.4
Joiners	19	57.9	5.3	21.1	15.8	57.9	42.1

between-years effects were stronger in males than females. A possible explanation might be that, as previously noted, the competition for the spots for the males is higher in German handball than for the females (15, 16). However, as argued for the within-year effects, all these effects should be looked at with caution because of the small sample sizes in these analyses.

7 General conclusion

The developmental nature of relative age effects is widely supported (3, 4). However, in the decades since Barnsley et al. (19) very few longitudinal studies have been presented (5, 6). The results of the current studies compliment and extend previous work suggesting the non-linearity of athlete development and the impact of RAEs. In study 2, there is evidence that during national youth development programs, different groups of athletes are entering and exiting the national development system over time. From an athlete development perspective, these changing populations are intriguing, although the mechanisms that promote or constrain these changes are currently unclear. Future studies should try to focus more on these phases of athlete development.

Taken together, these studies suggest relative age researchers should embrace longitudinal designs (5, 6). These types of prospective approaches would allow explorations of the association of other variables with the observed relative age

effects. For example, integrating aspects of psychological qualities like motivation with physical elements of growth and maturation to determine how they shift and evolve with relative age across development may provide a clearer picture of this phenomena. Certainly, solutions to this persistent inequality [see Webdale et al. (17)] will only come with more advanced approaches than the descriptive designs used in most work in this area.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: the data is not ours, but from the German Handball federation. Requests to access these datasets should be directed to joerg.schorer@uol.de.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

JS: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. IF: Writing – original draft, Writing – review & editing. DB: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. JB: Writing – original draft, Writing – review & editing. NW: Writing – original draft, Writing – review & editing.

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The Royal Netherlands Football Association (KNVB) relative age solutions project—part one: a call to action

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Introduction: Despite its widespread prevalence in youth soccer, there seems to be no widely implemented intervention to moderate or overcome Relative Age Effects (RAEs). The purpose of this study was a call to action for stakeholders to propose relative age solutions to the Royal Netherlands Football Association (KNVB).
Methods: The call to action consisted of a standardised, open-access questionnaire that contained questions focussed on: (a) the mechanisms of the proposal, (b) hypothesised effects, and (c) reference to empirical findings.
Results: Following the initial screening of 185 submissions, a total of 143 eligible proposals were included. Each proposal was categorised by two project members based on a taxonomy to classify different approaches designed to reduce RAEs by: (a) altering the behaviour of observers, (b) implementing rules when selecting teams, or (c) adjusting competition structures. From this, 13 lower-order independent solutions were categorised.
Discussion: Interestingly, whilst no new suggestions outside the existing literature were proposed in any of the submissions, only two have been empirically tested in soccer. Overall, the results present a useful first step in identifying possible relative age solutions. Due to the number of proposed solutions and their anecdotal nature, the next step for the KNVB was to utilise the knowledge of experts in the field via an adapted e-Delphi study to identify the most effective and feasible solutions to implement in practice (Part Two).

KEYWORDS

relative age effects, talent identification, talent development, athlete development, youth soccer, youth football

Introduction

Relative Age Effects (RAEs) are well known phenomenon in soccer. Many studies have highlighted how relatively older youth players (i.e., those born near the start of the selection cut-off date) are afforded a variety of advantages and are overrepresented in both participation (e.g., recreational/grassroots) and developmental (e.g., academies/talent pathways) settings. In comparison, relatively younger youth players (i.e., those born towards the end of the selection cut-off date) are often at a disadvantage and remain underrepresented across the sport [see (1) for an overview in soccer]. Such RAEs have been found in youth soccer across all four corners of the globe, ranging

from the United States (2) to Italy (3) and China (4) to Brazil (5). Contextual factors such as age [e.g., U12 vs. U19; (6)], competition level [e.g., recreational/grassroots vs. academies/talent pathways; (7)], gender [i.e., boys vs. girls; (8)], competitive success [e.g., more vs. less league points accrued; (9)], nationality [e.g., Belgium vs. France; (10)], and playing position [e.g., goalkeeper vs. defender; (11)] have been shown to influence the extent to which RAEs exist in soccer, highlighting the complexity involved when identifying, selecting, and developing young players.

The possible mechanisms that explain how RAEs occur remain inconclusive and mainly hypothetical. Initial relative age research in youth sport assumed that an advanced maturity status was the major underlying cause [e.g., the "maturation-selection hypothesis"; (12)]. Contrastingly, however, Hancock and colleagues (13) theorised the "social agents model" to suggest how it is in fact key stakeholders, including players [i.e., Galatea effect; (14)], coaches [i.e., Pygmalion effect; (15)], and parents [i.e., Matthew effect; (16)], who are responsible for perpetuating RAEs. Thereafter, Wattie and colleagues (17) proposed a "constraints-based developmental systems model" to explain how a variety of factors are responsible for RAEs in sport, based on environmental (e.g., access to soccer provision), individual (e.g., physical characteristics), and task (e.g., playing position) constraints. More recently, Kelly and colleagues (18) used the "personal assets framework" to underscore possible developmental outcomes due to RAEs in the immediate (i.e., personal engagement in activities, appropriate settings and organisational structures, and quality social dynamics), short-term (i.e., competence, confidence, connection, and character), and long-term (i.e., performance, participation, and personal development) timescales. Despite these theoretical efforts, limited empirical studies are available to show the exact causes of RAEs in youth soccer.

In light of the (dis)advantages that arise due to RAEs, researchers have suggested various potential solutions to mitigate these effects [see (19) for a review]. For example, applying 9-month age groups (20), rotating cut-off dates (21), implementing into coach education (22), adopting age-ordered shirt numbering (23), avoiding early deselection (24), using selection quotas (25), applying corrective adjustments (26), grouping athletes using characteristics other than age (27), considering a flexible chronological approach [i.e., playing-up and playing-down; (28)], moving each individual up to their next birthdate group on their birthday [i.e., birthday-banding; (29)], delaying the selection process (30), estimating developmental birthdates (31), and setting the average age of a team to a predetermined maximum (32) have all been proposed throughout the youth sport literature. Taken together, the general consensus from researchers has emphasised the need to explore potential solutions to combat RAEs. Despite numerous proposals from researchers, however, the design, implementation, and evaluation of such solutions in youth soccer remains mostly absent from the literature (23, 31). In addition to the lack of research testing potential relative age solutions, there are no studies that have explored stakeholder perspectives to better understand if these proposals are viable in real-life settings (33).

Although being considered a global leader when it comes to youth soccer development [e.g., (34, 35)], the Royal Netherlands Football Association (KNVB) are also guilty when it comes to creating RAEs [e.g., (36, 37)]. Indeed, they have received critical attention from popular media for creating inequitable opportunities for young players as a result of RAEs, which remain present throughout their existing age group structures [e.g., (38–40)]. As an example, data from UEFA (41) showed that the relatively youngest Dutch players selected to play in the men's 2016 U17 and U19 European Championships received the lowest proportion of playing time. Adding to the complexities of such RAEs at youth levels, it is also important to consider its implications on the long-term progression of players into international and professional levels [e.g., (42–44)]. In the case of the Netherlands, it appears to have knock-on effects on both the men's senior national team (45) as well as the men's Eredivisie domestic teams (10). As such, the efficacy of the current age group policies used in the Netherlands youth soccer pathways may not only have short-term effects at youth levels, but also potentially limits the potential talent transitioning to senior levels in the long-term. Therefore, the purpose of this study was a "call to action" for youth soccer stakeholders (e.g., academics, coaches, parents, policy makers, practitioners) to put forward their proposals for potential solutions that could be implemented into youth soccer to mitigate RAEs in the Netherlands.

Methods

The call to action consisted of a standardised online survey that enabled the collection of responses from participants via a publicly available link. The link was included in a news article that communicated the KNVB's efforts to assemble solutions to mitigate RAEs in youth soccer. The article and accompanying link remained pinned on the KNVB's homepage for the duration of the data collection period. In addition, the article was shared via the KNVB's social media (news)outlets, including Twitter (now called X) and LinkedIn. The online submission form was available for participants to submit their solution from March 15th, 2021, to May 1st, 2021. The registration form was designed with Microsoft Forms (Microsoft Corporation, USA) and consisted of three parts focussed on: (a) the mechanisms of the proposed solution for RAEs, (b) hypothesised mitigating effect(s) of the solution on RAEs, and (c) any reference to empirical findings if applicable.

First, participants were required to provide consent for their proposed solution to be shared and used within this project. Following consent, participants were asked to provide a maximum 250-word summary on their proposed solution. After they provided their summary, participants could indicate if they were aware of whether their solution had been implemented or trialled in other sports. In addition, they could indicate if they believed the following factors related to RAEs were most affected by their solution: (a) modification of cut-off dates, (b) selection decisions regarding players, (c) grouping players within teams, or (d) using corrective (mathematical) algorithms to control for relative age differences. Finally, participants were asked to provide a short description on their course of action, such as an

exemplary research design to trial their proposed solution within the context of the Netherlands youth soccer. For this, participants had the option to share any (peer-reviewed) research materials, if available, with the project team after they had registered their solution. See Supplementary File 1 for the Microsoft Forms (Microsoft Corp., Redmond, WA, USA) survey used for this study. The project was endorsed by the KNVB and ethically approved by the Health, Education, and Life Sciences Faculty Academic Ethics Committee at Birmingham City University (ethics code #9524).

Results

The online survey yielded 185 responses. Following the initial screening of each submission, 26 were excluded because participants did not consent to their solution being used in this project. A further 25 were excluded because they did not propose any solution for RAEs in the Netherlands youth soccer. This resulted in 134 eligible submissions, with eight responses proposing multiple solutions (two, $n = 7$; three, $n = 1$), creating a total of 143 proposed solutions. Data were extracted and copied into a specifically designed Microsoft Excel (Microsoft Corp., Redmond, WA, USA) sheet, which enabled the assessment of each submission. Two project members independently assessed and categorised each of the 143 proposed solutions based on the taxonomy provided by Mann (1). This taxonomy consists of three higher-order themes of different approaches designed to reduce RAEs when performance is assessed objectively, including: (a) altering the behaviour of observers ($n = 19$), (b) implementing rules when selecting teams ($n = 46$), and (c) adjusting competition structures ($n = 78$). From this, 13 lower-order independent solutions were categorised. The classification process resulted in an initial percent agreement of 0.9. Any disagreements about the inclusion of a solution within a certain category were discussed amongst all authors and resolved by final consensus.

Overall, while no new suggestions outside the existing literature were proposed in any of the submissions, only two have been empirically tested in soccer previously ("cueing differences in age" and "categorising based on chronological and biological age"). The most frequent higher-order theme that was put forward by the participants was "adjusting competition structures", with "modifying age bands" the lower-order theme that was suggested most often (Figure 1).

Discussion

This discussion has been structured to consider each of the 13 lower-order independent solutions that were categorised based on the three higher-order themes: (a) altering the behaviour of observers ($n = 3$), (b) implementing rules when selecting teams ($n = 6$), and (c) adjusting competition structures ($n = 4$). Given no new solutions outside the current literature were proposed, we detail the existing research to help better understand the potential mechanisms of each possible solutions, as well as propose how each solution could potentially be adapted and implemented within Dutch youth soccer context.

Altering the behaviour of observers

The first higher-order category considers solutions that alter the behaviour of observers (i.e., coaches, recruiters, talent scouts) when identifying and selecting young players. Overall, there were three solutions proposed in this category: (a) raising awareness of relative age effects ($n = 11$), (b) cueing differences in age ($n = 5$), and (c) testing objective skills ($n = 3$).

Raising awareness of relative age effects

National governing bodies and sport administrators are generally responsible for designing and delivering formal coach education programmes. The primary aim of such education provision is to ensure that coaches work effectively to create the most suitable learning environment for every young player to develop. Since the decision-making of coaches directly influences the development process of players (e.g., talent selection and/or identification), education programmes that raise awareness of RAEs (e.g., relative age information implemented into formal coaching awards) may be an effective method to reduce such effects (22, 47). Raising awareness of RAEs could be delivered in several ways [e.g., (48)]. Such approaches may include educating coaches on what RAEs are, outlining the causes and mechanisms of RAEs, and presenting examples of RAEs in action (47). Within the coach development pathway in Dutch soccer, there are several youth licencing requirements that all have their own educational programme. Here, the licencing process and accompanying education is regulated by the KNVB. As such, the implementation of new content focused on RAEs highly feasible.

Raising awareness could also change the way in which coaches think about long-term development. As an example, helping coaches understand how to remove the emphases on performance related outcomes (e.g., winning matches and leagues) and focusing on developmental assets (e.g., competence, confidence, connection, and character) could encourage long-term outcomes (e.g., performance, participation, and personal development) (49). Models such as the personal assets framework have been used to explain how RAEs affect the three dynamic elements (i.e., personal engagement in activities, appropriate settings and organisational structures, and quality social dynamics), which interact in the immediate timescale for sport development to occur (18, 50). For instance, the emphases on performance related outcomes might hinder the personal engagement of relatively younger players as they may lack confidence or advanced competencies. Therefore, educating practitioners and policy makers to change the emphasis of performance related outcomes to long-term developmental outcomes would likely affect how the dynamic factors interact, and subsequently enhance the sporting experience of relatively younger players.

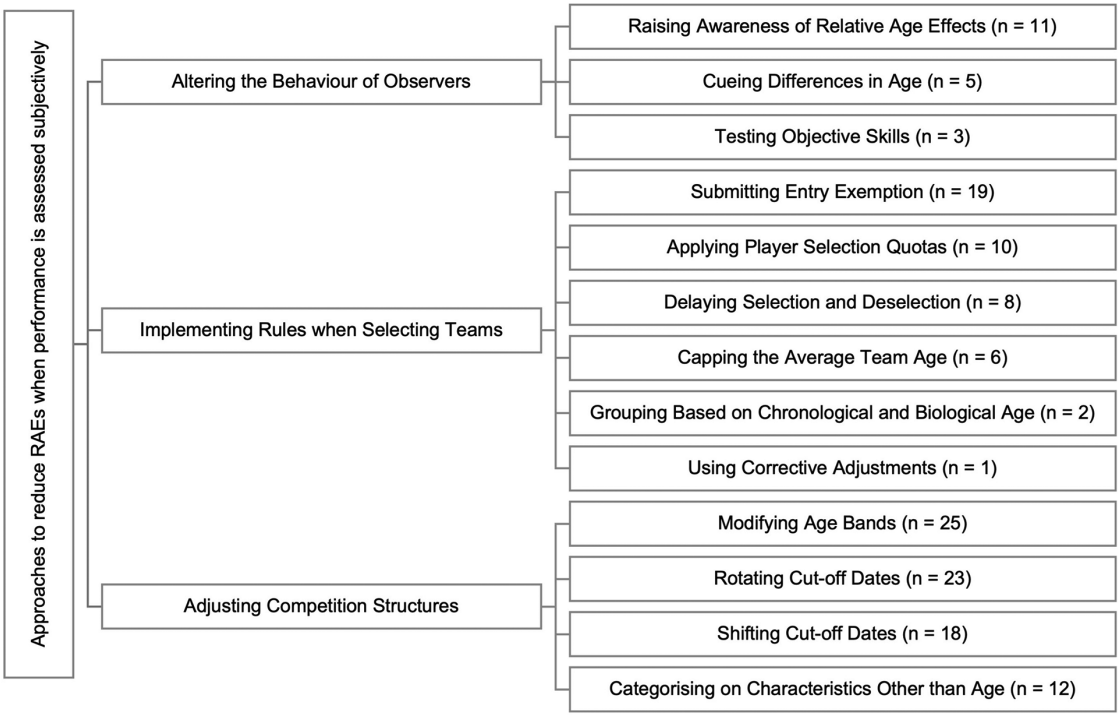


FIGURE 1
Categorisation of proposed solutions according to the taxonomy of Mann (1).

Cueing differences in age

Identifying, selecting, and developing young players is traditionally performed by coaches. Although it is common for coaches to acquire players' birthdates during these processes, RAEs still occur. One reason why the awareness of a player's birthdate may not reduce RAEs is that it is not usually transformed into an explicit prompt or integrated into coaches decision-making processes. In order to facilitate this, it is suggested that each player's relative age is explicitly provided to those who are charged with making decisions during talent identification and selection procedures. Interestingly, to our knowledge, this proposal is only one of two studies that has been empirically tested in the literature (23, 31).

Specifically, Mann and van Ginneken (23) showed how cuing differences in relative age, via age-ordered shirt numbering, positively impacted coaches and selectors decision making. In this case, coaches and selectors are provided with information about the relative age of players based on the numbers (e.g., birth quarter 1–4 or birth month 1–12) on bibs that correspond to the relative age of the players. Not only does this explicitly show the relative age of the players, but also simultaneously aligns only to those who are on the field during training and competition. The age-ordered shirt numbering experiment of Mann and van Ginneken (23) was conducted with scouts who were required to rank the potential of players after viewing one match. In Dutch youth soccer context, such one-off selection evaluations are relatively uncommon. More typically, especially in grassroots soccer, players are assessed over multiple occasions during training and matches across the season. This would require that players wear the same shirt number during all these assessments, which might limit the apparent simplicity of this solution.

Testing objective skills

The final proposed solution to mitigate RAEs by altering the behaviour of observers is to include objective skill tests as part of evaluation and selection procedures. These tests, which could minimize the impact of physical capacity, might provide a more equitable context for relatively younger players to perform and compete. Examples of such measures includes tests for technical skill (e.g., skills testing, performance analysis), tactical ability (e.g., positional awareness, perceptual-cognitive expertise), and psychosocial characteristics (e.g., friendships, leadership skills). In addition, these objective tests that are suggested to measure relevant skills in the context of soccer might provide a better indication of future performance, although the validity of such performance tests are currently debated (51). Since the typical evaluation and selection procedures in Dutch youth soccer consist of coaches or scouts evaluating a player's future potential during several training sessions and matches, combining these assessments with objective tests results would require a significant change. In addition, nationwide skills testing would require many resources (e.g., financial investment, highly trained staff, time allocation), likely making it only possible for a limited number of attributes and timepoints.

Implementing rules when selecting teams

The second higher-order category considers approaches that explicitly forces adjustments to grouping polices by implementing rules. There were six solutions proposed in this category: (a) submitting entry exemption ($n = 19$), (b) applying player selection quotas ($n = 10$), (c) delaying selection and deselection ($n = 8$), (d) capping the average team age ($n = 6$), (e) grouping based on chronological and biological age ($n = 2$), and (f) using corrective adjustments ($n = 1$).

Submitting entry exemption

Traditional age grouping and subsequent fixed cut-off dates means there is an upper age limit. As such, youth soccer players move up each year and remain in their respective under-age category until the end of the season (e.g., U11, U12, U13, etc.). This eligibility system allows younger players to compete in advanced age levels designed for older children, which is commonly known as "playing-up". Kelly et al. (52) found an overrepresentation of early birth quartiles who play-up and suggested that playing-up may impact chronological age grouping twofold: (a) moderate RAEs by presenting a new cohort of later birth quartiles, and (b) create an "underdog effect" for relatively older players. Goldman et al. (53) also captured players' perceptions of playing-up and the ways in which it may impact their development, with findings involving a balance between: (a) challenge, and (b) progress.

In contrast, allowing relatively younger players to "play-down" (i.e., submitting entry exemption) may be another way in which RAEs could be mitigated. Indeed, "playing-down" an age group may offer a more suitable developmental setting for relatively younger players whilst they "catch-up" with their relatively older peers (54). However, in contrast to playing-up, older players are not ordinarily allowed to compete in competitions designed for younger age groups. This solution suggests that enabling players to delay their entry into a higher age category might overcome the associated disadvantages of being relatively younger, whilst also providing a more challenging environment for those in a younger age group. In this sense, the player is provided with additional support in terms of extra time for development across a more appropriate level of challenge. Examples of such eligibility delays are known in North American university sport systems as "redshirting" or "taking a victory lap of high school" (55).

In some cases, within Dutch youth soccer, players are allowed to compete in a younger age group; although, this exemption is currently only available for players aged 13–17 years who experience severely delayed maturation, making it uncommon in practice. This policy, however, could be adapted to meet the needs of relatively younger children (e.g., those born in the second half of the selection year can play down an age group; clubs are allowed up to two players to play-down). However, it is important to note that this proposed solution is yet to examined and could create unintended consequences through the possible stigma attached to "playing-down", thus terminology such as "playing across" age groups may be more beneficial.

Applying player selection quotas

In traditional annual age grouping, all players born within a one-year period are eligible to play together in the same team. As a result, there is only one criterion when grouping players in a certain under-age team: all players must be born within that 12-month period (e.g., 1st January to 31st December). One proposed solution to mitigate RAEs was mandating (i.e., setting a quota) an equal proportion of players to be selected from each birth quartile (25%) or from the first and second half of the selection year (50%) [e.g., (56)]. This would ensure an even distribution of relatively older and younger players within teams, and thereby overcome the asymmetrical distribution of birthdates due to RAEs that favour relatively older players and disadvantaging relatively younger players (12).

Interestingly, selection quotas have been a part of a national discourse in an attempt to achieve racial transformation and inclusive representation in South Africa. For instance, Cricket South Africa mandated the "inclusion of a minimum average of six players of colour in the national team, of which at least two must be black Africans" (57). Such selection quotas, however, are yet to be evaluated in the context of RAEs. One potential reason could be the administrative burden that accompanies implementing this solution. In Dutch soccer, clubs can independently determine the structure of squads and thus implementing such quotas would significantly affect the autonomy of this process, while simultaneously, the KNVB has to check all squads during matchdays. To reduce these administrative challenges, the Belgian FA has recently announced that, for the time being, quotas will only apply to their elite academy teams (58).

Delaying selection and deselection

In popular sports such as soccer, children are grouped not only on their chronological age (e.g., U9, U10, U11, etc.), but also based on their ability (e.g., representative and non-representative teams). This means that, within annual age groups, there are parallel teams and/or competitive levels for players of different abilities. Generally, those who are considered more talented are selected for representative teams (i.e., academies/talent pathways), providing them with access to higher quality coaching, better facilities, and additional resources. Because selection procedures based on a child's ability are biased to favour relatively older players, a potential solution to overcome RAEs is to delay the process of selection and deselection (24). Encouraging stakeholders to avoid deselection at young ages will allow individuals to remain exposed to practice, competition, and resources without the option or fear of being deselected (59). This could decrease the emphasis on short-term outcomes (i.e., performance, winning) as well as the accompanying stress and pressure, particularly during critical stages of development (e.g., decrease in performance, maturation, and/or injury), and instead increase a focus to develop all players in the soccer system for as long as possible.

An example of how such a delay in selection and deselection may look in practice is to implement specific regulations that ensure clubs remove ability groupings until maturation is achieved (12, 60). Not only would this allow any maturational differences to have disappeared or levelled out between players before selection occurs, but it would also ensure the impact of relative age differences are minimised due to increasing age. For instance, a relatively older U5 could have lived up to 20% longer than their relatively younger equivalents, whereas a relatively older U15 could only be up to 6.6% older than their relatively younger peers. Selecting closer to the intended outcome (i.e., expertise in adulthood) will also help with the accuracy of talent identification in football (61). For example, the Belgian FA implemented national youth teams specifically focused on later developing players. Specifically, these "Future Teams" provide players with the opportunity to play competitive football while remaining in the national talent pathway, with other member associations, including the Netherlands replicating this initiative (62).

Capping the average team age

An alternative to using a single cut-off date and possibly minimize RAEs is grouping players according to a maximum average team age. This Average Team Age (ATA) grouping procedure sets the average age of a team to a predetermined maximum and simultaneously determines the maximum age difference between the oldest and the youngest player on a team. As such, both the mean and the range of ages are defined on a team eligibility basis rather than on an individual eligibility basis, allowing any individual player to participate across several different age groups (63). Accordingly, the ATA grouping procedure can be devised as follows: "a competing squad shall consist of no more than 'X' players whose average age on the competition start date shall be no more than 'Y'. No player in the team shall be more than 'Z' years older than the youngest player in the squad" (32, p. 114).

There is anecdotal evidence from Stoke City Football Club Academy in England who have trialled the ATA approach by mixing their U9 to U12 age groups. According to their academy staff, the grouping policy showed positive developmental opportunities for players in terms of social cohesion and additional challenges. Moreover, they stated how older players took on leadership roles when playing with younger academy teammates (64). Whilst this approach seems promising, it is yet to be empirically studied. In Dutch youth soccer, there is a long-standing tradition of (bi-)annual birth year grouping, therefore, implementing a new grouping approach based on a maximum average age would require significant changes to this process, especially at grassroots level. Similar grouping approaches, however, have been adopted in wheelchair rugby. Specifically, during a match at any given time, any four players may be on the floor if they do not collectively exceed eight points (with each player allocated a set number of points based on their functional mobility) (32). Indeed, the approach used here may help shed light on policy making and practical implementation of capping the average team age in the context of youth soccer.

Grouping based on chronological and biological age

A traditional underlying principle for annual age grouping in youth soccer is that children of a similar age will be of similar sizes and abilities and, as such, it will provide developmentally appropriate settings for all learners. Over the last two decades, however, a growing pool of literature has showed maturation status does not necessarily correspond to the chronological age of players (65), and thus maturity-associated differences might contribute to RAEs. Indeed, research has showed that there can be up to five years difference in biological age between those in the same chronological age, which can lead to later maturing players being systematically left out of academies, particularly those who are relatively younger (66). For instance, Hill et al. (67) showed that not one single late maturing player was part of their U15 and U16 English academy cohort, making it hard to consider how they can develop within the existing chronological structures.

To mediate the inequalities resulting from these maturity-related and relative age differences, it was proposed to group players based on their respective chronological birthdate *and* developmental birthdate (31). This approach estimates the developmental birthdate based on growth curves for stature, where the stature of a player is mapped on the average growth curve. In other words, stature is used as a proxy for biological maturation. For example, a 9-year-old Dutch boy would play in the U10. However, the child has the stature of 131 cm, which corresponds to a developmental age of 7 years and 10 months based on the normal growth curve of the Dutch male population. Grouping players is then based on the midway point of their chronological and developmental birth date. In this example, that would be 8 years and 5 months, reallocating the player to a lower age category (i.e., U9). Hence, this method could re-allocate players to a different age category if their estimated developmental birth date does not correspond with their chronological age. An empirical study by Helsen et al. (31) suggests that reallocation into new teams reduced both the variation in maturation status and the overrepresentation of players born in a certain birth quarter (i.e., RAEs). While including developmental birthdate based on stature would require some amendments to the traditional birthyear grouping, it could be implemented across the Dutch youth soccer context. For instance, stature is regularly assessed during primary and secondary school health checks and the outcomes can be used in tools such as the Dutch TNO Growth Predictor, to attain the corresponding chronological age based on the normal growth curve of the Dutch population (68).

Using corrective adjustments

In some sport contexts (e.g., long-jump, weightlifting, and swimming), performance can be measured objectively (i.e., in centimetres, grams, or seconds, respectively). Although this is not straightforward in team sports such as soccer, objective skills tests or performance analysis tools have been developed in which performance outcomes are assessed individually. For such measures, it is possible to adjust an individual's performance based on their relative age so that all children within the same chronological age group can be compared equally. Such corrective

adjustments are hypothesised to mitigate RAEs because they create a more equitable comparison of performance across players with different relative ages (69). More specifically, performance outcomes in terms of distance, weight, or time can be age-corrected for relatively younger players, creating a more equitable context to evaluate players. In swimming, for example, Cobley et al. (26) showed that when correctively adjusted swim times based on longitudinal reference data were implemented from accurate estimates of the relationship between decimal age (i.e., chronological and relative), RAEs were predominantly absent across age-group and selection levels. Thus, such an approach using performance metrics in soccer (e.g., player match analysis data) may be an avenue for future research for Dutch youth soccer.

Adjusting competition structures

The third and final higher-order category considers solutions that require adjustments to the current competition structure in youth soccer. There were four solutions proposed in this category: (a) modifying age bands ($n = 25$), (b) rotating cut-off dates ($n = 23$), (c) shifting cut-off dates ($n = 18$), and (d) categorising on characteristics other than age ($n = 12$).

Modifying Age bands

Age grouping in youth soccer generally applies 24- or 12-month bands. This means that players born in the first month can be up to 23- or 11-months older than the youngest player in an age band, respectively. Given that these age differences lead to RAEs, it is suggested that modifying the age band may help solve RAEs. To be specific, modifying age bands could result in decreasing the maximum relative age difference, whereby using multiple within-year cut-off dates limits the maximum age difference to, for instance, 6- or even 3-months. Moreover, as suggested by the so-called Novem system by Boucher and Halliwell (20), a smaller banding of 9-month age categories breaks the annual 12-month structure, reducing the systematic advantage of players born shortly after the cut-off date. This also creates greater diverse perspectives and a non-linear development pathway, since players become the relatively youngest and oldest throughout their development due to the 9-month annual cycles.

Rotating cut-off dates

January 1st is the most common cut-off date to group players based on their chronological age, although this can vary depending on each countries own policies (70). This cut-off date is then maintained throughout all youth age categories until senior soccer, creating a relative age difference that provides a consistent advantage for those children born earlier in the selection year throughout their entire development. Consequently, solutions to mitigate RAEs target this age advantage so that this advantage of being the oldest is balanced over all players within the selection year. Accordingly, rotating cut-off dates has been proposed as a potential solution for RAEs.

In practice, there are several ways that the cut-off date can be rotated. For example, every season the cut-off date could be shifted three months from January 1st to April 1st, which would see the oldest players move up to the older age cohort to become the youngest players amongst that cohort [i.e., the Relative Age Fair (RAF) cycle; (21, 71)]. Another version of this proposal that is used in the England Squash Talent Pathway is termed "birthday-banding" (29), whereby young athletes move up to the next age-group on their birthday. In Dutch youth soccer, for example, when a 'U13' player turns 14, they would advance to the 'U14' age group and remain in that age group until their next birthday. The aforementioned "modifying age bands" suggestions that aim to break the structure based on a multiple of twelve, such as 9-, 15-, or 21-month grouping procedures, would also create a new cut-off date after every annual cycle (72).

Shifting cut-off dates

Since 1997, most international youth soccer competitions adopt the cut-off date of January 1st (73). Although this shift has not resulted in any changes regarding the prevalence of RAEs in youth soccer, also not in the Netherlands, there have been some interesting cases where alignment of the cut-off date at school and in sport suggests a higher likelihood of RAEs. For instance, cut-off dates that are the same date for school enrolment and sport are likely to (dis)advantage the same children in both domains, while shifting cut-off dates would distribute these (dis)advantages across different domains (i.e., school and sports), so that each child could benefit from being relatively older and younger in diverse contexts (74). As such, shifting cut-off dates to deviate away from the educational cut-off date (e.g., September 1st) and other sports has been proposed as a possible solution for RAEs in soccer. However, after the US Soccer Federation changed its birth-year registration cut-off date from August 1st to January 1st (in 2015) to align the US youth soccer calendar with international standards, while simultaneously provide clearer information on player birthdates to "lessen" RAEs, it only shifted the athletes experience relative age (dis)advantages. Moreover, the related outcomes were negatively perceived by stakeholders at various levels of the sport (75). Therefore, the Dutch FA should be cautious about using this approach as it could lead to unintended consequences.

Categorising on characteristics other than age

To ensure equitable competition for players, individuals are grouped according to their chronological age. It is expected that players of a comparable same age will be of similar ability, size, and physique. However, individual variation in physical characteristics and the maturation status of players is not accounted for in chronological age grouping (13). As such, relatively older players, who may be more likely to have a physical advantage, are subsequently considered more gifted by coaches who misconstrue the enhanced growth, physical capabilities, and maturational status with talent (76, 77). Hence, alternative grouping approaches, such as "bio-banding", have been proposed to mitigate RAEs. So far, no nationwide alternative grouping approaches have been implemented in the Netherlands, although anecdotal evidence suggests individual clubs might use bio-banding next to regular age grouping [e.g., (78)].

This grouping approach accounts for individual variability in physical characteristics by grouping players on their biological age (i.e., maturity status), often using their percentage of predicted adult height [see (79) for a review]. As such, same-aged peers might play on different teams according to their maturational status in contrast to using chronological age as a grouping criterion. According to players, a key advantage of this grouping approach is that early-maturing athletes, who tend to be relatively older, can "play-up" thereby gaining valuable learning experiences from having to compete with older players (80). However, it is essential to note that biological age and relative age are two independent constructs, whilst bio-banding has been specifically designed to moderate maturity-related biases and has yet to be tested on its influence on RAEs.

Limitations

It is important to recognise that this call for action was made via the KNVB, and thus the benefits and drawbacks of these proposed solutions could differ based on other national contexts (81). For instance, the Netherlands is a relatively small but densely populated country where soccer is the most popular sport, which could have impacted on the knowledge of stakeholders, the mechanisms of the proposals, and their subsequent benefits and drawbacks. In contrast, the call to action was publicly available and not limited to Dutch participants, which could have yielded wider suggestions that may not be applicable to the Netherlands. Although, in our opinion, this widened the pool of proposed solutions rather than hindered the methods. In addition, RAEs effect boys and girls differently [e.g., (2, 8)], therefore potential solutions may benefit (or not benefit) each gender in different ways [see (82) for a review], which was generally not acknowledged throughout the proposed solutions. Overall, we recommend the reader should reflect on how effective and feasible the proposed solutions are within their respective youth soccer environment before testing them in practice.

Conclusion

Relative Age Effects are well established in youth soccer. To date, however, limited attempts have been made to better understand potential solutions in real-life youth soccer settings. In this call to action, 13 proposed solutions were suggested to mitigate RAEs, although no new solutions outside the existing literature were presented. Whilst the purpose of this study was to underscore possible relative age solutions, it was beyond its scope to explore the potential benefits and drawbacks of each proposal. Importantly, though, it should be recognised how solutions that alter the behaviour of observers and require adjusting competition structures can be driven from the KNVB as the governing body of Dutch youth soccer. Whereas, solutions that implement rules for selecting teams are much less dependent on a nationwide rollout and can more easily be introduced at regional/local club levels. A crucial next step for this research group was to utilise the knowledge of experts in this field via an adapted e-Delphi study, in order to identify the most effective and feasible solutions to apply in practice (Part Two). Furthermore, it will be important to design, implement, and evaluate solutions that are perceived to be the most effective and feasible across a variety of Dutch youth soccer settings.

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 Health, Education, and Life Sciences Faculty Academic Ethics Committee at Birmingham City University (ethics code #9524). 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

AK: Writing – original draft, Writing – review & editing. FZ: Funding acquisition, Project administration, Supervision, Writing – review & editing. DM: Writing – review & editing. JV: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing.

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Supplementary material

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Born to win? Investigating the relative age effects in the big five European women's football leagues

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Introduction: This study examines the presence of the Relative Age Effects (RAEs) among players in the top five European women's football leagues during the 2023/24 season.
Methods: A total of 1,634 professional players from the Women's Super League (England), Liga F (Spain), Frauen-Bundesliga (Germany), Serie A Femminile (Italy), and Division 1 Féminine (France) were analyzed. Birth date distributions were assessed to determine the prevalence of RAEs both collectively and within each league.
Results: Poisson regression analyses revealed significant overall RAEs, with a higher proportion of players born in the first semester of the year. Individually, significant RAEs were found in England, Spain, Italy, and France, while Germany did not exhibit statistically significant effects. When analyzed by playing position, significant RAEs were observed among goalkeepers and midfielders, but not among defenders and forwards.
Discussion: These findings highlight the ongoing influence of RAEs in elite women's football and underscore the need for strategies to mitigate its impact on talent identification and player development.

KEYWORDS

relative age effects, soccer, talent identification, birth date, development, maturation

1 Introduction

In recent years, women's football has experienced significant growth, particularly in European countries. Between 2019 and 2023, the number of registered female players increased by 45.03% in England, 66.7% in Spain, and 17.36% in France (1, 2). However, the United States still represents approximately 40% of all female football federation registrations worldwide (2), a statistic that justifies this nation's performance globally in the history of this sport.

This growth in participation has been accompanied by a notable increase in the volume of scientific research dedicated to women's football (3). This emerging volume of scientific research enabled researchers to transition away from the previously predominant unisex approach, wherein findings from men's football were indiscriminately applied to women's football due to the lack of sex-specific evidence (4). Among the underexplored topics in women's football research are the relative age effects (RAEs), a phenomenon extensively

studied in men's football but less comprehensively examined in the context of the female game (5, 6).

The relative age effects in sports, particularly in football, is defined as the consequences on performance stemming from differences between athletes' chronological and biological ages (7, 8). In recent years, the understanding of this issue has led to establishing a series of conclusions regarding talent selection at early ages (9). Consequently, different approaches have been proposed to eliminate or reduce the influence of these effects, one of the most notable being bio-banding. This method consists of categorizing young athletes, typically aged 11–15, into groups or "bands" according to their estimated biological maturity rather than solely their chronological age for specific competitions and training sessions (10). The assessment of maturity is generally based on the predicted percentage of an individual's final height at a given point in time. However, the authors emphasize that bio-banding should be applied in specific contexts and used primarily for short-term purposes, such as training periods or experimental tournaments.

Another emerging concept in the literature on relative age effects in sports is the "underdog" phenomenon (11, 12) which has been explored as a hypothesis in other studies (13, 14). This theory posits that younger athletes within a given cohort face challenges from their relatively older peers. It suggests a reversal of the traditional RAEs perspective, arguing that what truly defines elite players is their ability to overcome disadvantages, including those imposed by RAEs. To support this claim, studies not only examine the presence of the effects but also track athletes' development and career trajectories from their early years. Finally, other models have also been considered in the literature to analyze relative age, such as the social agents theory (15). This approach examines how parents, coaches, and athletes themselves influence the effects of relative age. Similarly, the developmental systems theory has been explored, highlighting the constraints associated with RAEs (16). These constraints fall into three categories: individual (date of birth), task-related (type of sport), and environmental (social factors and sports development).

In the specific context of women's football, several authors have investigated the influence of these effects, although the results found are often contradictory (17–33). One of the first studies (25) on women's football was conducted in the United States and aimed to demonstrate the occurrence of this selection bias in players from the US Olympic Development Program. These authors showed a slight bias toward overrepresentation of players born in the first half of the year compared to the second. However, this effect was not observed when the analysis was conducted based on the quarter of birth (25).

Following this initial evidence, research in Asia has provided further evidence into the prevalence of RAEs. Matsuda and Ishigaki (19) observed, after analyzing a sample of over 4,000 players, that the percentage of players born in the first quarter of the year was approximately 10% higher compared to those born in the last quarter of the year. Nakata and Sakamoto (27) further examined sex differences in RAEs among Japanese athletes, highlighting distinct patterns between male and female players. In China, Li et al. (28) explored the impact of the "one-child" policy on elite soccer players, suggesting that structural constraints in talent selection may have influenced the observed RAEs.

In Europe, multiple studies have confirmed the presence of RAEs across different levels of competition, particularly among players from national and regional teams (22). Research in Switzerland (29) and other recent studies on elite female soccer players in international tournaments (30, 31) have further highlighted the prevalence of RAEs, especially in younger age categories, with positional and regional variations. Additionally, Delorme et al. (17) found that RAEs were evident in lower divisions of French football. However, relative age effects did not occur in adult players; on the contrary, there was an underrepresentation of players born in the first quarter of the year (17), which could be justified by the "underdog" theory (11), according to which future performance and the duration of sports careers could be greater for athletes born in the later quarters of the year. A broader analysis in Italy with a sample of 1,535 female basketball, volleyball, and football players, with greater effects observed in football (34). It is also interesting to note the study conducted in Germany, which analyzes RAEs from two perspectives: as within-year effects (WYEs), examined within the same birth year, and as between-year effects (BYEs), where athletes are grouped into two-year age bands. In the latter case, disadvantages are more pronounced (33).

On the other hand, numerous studies have not found evidence of relative age effects in women's football. For example, a recent study (21) conducted on the FIFA Women's World Cup championships held since 2007 in the absolute, U20, and U17 categories observed that relative age effects in the U17 and U20 samples were not significant until the years 2016 and 2018, respectively, when the effects were observed. Furthermore, no effects were observed in 2007, 2011, 2015, and 2019 editions of the FIFA Women's World Cup (21). Similarly, a recent investigation found no effects of relative age in 2,387 female players from the qualification squads/teams for the most recent European Championship campaigns (35).

In addition, other studies have also failed to detect significant RAEs in elite women's football. For instance, Riveiro et al. (31) analyzed under-17, under-20, and adult elite female soccer players, reporting no significant relative age effects in adult categories. Likewise, Delorme et al. (17) investigated the prevalence of RAEs in elite sports in France, considering the possible influence of gender. Their results indicated that, although RAEs are evident in men's sports, its presence in women's sport is less consistent, suggesting that the effects may vary depending on gender and the specific sport. Nakata and Sakamoto (27) examined RAEs among elite Japanese athletes and found that, in the case of female athletes, only volleyball showed significant RAEs. In other female sports analyzed, such as football, no skewed distribution of birthdates was observed. These findings highlight the complexity of relative age effects in women's football and suggest that its presence may be influenced by multiple contextual and structural factors.

Considering all the studies mentioned, it is essential to continue exploring the relative age effects in women's sports, specifically in the world of football. Therefore, this research aims to address two objectives: first, to determine the presence of

relative age effects across the five major European leagues, both collectively and individually; and second, to evaluate whether these effects varies based on players' positional roles.

2 Materials and methods

2.1 Study design

This research employed a cross-sectional observational design to evaluate the presence of Relative Age Effects (RAEs) among players in the top five European women's football leagues (based on their economic impact, competitiveness, and visibility, as highlighted annually in Deloitte's Football Money League reports) during the 2023/24 season: the Women's Super League (England), Liga F (Spain), Frauen-Bundesliga (Germany), Serie A Femminile (Italy), and Division 1 Féminine (France). The study focused on the entire roster of registered players for each team within these leagues, aiming to provide a comprehensive view of RAEs at the elite level of European women's football.

2.2 Participants

The study sample consisted of 1,634 professional female football players distributed across the five leagues. To ensure accuracy, data collection was conducted between February 1 and February 10, 2024, shortly after the closure of the mid-season transfer window. Only players officially registered with their respective clubs at this time were included. Any players on long-term leave, such as maternity or injuries, were also considered part of the roster if they remained registered.

2.3 Data collection

Data were sourced from publicly available records on official club websites and the specialized football statistics platform Livefutbol (36). Information for each player included: full name, date of birth (used to determine the player's relative age within the competition year), playing position (classified as goalkeeper, defender, midfielder, or forward), and club affiliation.

Additional manual verification was performed to cross-check data discrepancies between club websites and the Livefutbol platform. This ensured consistency and accuracy of the dataset used in the analysis.

2.4 Determination of relative Age effects and data analysis

The standard cut-off date for categorization by birth year is January 1st. However, England's Women's Super League uses a September 1st cut-off date, in line with the academic year. For the English league, player birth dates were adjusted to align with this variation. Adjusted dates were used in subsequent calculations to maintain consistency across leagues.

Relative Age Effects (RAEs) were first evaluated and proved ($\chi^2 = 46.77$; $p < 0.001$) using the Chi-square goodness-of-fit test for a hypothetical equal distribution across the four quartiles. Similarly, an association analysis was conducted between the birth quartile variable and the league and position variables, taking into account that for this second analysis, the expected values for each of the positions and leagues were those observed in the overall sample (i.e., 27.4%, 28.4%, 22.2%, and 20.0%). The effect size for this association quantified using Cramer's V. Finally, Relative Age Effects were calculated through Poisson regression (37, 38). The Poisson regression formula $y = e$ (b0 + b1x) serves to explain the frequency count of an event (y) by an explanatory variable x. The data used for Poisson regression were week of birth (WB) whereby the first week in January was designated WB 1, and time period of birth (Tb) describing how far from the beginning of the year a player was born. This last index ranging between 0 and 1 was calculated as Tb = (WB − 0.5)/52. In the Poisson regression, the event (y) was the frequency of birth in a given week and the explanatory variable (x) was Tb. We also calculated the index of discrimination (ID) according to Doyle and Bottomley (38) as e-b1. This index measures the relative odds of a player born on day 1 vs. day 365 of the competition year being selected. The likelihood ratio D^2 was determined according to Cohen et al. (39). All statistical tests, including descriptive analysis, were performed using the software package R (version 4.3.2). Significance was set at $p < 0.05$.

3 Results

3.1 Distribution of birth dates by league

The distribution of players' birth dates according to their quartile (Q) of birth across the five leagues is summarized in Table 1.

As shown in Table 1, Q1 (27.4%) and Q2 (28.4%) together account for the majority of players, whereas Q3 (22.2%) and Q4 (22.0%) present lower proportions. This trend is consistent when analyzing each league individually: (a) Women's Super League (England) with 55% of players were born in Q1 and Q2; (b) Liga F (Spain) with 58%; (c) Frauen-Bundesliga (Germany) with 53%; (d) Serie A Femminile (Italy) with 55% in; (e) Division 1 (France) with 57%. Notably, Serie A Femminile shows a particularly high representation of Q1 (29.6%), while Liga F stands out with a higher share of Q2 (32.3%). Despite these variations, the association analysis revealed no significant dependency between the league and the birth quartile ($\chi^2 = 17.808$; $p = .33$). Additionally, the association analysis between both variables showed that there was no dependency between the league and the birth quartile.

At the club level, the majority of clubs within each league also exhibited a higher number of first-semester-born players. Specifically: (a) Women's Super League (England): 9 out of 12

TABLE 1 Association between birth quartile and league.

League	Q1 (*n* = 441–27.4%)	Q2 (*n* = 457–28.4%)	Q3 (*n* = 358–22.2%)	Q4 (*n* = 354–22.0%)	*P* [ES]
Division 1 Feminine	93 (28.8%)	92 (28.5%)	78 (24.1%)	60 (18.6%)	
FA Women's Super League	86 (29.0%)	77 (25.9%)	67 (22.6%)	67 (22.6%)	
Frauen – Bundesliga	79 (24.3%)	92 (28.3%)	77 (23.7%)	77 (23.7%)	$p = .33$
LigaF	100 (25.8%)	125 (32.3%)	67 (17.3%)	95 (24.5%)	
Serie A	83 (29.6%)	71 (25.4%)	69 (24.6%)	57 (20.4%)	

clubs had more first-semester players; (b) Liga F (Spain): 14 out of 16 clubs had more first-semester players; (c) Frauen-Bundesliga (Germany): 6 out of 12 clubs had more first-semester players; 5 clubs had more second-semester players, and 1 club had an equal number; (d) Serie A Femminile (Italy): 8 out of 10 clubs had more first-semester players; (e) Division 1 (France): 10 out of 12 clubs had more first-semester players.

Figure 1 illustrates the distribution of players' birth dates by quarter across the five European leagues. The figure demonstrates that the first two quarters (Q1 and Q2) account for a larger percentage of players (56%) compared to Q3 and Q4 (44%).

3.2 Poisson regression analysis by league

To statistically assess the presence of RAEs, Poisson regression analyses were conducted for the overall sample and for each league individually. The results are presented in Table 2.

The Poisson regression for the overall sample revealed a significant negative association between time of birth (Tb) and the frequency of players ($b_1 = -0.45$, $p < 0.001$), indicating the presence of RAEs. The Index of Discrimination (ID) was 1.57, suggesting that players born at the beginning of the year are 1.57 times more likely to be selected than those born at the end of the year. The Poisson regression analysis revealed the presence of a significant ($p < 0.001$) overall RAEs in players in the first division of the teams in Division 1 (France). There is also a significant difference ($p < 0.01$) in Serie A Femminile (Italy), and a significant difference ($p < 0.05$) in Liga F (Spain) and Women's Super League (England). There is no significant difference ($p = 0.36$) in Frauen-Bundesliga (Germany). The McFadden's D^2 values indicate a moderate model fit, with higher values in Serie A Femminile ($D^2 = 0.16$) and Division 1 Féminine ($D^2 = 0.17$). In contrast, the Frauen-Bundesliga shows the lowest D^2 (0.02), aligning with the non-statistically significant RAEs observed in this league.

Figure 2 shows the frequency of week of birth and the Poisson regression line for the overall sample. The negative slope of the regression line in Figure 2 indicates a decrease in the number of players born later in the year, consistent with the presence of RAEs.

3.3 Distribution of birth dates by playing position

The distribution of players' birth dates according to quartile by playing position is detailed in Table 3. Statistically significant differences were found between the specific position and the birth quartile ($\chi^2 = 46.77$; $p < .05$; ES = .06).

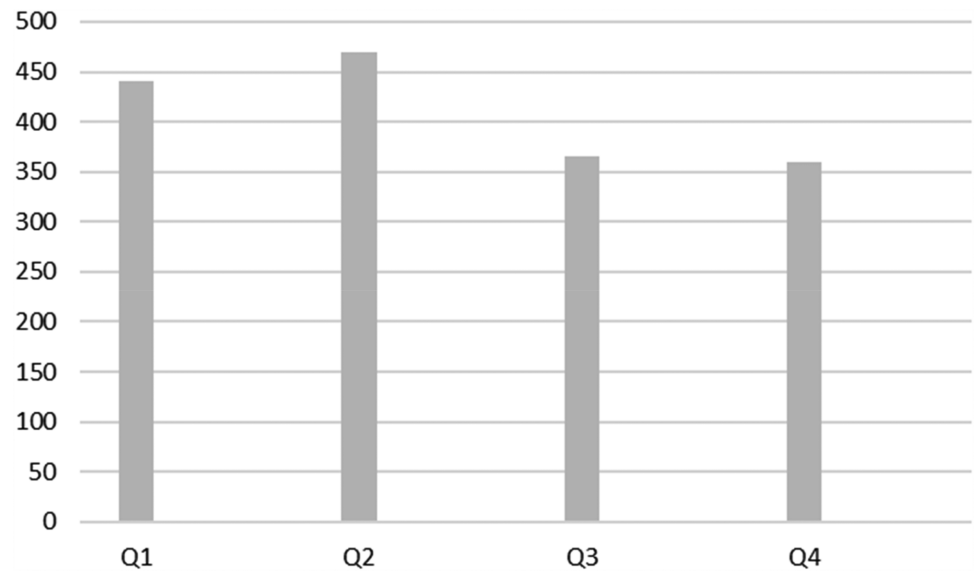


FIGURE 1
Frequency of players by quarter for all players in the five European leagues.

TABLE 2 Poisson regression analysis of RAEs by frequency for all players by league.

League	*n*	WB (Mean ± SD)	Tb (Mean ± SD)	b_0	b_1	ID	D^2 (McFadden)	*p*-value
Overall (5 Leagues)	1,634	25 ± 15	0.47 ± 0.28	3.65	−0.45	1.57	0.24	<0.001
Women's Super League	297	25 ± 15	0.47 ± 0.28	1.94	−0.43	1.54	0.08	<0.05
Liga F	389	25 ± 15	0.47 ± 0.28	2.19	−0.41	1.50	0.06	<0.05
Frauen-Bundesliga	344	26 ± 15	0.49 ± 0.28	1.95	−0.17	1.19	0.02	0.36
Serie A Femminile	281	24 ± 15	0.45 ± 0.28	1.99	−0.66	1.93	0.16	<0.01
Division 1	323	24 ± 14	0.45 ± 0.26	2.11	−0.64	1.88	0.17	<0.001

WB, week of birth; Tb, Time period of birth; ID, Index of Discrimination [e^(−b_1)]; D^2: likelihood ratio.

When analyzing by position, there is a greater presence of players born in the first semester (Q1 and Q2) across all positions, goalkeepers are more frequently born in Q1 (33.3%) and Q2 (33.9%), while their presence is statistically significantly lower in Q3 birth quartile ($Z < -1.96$), indicating an underrepresentation in this quartile Defenders show the highest proportion in Q2 (32.9%, followed by Q1 (27.4%), with Q3 (19.4%) and Q4 (20.3%) being less common. Midfielders are more evenly distributed, but Q3 stands out with a statistically significantly higher representation compared to Q4 (17.6%), the lowest among all quartiles. Strikers follow a more gradual trend, with the highest proportion in Q1 (28.0%) and a continuous decrease toward Q4 (21.6%). When breaking it down by championship, the overall trend shows more players born in the first semester for the entire sample. However, there are two exceptions: forwards in the Frauen-Bundesliga have a higher presence of players born in the second semester, and defenders in England have an equal number of players born in the first and second semesters.

3.4 Poisson regression analysis by playing position

Poisson regression analyses were conducted for each playing position, with results summarized in Table 4.

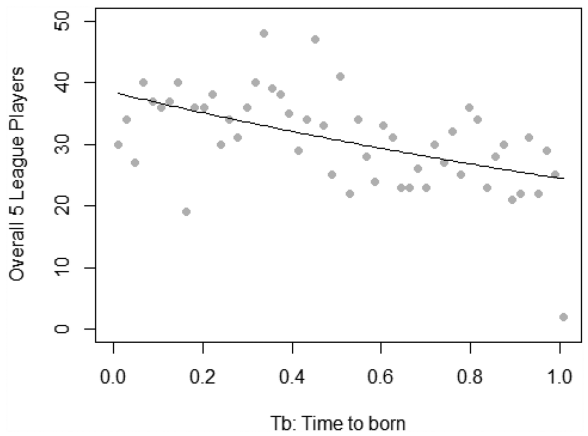


FIGURE 2
Frequency of week of birth (WB) for all players and poisson regression line for the overall five leagues.

The analyses reveal the presence of significant relative age effects (RAEs) in midfielders ($p < 0.001$, ID = 1.72) and goalkeepers ($p < 0.01$, ID = 2.11). However, no significant RAEs were found among defenders ($p = 0.13$, ID = 1.27), while forwards showed no significant RAEs but presented a marginal trend ($p = 0.056$, ID = 1.38). These findings align with the results of the Poisson regression by demarcation, which identified significant RAEs in midfielders and goalkeepers, but not in defenders or forwards. The McFadden's D^2 values suggest a stronger model fit for goalkeepers ($D^2 = 0.11$) and midfielders ($D^2 = 0.18$), supporting the presence of statistically significant relative age effects in these positions. Conversely, defenders ($D^2 = 0.03$) and forwards ($D^2 = 0.06$) show lower values, indicating a weaker or non-statistically significant effects.

Figure 3 exhibits the frequency of week of birth and Poisson regression for each playing position.

3.5 Distribution of birth dates by playing position and league

Finally, Table 5 presents the results of the contingency table and association analysis between the variables birth date and playing position for each of the leagues independently. The results obtained indicate that there is no statistically significant association between these variables when analyzed within each league separately, in contrast to the statistically significant association observed when assessed overall.

4 Discussion

Our results suggest noticeable tendency towards Relative Age Effects in the most important female football leagues in Europe with the exception of German Frauen Bundesliga. This aligns with similar research that analyzed Japan Woman Soccer League (i.e., Nadeshiko League) and stated that RAEs were also present at the top female football league in Japan with a clear predominancy of Q1 born players (19). Similarly, in Spanish female football, the top three divisions, regional, and national teams showed the presence of Relative Age Effects (22). Same results were also found in the Turkish Women's Super League during the 2022–2023 season (24), but it is worth noting that the effects were mild when only the top teams in the league were analyzed, while these effects disappeared in the total sample of the league, possibly due to significant

TABLE 3 Association between birth quartile and player position.

Position	Q1 (*n* = 441–27.4%)	Q2 (*n* = 457–28.4%)	Q3 (*n* = 358–22.2%)	Q4 (*n* = 354–22.0%)	*P* [ES]
Goalkeeper	61 (33.3%)	62 (33.9%)	**26 (19.4%)****	34 (20.3%)	$p < .05$ [.06]
Defender	124 (27.4%)	149 (32.9%)	88 (19.4%)	92 (20.3%)	
Midfielder	146 (28.9%)	144 (28.5%)	**126 (25%)***	89 (17.6%)	
Striker	110 (28.0%)	102 (26.0%)	96 (24.4%)	85 (21.6%)	

*More observed than expected values obtained through the z value of the adjusted residual.
**Less observed than expected values obtained through the z value of the adjusted residual.

TABLE 4 Poisson regression analysis of RAEs by frequency for all players by playing position.

Position	*n*	WB (Mean ± SD)	Tb (Mean ± SD)	b_0	b_1	ID	D^2 (McFadden)	*p*-value
Goalkeepers	191	24 ± 15	0.45 ± 0.28	1.64	−0.75	2.11	0.11	<0.01
Defenders	459	26 ± 15	0.49 ± 0.28	2.28	−0.24	1.27	0.03	0.13
Midfielders	522	25 ± 15	0.47 ± 0.28	2.55	−0.54	1.72	0.18	<0.001
Forwards	407	26 ± 15	0.49 ± 0.28	2.20	−0.32	1.38	0.06	0.056

WB, week of birth; Tb, time period of birth; ID, Index of Discrimination [e^(−b_1)]; D^2: likelihood ratio.

differences in level between the teams analyzed. Curiously, in the case of the Brazilian Female Football First Division (i.e., Campeonato Brasileiro Futebol Feminino A1), Relative Age Effects were trivially present when all players of the competition were analyzed together; however, it was not found when the players were categorized by their specific position (23).

In regards to playing positions and RAEs, our findings indicate significant RAEs among goalkeepers and midfielders, but not among defenders and forwards. This contrasts with findings by Bilgiç and Işin (30) in the 2016, 2018, and 2022 FIFA Women's World Cup. These authors (30) reported statistically significant RAEs across all positions in U17 and among defenders and midfielders in U20. This suggest that age-related selection biases may vary by competition level and tournament structure. Complementarily, Ribeiro et al. (31) observed, in the Women's Football World Cup from 2018 to 2019, a strong overrepresentation of players born in Q1, particularly among midfielders, which aligns with our results, as midfielders exhibited significant RAEs. Moreover, goalkeepers and defenders were found to be influenced by the highest RAEs in Spanish female football national teams and top competitive levels (22), which aligns with our present results, except for the case of defenders in the Women's Super League (England). Additionally, recent research in U.S. youth women's football has reported that RAEs are particularly pronounced among goalkeepers, central defenders, midfielders, and center forwards during the talent identification phase, though these positional biases diminish when players reach the youth national team (40).

A similar study of the top BIG 5 European leagues (i.e., British Premier League, Spanish LaLiga, French Ligue1, Italian Serie A, and German Bundesliga) was conducted by Úbeda-Pastor et al. (41) using a male sample. The results indicated the presence of RAEs in four out of the five leagues (LaLiga, Ligue 1, Serie A, and Bundesliga), with statistically significant overrepresentation of players born in the first quarter of the year. However, no significant differences were found in the English Premier League. Moreover, more recent comparative study has emphasized that while RAEs are robustly evident in male competitions, the magnitude and patterns in female competitions differ (17, 35), suggesting that selection dynamics may operate differently across genders.

On an overall scope, it´s interesting to point out the importance of RAEs in youth stages, since high presence of RAEs in adolescence translates in a presence of RAEs also early adulthood career phase (i.e., younger than 25 years old) in different sports (e.g., rugby, volleyball and basketball) with an special note on football, where results has shown that not only affect early adulthood but also later phases as well (42). In this regard, recent investigations in other sports, such as athletics, have underscored that the developmental trajectories contributing to RAEs are complex and evolve over time, with early advantages potentially diminishing as athletes mature (31, 43).

One explanation for RAE been considered lees influential in female sport could be the lower level of competition among female athletes for positions in elite teams. If an activity is far more popular among boys than girls in a given country, and if similar elite structures exist with a similar selection system, it is not surprising to find higher RAEs among males than among females (17). The second major determinant, physical development, also deserves to be interrogated with regard to potential sex differences. Baxter-Jones (44) suggested that the stronger RAEs among male athletes are the result of the earlier maturation of girls and the higher variance of the maturity status of boys. During the period of selection, there would thus be more significant differences between boys than between girls. Gredin et al. (45) examined psychological risk factors and found that perceptions of sport competence and motivational climate significantly affected athletes' likelihood of continuing in the sport. Vincent and Glamser (25) argued that social pressures to conform to a socially constructed gender role (i.e., stereotyped definition of femininity) "could make early maturing females less motivated to achieve excellence in competitive sport because of a perception that society does not value female athletic accomplishments in the same way it does those of males". Thus, early maturing females are more subject to leaving competitive sports than later maturing females (25).

As stated in the introductory part of the present manuscript, female football is an emerging sport in many European countries

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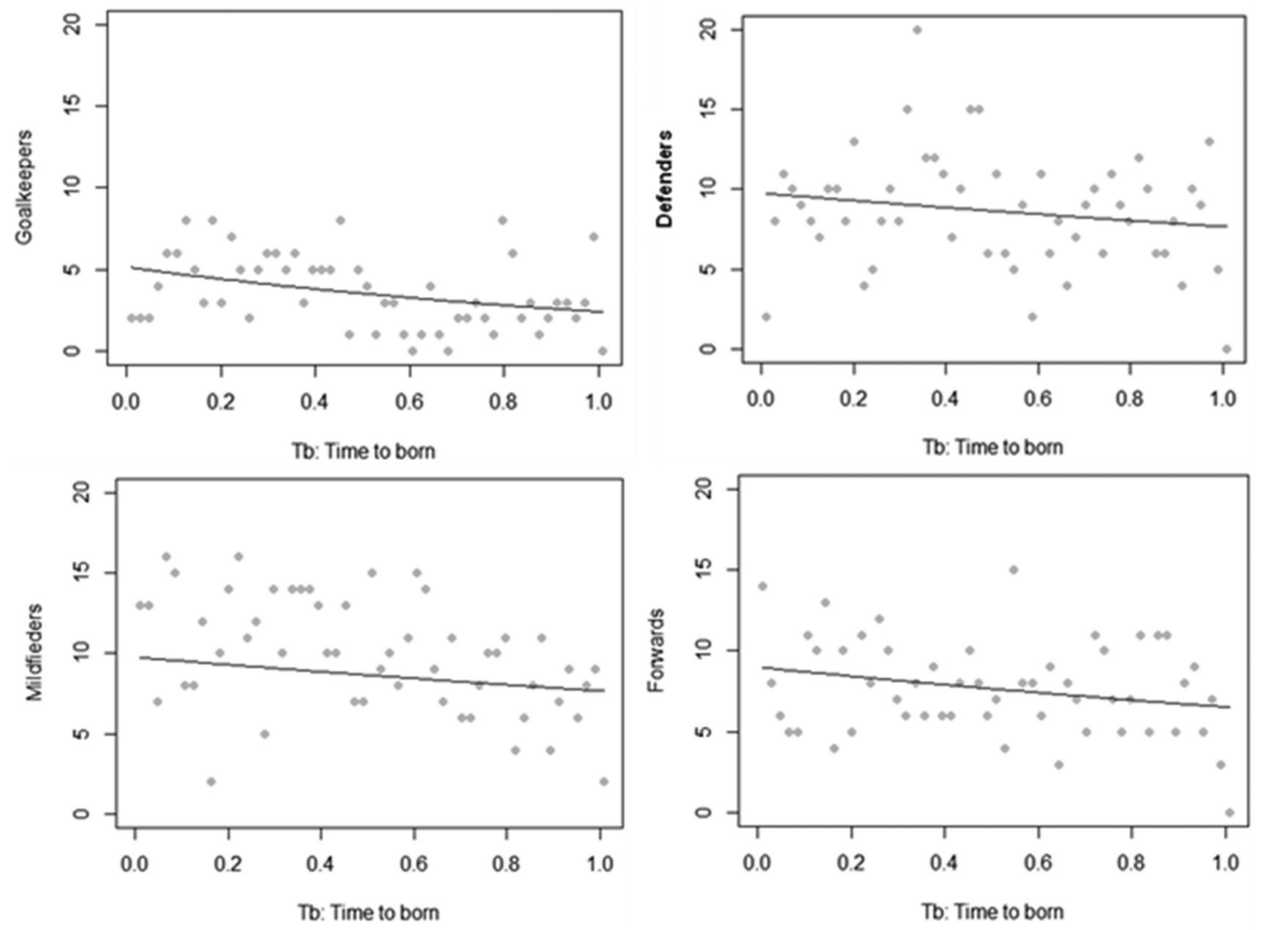


FIGURE 3
Frequency of week of birth (WB) and poisson regression for each playing position.

TABLE 5 Association between birth quartile and player position in top-5 female European leagues.

League	Position	Q1 (*n* = 441–27.4%)	Q2 (*n* = 457–28.4%)	Q3 (*n* = 358–22.2%)	Q4 (*n* = 354–22.0%)	*P* [ES]
Division 1	Goalkeeper	13 (33.3%)	10 (25.6%)	8 (20.5%)	8 (20.5%)	.74 [-]
	Defender	34 (35.1%)	28 (28.9%)	20 (20.6%)	15 (15.5%)	
	Midfielder	22 (22.9%)	30 (31.3%)	27 (28.1%)	17 (17.7%)	
	Striker	24 (26.4%)	24 (26.4%)	23 (25.3%)	20 (22.0%)	
Serie A Femminile	Goalkeeper	11 (30.6%)	10 (27,8%)	5 (13.9%)	10 (27.8%)	.68 [-]
	Defender	24 (28.2%)	23 (27,1%)	19 (22.4%)	19 (22,4%)	
	Midfielder	31 (33.0%)	20 (21.3%)	25 (26.6%)	18 (19.1%)	
	Striker	17 (26.2%)	18 (27.7%)	20 (30.8%)	10 (15.4%)	
Liga F	Goalkeeper	12 (30.0%)	14 (35.0%)	5 (12.5%)	9 (22.5%)	.60 [-]
	Defender	24 (19.2%)	48 (38.4%)	22 (17.6%)	31 (24.8%)	
	Midfielder	34 (29.3%)	36 (31.0%)	20 (17.2%)	26 (22.4%)	
	Striker	30 (28.3%)	27 (25.5%)	20 (18.9%)	29 (27.4%)	
Women's Super Lige	Goalkeeper	13 (36.1%)	12 (33.3%)	2 (5.6%)	9 (25.0%)	.56 [-]
	Defender	21 (25.6%)	20 (24.4%)	21 (25.6%)	20 (24.4%)	
	Midfielder	28 (28.3%)	26 (26.3%)	25 (25.3%)	20 (20.2%)	
	Striker	24 (30.0%)	19 (23.8%)	19 (23.8%)	18 (22.5%)	
Frauen-Bundesliga	Goalkeeper	12 (27.9%)	16 (37.2%)	7 (16.3%)	8 (18.6%)	.35 [-]
	Defender	21 (22.8%)	30 (32.6%)	15 (16.3%)	26 (28.3%)	
	Midfielder	31 (25%)	32 (25.8%)	36 (29%)	25 (20.2%)	
	Striker	15 (22.7%)	14 (21.2%)	19 (28.8%)	18 (27.3%)	

such as Spain and England (2). A strong growing popularity and competitiveness of the sport often translates into a higher presence of Relative Age Effects at different female football levels, since a higher number of footballers can lead to discrimination against players born in Q3 and Q4 in their selection to participate in different football squads (46). In the case of Luxembourg, due to their limited pool of players, RAEs are not present at any of their either female or male youth football (46). Also, this argument can be extracted from the analysis of Pedersen et al. (21), who studied the historic evolution of RAEs presence at the Women's World Cup U17 and U20, and their findings proved how RAEs weren't present during 2008, 2010, 2012, and 2014 in contrast with more recent editions (2016 and 2018). Even stronger evidence of such effects were detected at the U18 World Cup, where RAEs weren't present over the 2002–2016 period; however, it appeared at the 2018 edition (21). The same tendency as the French Division 1, a league that didn't present RAEs back in 2009 (17) but does recently (e.g., 2023 season) as the present investigation has proved. The Swiss national teams didn't present RAEs either in 2011, attributed to the low number of potential players, but another variable needs to be taken into account: the lack of professionalization (29). This temporal shift underscores the dynamic and evolving nature of RAEs, reflecting changes in youth development and selection policies over time (30). Furthermore, such trends illustrate that as competitive structures mature and professionalization increases, RAEs may emerge or intensify in leagues where they were previously undetectable, as supported by findings from Bezuglov et al. (47), who identified widespread RAEs in European professional soccer, particularly pronounced in more competitive leagues.

The more professionalized the clubs and academies, the stronger RAEs effects in Portuguese female and male football and futsal (48); so definitely, we can say that at the elite level the RAEs level would always be higher, and that aligns with most of our current results in the BIG 5 leagues. Historically speaking, especially at their development level, female football has focused a big share of their resources on the development of female sport adherence, transmission of sport values, and the increase of female participation in football (49). The fact that this stage has been robustly achieved has led to a new stage where teams aim not only at participation and sport values but the competitiveness of their teams as well. In other words, a higher focus on winning translates into a higher level of RAEs as the studies of the higher divisions of female Spanish football showed higher levels of RAEs than the other lower divisions (22, 50).

4.1 Limitations, practical implications and future research

Despite the detailed analysis, the study deals with some limitations. The research focused solely on the top-tier leagues during a single season (2023/2024), which may not capture longitudinal trends or account for variations in lower-tier leagues and other countries. Furthermore, factors such as cultural differences, developmental systems, and league-specific regulations were not examined, which could influence the presence and extent of RAEs.

The practical applications of these findings are significant for talent identification and development in women's football. Recognizing the existence of RAEs can help coaches, scouts, and administrators implement strategies to mitigate its impact, such as adjusting scouting practices or providing additional support to later-born players. This could lead to a more equitable selection process, ensuring that talent is recognized regardless of relative age, ultimately enhancing the overall quality of the sport.

Future research should consider longitudinal studies to assess changes in RAEs over multiple seasons and include a broader range of leagues and age groups. Investigating the underlying causes of RAEs in women's football, such as physical maturation rates, social influences, and selection biases, would provide deeper knowledge. Additionally, exploring intervention strategies like bio-banding or alternative age groupings could offer practical solutions to reduce the RAEs' impact on player development and selection.

Data availability statement

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

Author contributions

BP-G: Conceptualization, Data curation, Methodology, Project administration, Software, Writing – original draft, Writing – review & editing. II-B: Formal analysis, Visualization, Writing – original draft, Writing – review & editing. JB: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. JL-Q: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. ÁF-L: Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. PB: Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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The relative age effect and the relationship between biological maturity and athletic performance in Austrian elite youth soccer players

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Purpose: Publications from recent years suggest that the biological developmental stage of underage athletes has a significant impact on their athletic performance. This scientific study is the first quantitative attempt in Austria to investigate the impact of the relative age effect and biological maturity on the physical performance of young elite soccer players.
Methods: Birth data from a total of 98 male players in the U13 to U18 age groups of a first-division Austrian soccer club were collected. By measuring height, sitting height and body mass, the individual biological age was calculated using the Mirwald equation. The athletes underwent a standardized battery of tests, which included assessments of speed, strength and endurance.
Results: The results indicate a significant effect of the relative age effect on player selection in the U14 and U15 teams ($p < .05$), which diminishes with increasing player age. Compared to typical Austrian adolescents of similar age, U13, U14 and U15 players demonstrate a higher level of biological maturity ($p < .05$). Correlational analyses revealed that the maturity offset, reflecting the time before or after the greatest individual growth spurt, was positively related to eccentric hamstring strength ($r = 0.82$) and vertical jumping ability ($r = 0.61$) and positively related to sprint performance over 5, 10 and 20 m ($0.62 < r < 0.69$; all $p \leq .001$).
Conclusion: Biological maturity and the associated anthropometric adaptations are decisive for athletic performance. The study supports the notion that biologically more mature players achieve better athletic performance than less mature players, especially before the onset of puberty.

KEYWORDS

European football, youth athletes, biological age, talent identification, physical fitness, maturation

Introduction

Modern academies of competitive youth soccer differ from health-related recreational sports in that they focus on identifying and developing underage talent (1). Supported by specially trained coaches and advanced training equipment, professional soccer clubs around the world aim to foster the development of young players to gain sporting and financial benefits (2, 3).

Thanks to the increasingly sport-specific training methods and individualized load management, the physical performance of professional soccer players has gradually

improved in recent decades (4, 5). Similar developments can be observed in Austria, where youth competitive soccer players are now taller and heavier compared to their age-matched colleagues from the last decade and perform significantly better in performance-related tests for (reaction) speed, endurance, agility, coordination and (jumping) strength (6, 7).

The increased emphasis on physical development is also reflected in match demands. High-intensity actions, such as sprinting (>25.2 km/h) or high-speed running have become key determinants of sporting success in modern soccer (8). Consequently, physical performance is now prioritized alongside technical and tactical skills in player development.

At the same time, youth soccer players are typically grouped by calendar year, usually with a January 1st cut-off (9, 10). Although this system aims to promote fairness and equal opportunity, it can result in chronological age (CA) differences of up to twenty-four months within the same cohort.

Chronologically older children tend to be more advanced anthropometrically, physically and cognitively. Moreover, they may benefit from greater early sporting success, enhanced confidence and more playing time, which in turn leads to more practice opportunities, and increased motivation (11). These cumulative advantages may contribute to their overrepresentation in youth academies (3, 12). This pattern of selection bias based on birthdate is commonly referred to as the relative age effect (RAE), which describes the "asymmetry in birth date distribution that favors those players born early in the selection year and discriminates against participants born later in the year" (11). It has been robustly demonstrated across nations, age groups, and time spans, particularly in male youth competitive soccer (13–15).

However, recent studies suggest that biological maturity status, rather than CA or RAE alone, may better explain differences in anthropometry and athletic performance during puberty (16, 17). Unlike CA, which is determined by birthdate, biological age (BA) is inherently influenced by genetic and epigenetic factors (18, 19). This implies that not all adolescents commence or progress through the maturation process at the same time or rate (20, 21). For example, Johnson and colleagues (22) reported that skeletal age among youth soccer players of the same CA can vary by up to five years.

This biological variability has significant performance implications. More mature players tend to have advantages in height, body mass, strength or speed, and often outperform their less mature peers in key soccer tasks such as changes of direction, tackling or sprinting (23, 24). These maturity-related advantages increase their likelihood of being selected for youth academies (25).

To assess biological maturity, skeletal age estimation via X-ray of the left carpal bone is considered the gold standard. Alternatively, pubertal stage can be inferred from secondary sexual characteristics (26–28). However, both methods present practical and ethical limitations: X-ray involves a (low) dose of radiation, is costly and requires evaluation by experienced physicians, while assessments of secondary sexual characteristics raise significant privacy concerns and are rarely used in practice (29).

To address these challenges, Mirwald and colleagues developed the "maturity offset" (MO) method, a non-invasive and widely adopted technique for estimating biological maturity status from anthropometric data (30). This method, considered sufficiently valid and reliable for research purposes (29), calculates the time before or after peak height velocity (PHV) based on the date of birth, body mass, height and sitting height. In Austrian males, PHV typically occurs at 13.8 years (29). Hence, an MO of −0.5 years would correspond to a BA of 13.3 years, providing insight into an individual's current biological maturity status (30, 31).

Although the effects of relative age and biological maturity on youth soccer performance have been examined independently, few studies have considered their combined influence – particularly in the context of elite Austrian youth soccer. Moreover, little is known about how these factors relate to both physical performance and selection decisions within structured academy environments. By addressing both factors simultaneously in a real-world academy setting, this study aims to offer new insights into the interplay between maturity, performance, and selection in youth talent development. In line with recent findings (32–34), this study tests the hypothesis that chronologically older and biologically more mature players not only perform better in physical performance tests for strength, jumping ability, speed and endurance, but are also more likely to be selected into an Austrian elite soccer academy.

Materials and methods

Study design

This study used existing data from the 2022/2023 season, collected during routine assessments of youth teams at the academy of an Austrian first-division soccer club. Physiotherapists conducted the anthropometric measurements, while sports scientists were responsible for administering the performance tests. The testing was conducted by staff who were familiar with the standardized testing protocols and had prior experience administering these tests. Each member of the team involved in the testing held at least a bachelor's degree and had been affiliated with the club for a minimum of three years. All tests took place at the club's training facilities. While players ate at the academy twice a week, no additional dietary guidance was provided in relation to the individual tests.

Participants

To be included in the study, participants had to be officially registered as players of the first-division club's (Bundesliga) soccer academy as of June 1st, 2022, and must have completed the most current standardized test battery. The birthday cut-off date for team assignment was January 1st, as dictated by regulations of the Austrian Soccer Federation and no athlete was represented on more than one team. The sample consisted of all eligible and available players from the mentioned youth teams, forming a convenience sample.

To capture a broad cross-section of the influence of biological maturity on performance, data were collected from five teams (U13, U14, U15, U16 and U18). In Austrian competitive soccer, the U18 team represents the oldest age group in the academy, hence no older teams were included. Teams younger than the U13 level were not considered, as our primary interest was in the interaction between RAE and biological maturity, which becomes more pronounced and performance-relevant as players approach and progress through puberty. All players were born between 2005 and 2010.

Eighteen U18 players were excluded due to injuries or because their commitments with youth national teams prevented their participation. Given the methodological challenges of assessing PHV in older players, a retest was not conducted (35).

Finally, the sample comprised a total of 98 participants distributed among the teams as follows: U13 ($n = 23$), U14 ($n = 21$), U15 ($n = 23$), U16 ($n = 16$), U18 ($n = 15$).

Anthropometric measurements

At the start of the season in July and during the winter preparation period in January, the players' height, sitting height, and body mass were measured to the nearest of 0.5 cm and 0.1 kg by physiotherapists using calibrated scales (Soehnle, Style Sense Compact 300, Nassau, Germany), a portable stadiometer (Seca GmbH & Co. KG, Seca 217, Hamburg, Germany), and a standardized chair. The chair height was adjusted to ensure that, during the seat height measurements, participants could sit upright with their feet flat on the floor, thighs fully supported, and knees bent at a 90-degree angle. These measurements were used to calculate the body mass index, PHV and BA using the Mirwald et al. equation (30). CA at the time of the anthropometric testing, as well as the players' month and year of birth, were retrieved from the club's player database (Spectator Sports, SoccerLab, Hasselt, Belgium).

Performance measurements and test protocol

Strength and jumping power tests were conducted separately for the U15, U16 and U18 teams in January, following a three-week winter break marking the start of the preparation period. Although all players had previously completed the test battery at least once in their careers, the procedures were explained in detail, and any questions were addressed by the sports scientists involved. Of note, for the purpose of this study, the jump and strength tests described above were also administered to U13 and U14 players, as these assessments are not part of the club's routine testing for younger age groups. These additional tests were conducted by the lead investigator at the end of the season, between late May and early June. All participants wore technical clothes provided by the club.

Players were scheduled alphabetically and attended the gym in 20-min intervals throughout the day between 9 am and 6 pm. To minimize potential variability caused by different shoe models, the jumping and strength tests were performed in socks (36). Players were allowed two attempts per test, with the best attempt recorded. If requested, a practice attempt was permitted. Following the guidelines of Markovic et al., a 60-s rest period was provided between trials (37).

After completing anthropometric measurements and a mobility assessment conducted by the team's physiotherapist, players performed a standardized 5-min warm-up on an ergometer (Matrix, CXP Target Training Cycle, Frechen, Germany) set at 100 watts. This was followed by a 5-minute individual preparation phase, during which most players performed preparation jumps, dynamic stretching, and an individual warm-up targeting the hamstrings.

Jumping tests were then performed on a force plate (VALD Performance, FDLite, Newstead, Queensland, Australia). Vertical jump height was assessed using the Counter-Movement Jump (CMJ), where players executed vertical jumps with their hands on their hips to minimize measurement errors (38). Each participant was instructed to start from an upright standing position, perform a rapid downward movement to a 90° knee angle, and simultaneously initiate the push-off.

In addition, the Reactive Strength Index (RSI) was measured through a hop test. The athletes were instructed to jump as high as possible while minimizing ground contact time. Players completed ten ankle jumps with minimal knee flexion while keeping their hands on their hips to minimize measurement errors. The best five jumps were averaged. The RSI was calculated based on jump height and ground contact time, with the result expressed in meters per second (m/s) (39).

Following the jump tests, strength measurements were conducted. Hamstring strength was assessed using a Nordic bench (VALD Performance, Nordboard, Newstead, Queensland, Australia) through the Nordic Hamstring Curl and Iso Prone tests. Each player completed one practice trial followed by two test attempts. During the Nordic Hamstring Curl, players were instructed to lower themselves from a kneeling position to the ground as slowly and evenly as possible over three seconds, maintaining a straight body, with their head up and chest lifted. Arms were crossed in front of the chest. The recorded values represent the average bilateral maximum force, measured in Newtons (N). In the Iso Prone test, players held a plank position with a 0° hip angle and elbows on the ground. Players were instructed to keep their legs straight and pull on the hooks while maximally tensing their hamstrings isometrically for three seconds. The bilateral isometric maximum force was similarly recorded in N.

Speed tests were conducted during the international break in April. To ensure optimal recovery, players were given three days off prior to the test and refrained from training or playing matches. Testing for all teams took place on the same Monday afternoon between 5 pm and 7 pm. Although all players had previously completed the test battery at least once in their careers, the procedure was thoroughly explained, and any questions were addressed by the sports scientists involved. A standardized 10-min warm-up, following the Raise, Activate,

Mobilize, and Potentiate (RAMP) method, was led by the team's sports scientist (40). The athletes were instructed to perform each trial with maximal effort. To ensure optimal recovery, players were tested individually before proceeding to the next participant. A passive recovery period of 5 min was provided between the two attempts. Players were tested in alphabetical order. To minimize measurement errors through distinct reaction times or body position differences (41), players began the test in a standing position, 50 cm in front of the first timing gate (SmartSpeed Dash, VALD Performance, Newstead, Queensland, Australia). To reduce single-beamed timing errors caused by inappropriate height adjustments (42), the photocells were positioned at hip height (43). The athlete initiated the start independently upon receiving a signal from the sports scientist. Wearing soccer shoes, they sprinted on artificial turf. Split times were recorded at 5, 10, and 20 m, with each player completing two attempts. The fastest time for each section was used for analysis.

Aerobic capacity was assessed for all teams during the final week of June, on a Monday afternoon between 5pm and 7pm just before the season's conclusion, using the Intermittent Fitness Test proposed by Buchheit and Rabbini (44). To ensure optimal recovery, players were given two days off prior to the test and refrained from training or playing matches. Following the recommendations of the developers, players performed a light individual warm-up and stretching routine before starting the endurance test (44). The procedure was explained in detail by the responsible sports scientist, and any questions were addressed. All players from each team completed the test simultaneously and the players were instructed to complete as many stages as possible. Conducted on artificial turf with players wearing soccer shoes, the test continued until the player could no longer maintain the required pace or failed to reach the 3-m zone three consecutive times. The final speed at which the player stopped was recorded and divided by a factor of 1.2 to calculate the maximum aerobic speed (MAS), expressed in km/h.

Academy training structure and long-term player development

Players typically join the academy at the earliest opportunity, with many having been part of the club since the U9 or U10 age groups. By this stage, most players already have experience playing for lower-level clubs. Training for U9, U10 and U11 players takes place three times a week for a total of 4.5 h and emphasizes a multi-sport approach, including different ball games, track and field activities, and gymnastics to promote general motor skill development and coordination. In the U12 age group, the training frequency increases to four sessions for a total of 5 h per week. By the time players enter the U13 team, those who joined the club at the U9 level have accumulated four years of multi-sport training experience.

From the U13 level onwards, training shifts toward more specific soccer-related training. U13 and U14 players train four times per week for a total of 6 hours, including one gym-based session dedicated to age-appropriate strength training. At the U15 and U16 levels, training frequency increases to six sessions per week for a total of 9 h, with two strength sessions designed to develop basic strength and technique, and increase muscle cross-sectional area.

For U18 players, training intensity and specificity peak, with seven weekly sessions for a total of 10 hours, including two strength sessions targeting hypertrophy and maximum strength development, depending on the season's phase.

Up to the U14 level, teams participate exclusively in weekly friendly matches or tournaments organized by the club rather than a dedicated league. From the U15 level onwards, players compete in a nationwide league organized by the Austrian Football Association, with each club playing a total of 22 matches. The season runs from late August to May, with matches typically held on Saturdays. Three-week breaks occur in December and June, while January, February, July, and August are designated as preparation periods.

Data processing and statistical analyses

To examine the RAE in all teams, Chi^2 tests were employed to assess the distribution of players across birth quartiles. If the results indicated significant deviations from a uniform distribution, Cramer's V was computed to quantify the effect size. Comparisons of the respective test statistics between teams provided insight into potential variations in the RAE across different age groups.

According to a study by Müller and colleagues the age of PHV determined by carpal bone X-ray in Austrian adolescents is 13.8 ± 0.4 years (29). Using this information, an expected MO for each team was calculated as the difference between the average player age expected in the absence of RAE and the average age of PHV of male Austrians. Thus, the expected MOs were −1.3 (12.5–13.8), −0.3 (13.5–13.8), 0.7 (14.5–13.8), 1.7 (15.5–13.8) and 3.2 (17–13.8) years in the U13, U14, U15, U16 and U18 teams, respectively. While classical RAE studies often compare the distribution of players' birthdates to that of the general population, such population-level reference data (by birth month or quarter and year) were not available for this study. Therefore, RAE effects were operationalized indirectly by comparing the players' actual MO and BA to team-level expected values under the assumption of a uniform age distribution. To assess whether player selection was influenced by both RAE and the pace of biological maturation, the players' actual MOs were calculated using the Mirwald equation and compared to these theoretical values using one-sample t-tests (30). When significant results were found, Cohen's d was reported as measure of effect size. Raincloud boxplots, grouped by team, were generated to visually illustrate potential differences between expected and actual MOs.

To further isolate the effects of the pace of biological maturation, the difference between the players' actual BA – derived from the difference between CA and actual MO – and the expected BA (12.5, 13.5, 14.5, 15.5, and 17 years,

respectively) was computed. These differences were then evaluated against the expected value of 0 years using additional one-sample *t*-tests, with Cohen's *d* calculated for effect size in cases of significant results.

To examine potential differences in performance metrics between players born in different birth quartiles, one-way ANOVAs were conducted for each outcome variable using pooled data from all age groups.

Finally, Pearson correlation coefficients and scatter plots were used to examine the relationship between the MO, performance measures and anthropometric data collected. All statistical analyses were performed using R (version 4.3.0, R Core Team, 2023). A significance level of $\alpha < .05$ was set for all tests.

Results

Descriptive statistics reflecting the players' CA and estimated BA as well as anthropometric characteristics are shown in Table 1.

Across the entire sample, the distribution of players born in different birth quarters was notably left-skewed ($\chi(3) = 33.586$, $p \leq .001$, $V = .311$). The team-specific analyses are depicted in Figure 1. While the U13 team results did not reach significance, statistically significant deviations from a uniform distribution were observed in the U14 and U15 teams ($\chi^2_{U13}(3) = 7.783$, $p = .051$; $\chi^2_{U14}(3) = 11.091$, $p = .011$, $V = .410$; $\chi^2_{U15}(3) = 10.333$; $p = .016$, $V = .379$). In the older teams, the RAE was less pronounced, resulting in non-significant findings ($\chi^2_{U16}(3) = 4.714$, $p = .194$; $\chi^2_{U18}(3) = 3.231$; $p = .357$).

Comparisons of MOs revealed substantial differences between expected (U13 = −1.3; U14 = −0.3; U15 = 0.7; U16 = 1.7 and U18 = 3.2) and observed values (see Figure 2). The players in the U13, U14, U15 and U16 teams were consistently biologically older than expected, with one-sample *t*-tests confirming significant differences in the U13, U14 and U15 teams ($t_{U13}(22) = 4.399$, $p < .001$, $d = .917$; $t_{U14}(20) = 3.572$, $p = .002$, $d = .780$; $t_{U15}(22) = 6.043$, $p < .001$, $d = 1.260$; $t_{U16}(15) = 1.393$, $p = .184$). In the U18 age group, however, the actual MOs were significantly

TABLE 1 Players' CA and estimated BA as well as anthropometric characteristics.

Team	*n*	CA (yrs)	BA (yrs)	Height (cm)	Mass (kg)	BMI ($kg \cdot m^{-2}$)
U13	23	12.9 ± 0.3	13.2 ± 0.7	162.1 ± 9.2	47.1 ± 7.7	17.8 ± 1.6
U14	21	13.9 ± 0.3	14.1 ± 0.7	166.5 ± 9.2	54.7 ± 10.5	19.5 ± 1.9
U15	23	14.6 ± 0.3	15.1 ± 0.5	176.1 ± 7.1	63.8 ± 6.8	20.6 ± 1.7
U16	16	15.0 ± 0.3	15.2 ± 0.9	172.2 ± 7.9	63.3 ± 7.8	21.3 ± 1.6
U18	15	16.5 ± 0.6	16.6 ± 0.6	176.1 ± 7.1	67.6 ± 7.7	21.8 ± 2.3

CA, chronological age; BA, biological age; BMI, body mass index.

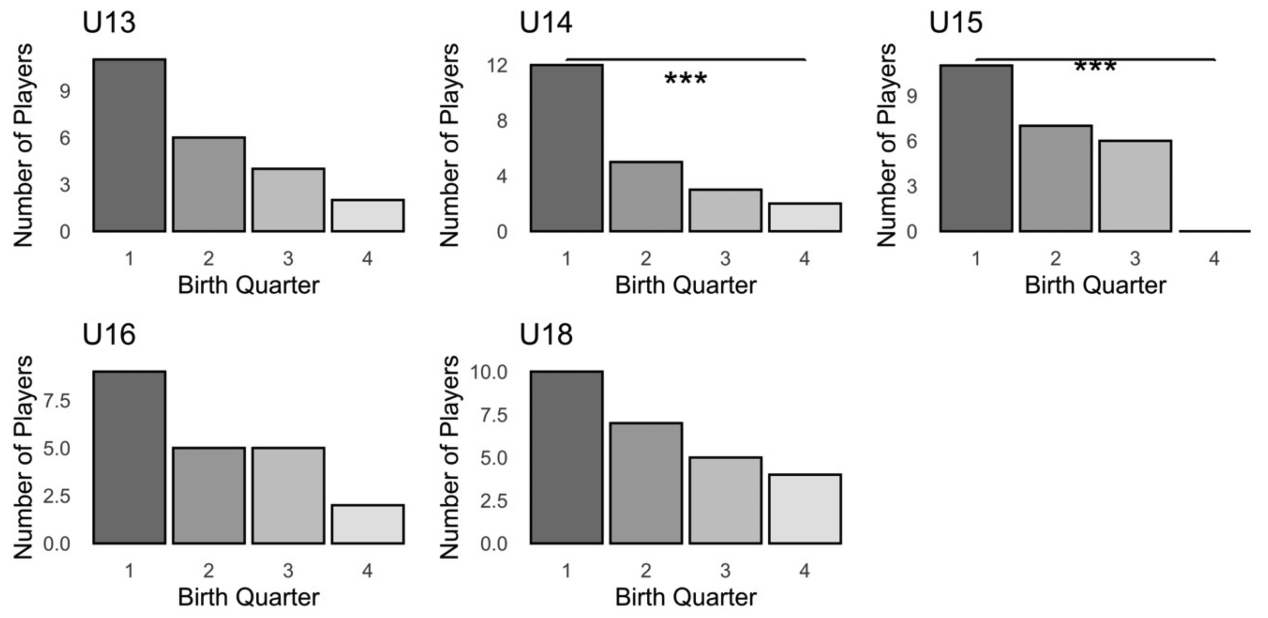


FIGURE 1
Distribution of players born in different birth quarters across teams. *** indicate significant deviations from a uniform distribution.

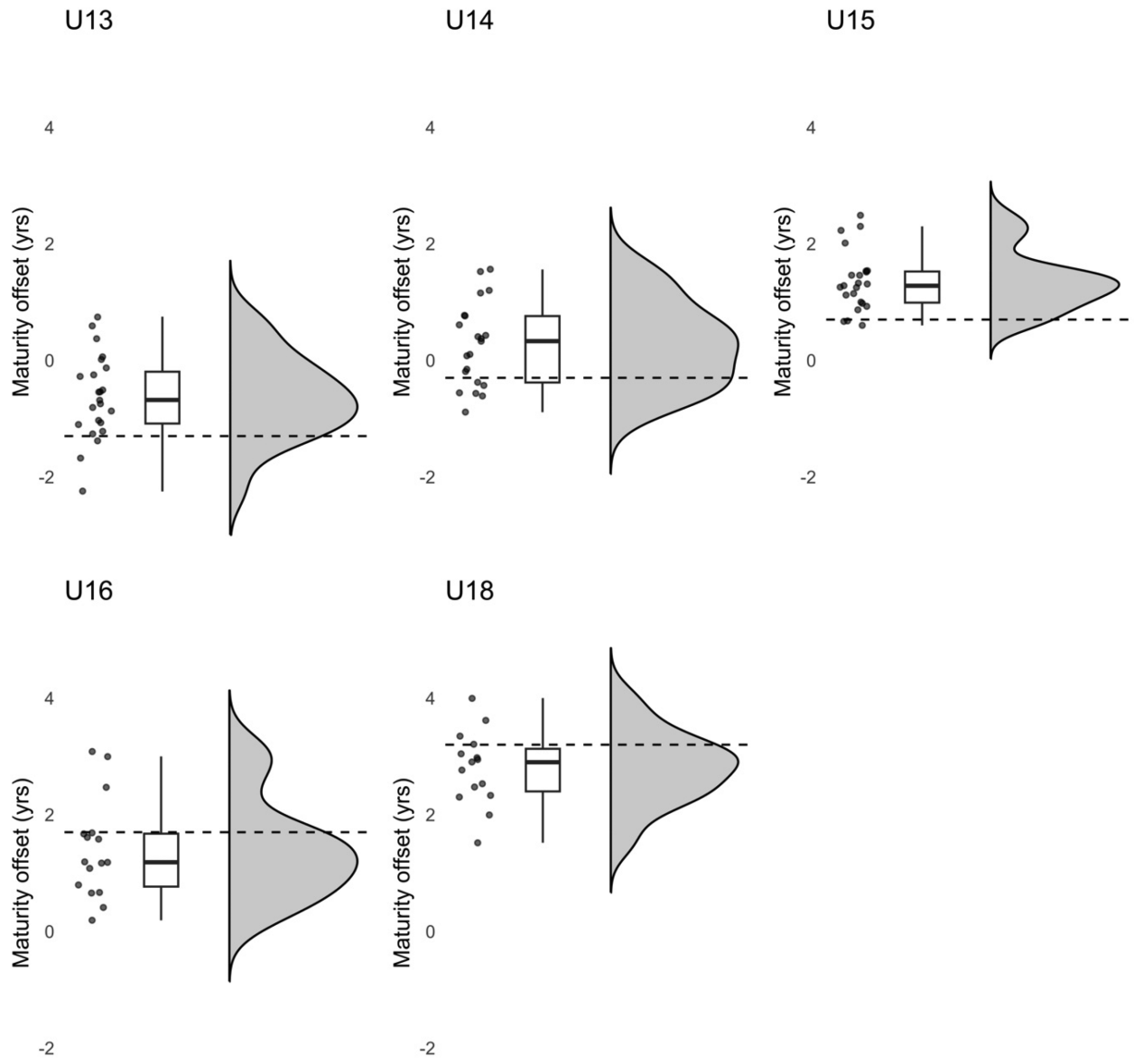


FIGURE 2
Expected (dashed line) and observed maturity offsets across teams.

smaller than the expected values ($t_{U18}(14) = -2.457$, $p = .028$, $d = -.634$).

Comparing the differences between CA and BA against an expected value of 0 years, one-sample *t*-tests revealed significant disparities within the total sample, which contained data pooled from all teams ($M = -0.27$, $SD = \pm 0.64$; $t_{total}(97) = -4.162$, $p < .001$, $d = -.420$), as well as in the U15 category ($M = -0.59$, $SD = \pm 0.46$; $t_{U15}(22) = -6.123$, $p < .001$, $d = -1.277$). Although statistical significance was not reached in the other teams, descriptive statistics indicate that players exhibited a biological development beyond what their CA predicted ($M_{U13} = -0.24$, $SD_{U13} = \pm 0.65$; $M_{U14} = -0.19$, $SD_{U14} = \pm 0.69$; $M_{U16} = -0.16$, $SD_{U16} = \pm 0.75$; $M_{U18} = -0.07$, $SD_{U18} = \pm 0.60$).

One-way ANOVAs, conducted on the pooled data from all teams, to assess differences in body height, body mass, and performance metrics across birth quarters revealed no statistically significant results ($0.378 < p < 0.935$).

The correlational analyses unveiled strong associations between MO and eccentric and isometric hamstring strength, as well as CMJ height, while exhibiting a positive correlation with sprint performance over 5, 10 and 20 m ($r > .50$; $p < .001$). An average positive correlation was found between MO and RSI as well MAS ($.30 < r < .50$; $p < .001$). The corresponding scatter plots illustrating the relationships between MO and performance parameters are shown in Figure 3. For comparison, Figure 4 presents the same correlations using CA instead of MO. With the exception of MAS, for which the correlation was slightly higher with CA, all other performance variables showed consistently stronger correlations with MO than with CA.

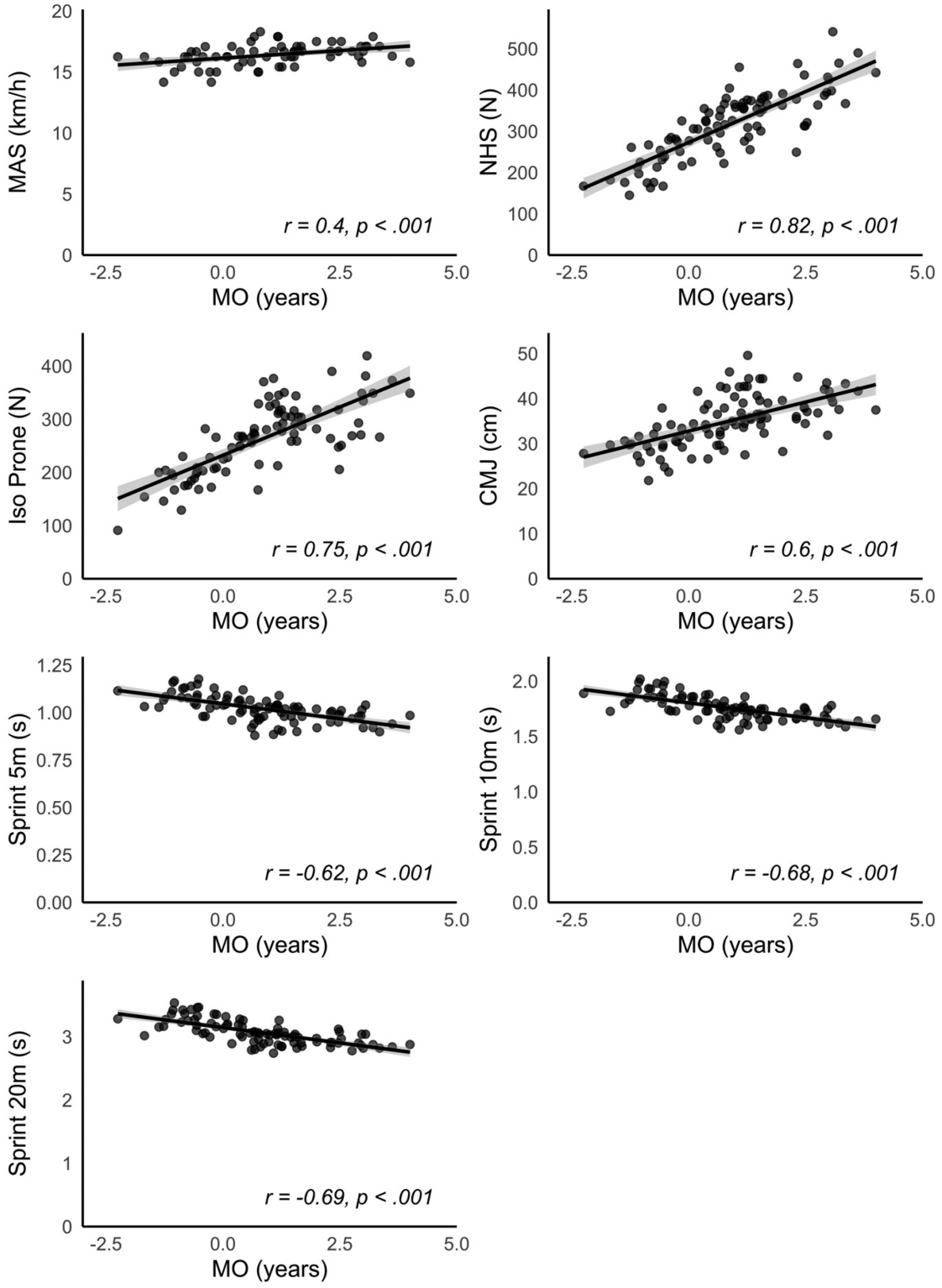


FIGURE 3
Relationship between maturity offset (MO) and performance test results conducted across the entire group. MAS, maximal aerobic speed; NHS, nordic hamstring strength; CMJ, countermovement jump height, 5 m/10 m/20 m: sprint times over 5, 10 and 20 m, respectively.

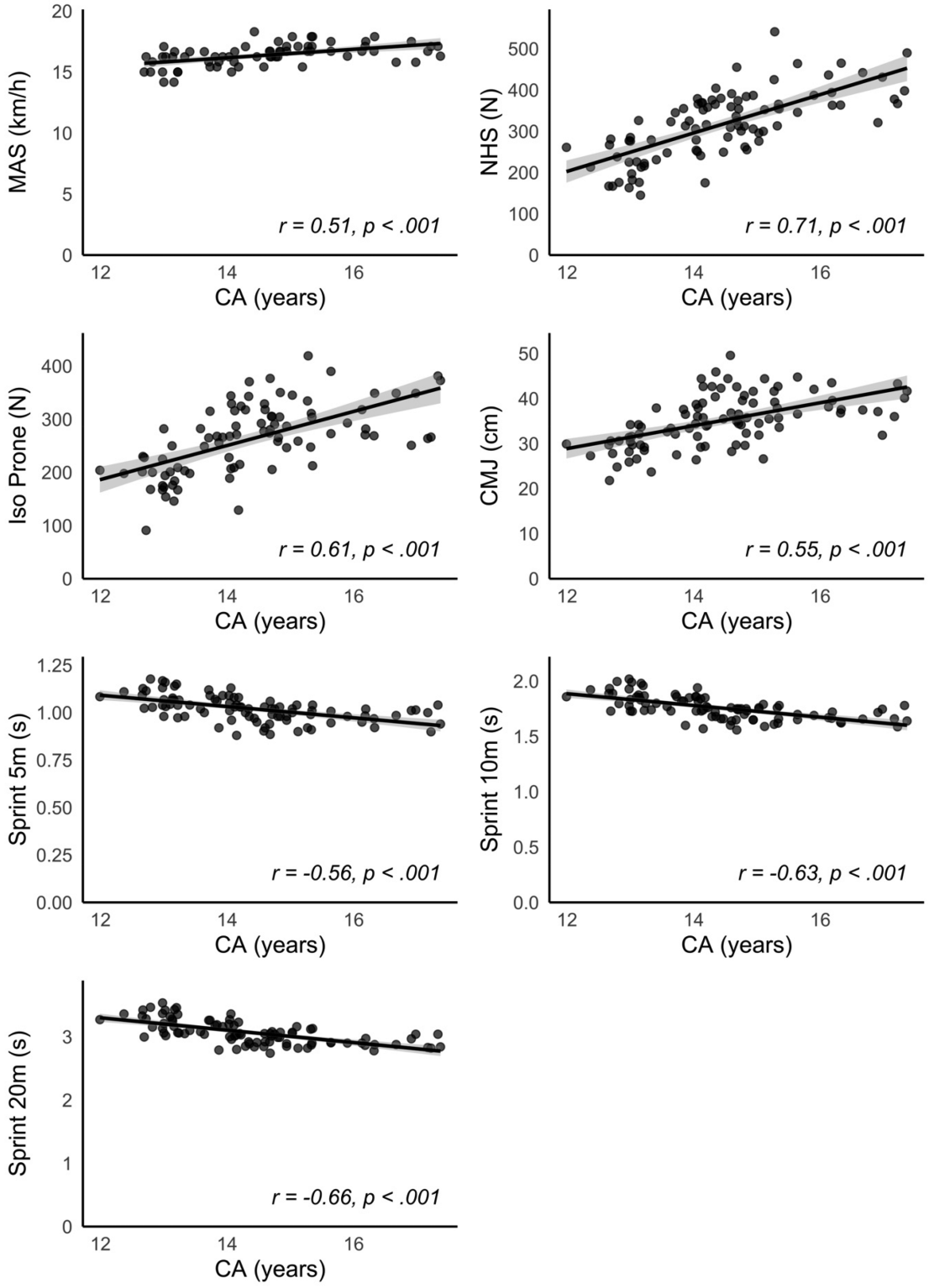


FIGURE 4
Relationship between chronological age (CA) and performance test results conducted across the entire group. MAS, maximal aerobic speed; NHS, nordic hamstring strength; CMJ, countermovement jump height, 5 m/10 m/20 m: sprint times over 5, 10 and 20 m, respectively.

Discussion

This study aimed to evaluate the influence of the RAE on player selection within the youth teams of an elite Austrian soccer club. We hypothesized that chronologically older and biologically more mature players would not only perform better in physical performance tests for strength, jumping ability, speed and endurance, but also be more likely to be selected into an elite soccer academy. Our findings support this hypothesis. A clear RAE was observed, particularly in the younger age groups, and biological maturity showed consistent associations with key physical performance parameters. These results highlight the combined impact of relative age and biological maturity on both selection and performance within the structured academy setting.

While previous studies have investigated the presence of the RAE in elite youth soccer, this study provides novel insights within the context of Austrian elite soccer. For the first time, we offer data on the current state of youth elite soccer in Austria, incorporating a comprehensive range of physical performance tests within the same population. These assessments cover aerobic endurance, isometric and eccentric strength, explosive power, and neuromuscular capacity through jumping and sprinting measurements. Furthermore, the study examines five distinct age groups from the same club environment, allowing for a unique analysis of how biological maturity correlates with performance metrics and how these relationships evolve across different developmental stages.

Our findings clearly demonstrate the presence of the RAE, as, across teams, there was a significant overrepresentation of players born in the first quarter of their respective selection periods, starkly contrasting with the uniform distribution of births per month in the general Austrian population. The analysis of the individual teams showed that within the U13, U14 and U15 teams there was a birth ratio of 3:1 favoring of players born in the first semester, although this ratio decreased to approximately 2:1 in the U16 and U18 age groups. Notably, in the U15 team there was not a single player born in the last quarter of the year. Our results are consistent with those reported in studies conducted in other European countries, which have documented similar distributions in youth soccer academies over the last 15 years (10, 11, 45).

The diminishing impact of the RAE observed from U16 level onwards suggests that scouting and the player selection are especially influenced by the RAE in pre- and peripubertal boys (33, 46). This phenomenon could be attributed to the advantage of older players, who may compensate for technical, tactical or psychological shortcomings with superior physical attributes before puberty. However, as their teammates catch up during the growth spurt phase, these players may ultimately be identified and excluded due to potential skill deficits. Conversely, it is plausible that younger players, who may initially lag behind in performance, experience improvements after puberty. Consequently, they might have to leave the academy less often after reaching this stage.

Even though the players studied reached their age of PHV at 13.7 years, which aligns with both that reported in other studies in youth soccer players and that found in general Austrian adolescents (29, 47, 48), our results indicate that especially in younger age, the academy tends to preferentially accept early biological developers. Indeed, across all teams, the players' average BA consistently exceeded their CA, although in the team-specific analyses significant differences were only observed in the U15 team.

The findings indicate that biological maturity status, rather than birth quarter, plays a more significant role in individual sports performance, as players with advanced maturity tend to outperform their less mature peers. With respect to the connections between biological maturity and performance metrics, the correlational analyses and scatter plots revealed significant linear relationships between MO and strength and speed parameters, such as eccentric and isometric strength of the hamstrings, vertical jumping ability and speed over 5, 10 and 20 m. Previous research suggests that more than a quarter of the variance in sprint performance among competitive youth soccer players can be explained by eccentric strength as measured by relative Nordic hamstring power (49).

Our findings underscore the advantages conferred by advanced biological maturity and the associated anthropometric adaptations in improving strength and speed parameters, which are crucial for physical contact sports like youth soccer. These attributes are strongly correlated to success metrics and playing time (50–52). Interestingly, the Austrian soccer academy system operates as a closed system, with no relegation among its twelve members. While the system aims to foster the development of all players, our data suggest that current selection patterns may unintentionally favor chronologically older or biologically more mature players. This could reflect a tendency to prioritize short-term performance over long-term development. However, without comparison to unselected players, it is not possible to fully distinguish between selection bias and sport-inherent demands that naturally favor more physically developed athletes.

To mitigate the developmental disadvantages faced by relatively younger or late-maturing players within such systems, several alternative strategies have been proposed. One practical approach to addressing these challenges is bio-banding, which groups athletes based on their biological rather than chronological age (53, 54). Bio-banding aims to create more equitable and developmentally appropriate opportunities for all players, regardless of their birth date or maturation rate (55, 56). At the club level, bio-banding can group U13, U14 and U15 players by biological rather than chronological age for soccer and strength training. Organizing friendly matches or tournaments between bio-banded teams, alongside official competitions, ensures that less biologically developed players receive ample playing time and skill development opportunities. Scouts, coaches, and relevant personnel should regularly reassess their selection criteria and receive ongoing education on the RAE, BA, and their impact on short- and long-term player development (57).

In conclusion, the presence of the RAE was observed among young players in the academy of an elite Austrian soccer club. During the prepubertal age, differences in both CA and the pace of biological development can result in differences of several years in biological maturity. Our findings underscore the interconnectedness of advanced biological maturity and key sports motor skills such as speed and strength, which are crucial

for youth soccer performance. Since sporting talent is not tied to one's birth month, it is evident that the current setup systematically excludes numerous talented but later-born or less-developed players from the system at a young age (58).

Limitations

While the performance tests were carried out according to a standardized test protocol, it cannot be ensured that all tests were conducted under identical conditions, including timing, explanation, and execution of movements, owing to variations among test instructors. Discrepancies in the accuracy of the measurement of some parameters may have occurred, potentially leading to unprecise calculations of the age of PHV and, consequently, biological maturity. The fact that the players' nutritional status was not assessed may have introduced variability in the testing outcomes. The study is also limited due to the small sample sizes in each group, which is why the reported effect sizes should be interpreted with caution. Several authors have noted that the Mirwald equation tends to overestimate the age of PHV in early-maturing children, while underestimating it in late developers (59, 60). This systematic bias can result in a regression toward the mean, potentially misclassifying individuals at the extremes of the maturity spectrum. The method also appears to be more accurate in younger adolescents (approximately 10–13 years), which may reduce its accuracy when applied to older age groups who are closer to or beyond their age of PHV. In addition to these statistical limitations, it is important to recognize that most anthropometry-based equations – including those by Mirwald, Khamis-Roche, and Fransen – were developed in largely homogeneous, predominantly Caucasian populations. This raises questions about the validity of applying these methods to the ethnically diverse groups typically found in elite youth soccer settings. As Fransen (2021) recommended, such estimations should be interpreted with caution when used outside their original reference populations (61). Other non-invasive, anthropometry-based methods face similar limitations in accuracy and produce similar estimates of BA (62), although recent equations such as the one proposed by Fransen and colleagues (63) may help mitigate some of the known biases of earlier models. More precise techniques, such as skeletal age assessment via X-ray or the evaluation of secondary sexual characteristics, were not feasible in our setting due to ethical, logistical, and privacy-related constraints, and promising newer alternatives such as skeletal ultrasound were not available. Finally, it is important to note that the RAE may vary between countries. Therefore, caution is warranted when extrapolating the findings of this study, which focuses exclusively on Austrian athletes, to populations in other countries.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Ethics statement

The study was reviewed by the Ethics Committee of the University of Vienna and conducted in accordance with local legislation and institutional requirements. Written informed consent for participation was not required from the participants or their legal guardians because the study analyzed pseudonymized anthropometric and physical fitness test data from youth soccer players, collected during routine assessments in their academy. The Ethics Committee confirmed that, according to Austrian national laws, the study is exempt from mandatory formal ethical approval. All players (and/or their legal guardians) had provided informed consent for participation in the routine testing procedures. The study complied with key principles of the Declaration of Helsinki, including risk minimization, respect for participants, and protection of personal data. However, the study was not pre-registered.

Author contributions

MW: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – review & editing, Investigation, Resources, Writing – original draft. RC: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Supervision, Visualization.

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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.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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Selection biases in elite youth handball: early maturation compensates for younger relative age

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Talent selections in youth sports are frequently biased regarding the maturation and relative age of the players, with preference given to more mature and relatively older players. It thus can be hypothesized that relatively younger players born at the end of the selection year must mature earlier to compensate for this disadvantage. Hence, this study investigated maturation, relative age, and their association in the talent selection of German youth handball players. A secondary data analysis within an ex post facto design was conducted to examine the birth quarter distributions and maturation parameters of 2,259 female U15 players and 2,340 male U16 players. Practically significant maturation bias was detected in male players, who matured almost one year earlier than common German boys (g = –1.67). This was not evident in female players. Relative age selection biases were observed in female (פ = .16) and male (פ = .20) players. An analysis of maturation timing across birth quarters revealed that relatively younger players born later in the selection year mature earlier than their relatively older peers in both female (g = 0.99) and male players (g = 0.56), thereby partially offsetting relative age disadvantages. Consequently, it may be crucial for relatively younger players to be early-maturing to increase selection odds. Considering the evidence indicating the presence of both maturation and relative age selection biases, it seems prudent to acknowledge the significant impact that these can have on talent selection and development in German youth handball. The development of solutions is currently underway in collaboration with the regional and national handball federations.

KEYWORDS

adolescent, biological age, development, maturity, relative age effect, secondary data, talent

1 Introduction

National sports federations employ structured talent identification and development (TID) systems in youth sports with the objectives of identifying young athletes with the greatest potential for long-term success and preparing them for the challenges they will encounter in adult international competition (1, 2). The players selected for the development system benefit from the provision of professional coaching, sports science, and medical support, gain access to superior training equipment and facilities, and are

exposed to high levels of competitive challenge to facilitate their long-term progress and increase the likelihood of attaining success at the senior level (3). The German Handball Federation (DHB; Ger.: Deutscher Handballbund) annually conducts scouting camps at the beginning of the year to select female U15 and male U16 players for talent development programs and to recruit them for the youth national squads (4). Each coach of the 20 regional handball federations in Germany selects out of their regional pool approximately twelve female and twelve male players across all playing positions who are perceived as "talented" and sends them as one female and one male team to the National Talent Selection Camp of the German Handball Federation (SelCamp; Ger.: DHB-Sichtung). Due to organizational considerations, the five-day SelCamp is conducted on two consecutive occasions, with ten teams participating in each session for each sex (four three-day SelCamps, with five teams each for each sex since 2024). During this selection process, candidates are required to demonstrate their abilities in general motor tests, their skills in handball-specific tests as well as their technical and tactical qualities in matches and competitions. Based on these observations, the national coaches then select the most promising players to participate in the National Talent Nomination Camp of the German Handball Federation (NomCamp; Ger.: 1. DHB-Lehrgang), which ultimately serves as the recruitment pool for the youth national team (4). However, two nonmodifiable factors that can bias these (pre)selections are the biological maturation of the players as well as their relative age (5–10).

The process of biological maturation refers to the progression toward a fully developed mature stature. It can be characterized in three ways: the maturation stage at the time of observation (i.e., maturity status), the age at which specific maturational events occur (i.e., maturity timing), such as the age of peak height velocity (APHV), and the rate at which maturation occurs (i.e., maturity tempo) (7, 11). An advanced biological maturity status may result in advantageous anthropometric (e.g., body height, wing span) and physical (e.g., strength, power, endurance) characteristics, which are considered to underpin high sports performance (12, 13). It is thus unsurprising that an advanced maturity status has been shown to increase selection odds in sports where greater size, strength, and power are desired attributes, which in turn promotes biological maturation selection bias (6–10, 14–20). This phenomenon is not unprecedented in sports; rather, it has been documented for several decades (21). However, while early/advanced maturation may confer an initial advantage in highly physical sports, it does not necessarily translate to success at the senior level. In fact, it has been suggested that late-maturing players may perform better in adulthood when retained in TID systems (22, 23).

Abbreviations

ANOVA, analyses of variance; APHV, age at peak height velocity; DHB, German Handball Federation; SelCamp, selection Camp of the German Handball Federation; TID, talent identification and development; NomCamp, National Talent Nomination Camp of the German Handball Federation; Q, birth quarter; PHV, peak height velocity.

Recent observations in handball players indicate that an advanced biological maturity status results in superior anthropometrical and physical performance characteristics (13). Moreover, early-maturing handball players have been shown to exhibit advantages in anthropometry, strength, speed, and jump performance compared with their later-maturing peers (19, 24). Consequently, handball may be susceptible to a maturation selection bias. This is supported by data obtained by de la Rubia et al. (19), Tróznai et al. (14), and Tróznai et al. (20). De la Rubia et al. (19) reported an overrepresentation of early-maturing players in U16 and U17 Spanish academy handball. Tróznai et al. (14) observed a mean difference (with standard deviations in parentheses) between bone age and chronological age (as a proxy for maturity status) of 0.9 (1.1) years in female U14 and 1.8 (1.0) years in male U15 Hungarian handball players which indicates a bias toward players exhibiting an advanced maturity status. The data provided by Tróznai et al. (20) further indicates that the difference between bone age and chronological age increases with rising selection level.

In addition to maturation, player selections can also be biased regarding the relative age of the players. Relative age refers to chronological age differences between individuals within the same age cohort, and its consequences are known as relative age effects (25, 26). For example, an individual born close to the cutoff date at the beginning of the selection year (e.g., 1st January) is almost 12 months older than their peers born at the end of the selection year (e.g., 31st December) and therefore relatively older. Although annual age grouping in youth sports is employed to maintain general developmental similarities among players within the same age group to allow for more balanced coaching and evaluation as well as equal and fair competition, it can still provide disadvantages to some of the group members, causing relative age effects (12, 27). These effects typically manifest themselves in selections as an underrepresentation of players born at the end of the selection year (i.e., relatively younger players) and an overrepresentation of players born at the beginning of the selection year (i.e., relatively older players) (12). Several mechanisms have been proposed to account for this phenomenon, with differences in maturation primarily held responsible for the development of relative age effects (12, 26). It has typically been suggested that relatively older children have an increased probability of being physically more mature and entering puberty earlier than their relatively younger peers due to their advanced chronological age (26). During circumpubertal ages in particular, an age difference of almost a year can result in significant differences in physical qualities (26, 28). The maturation-selection hypothesis, which is frequently invoked when elucidating relative age effects, posits that coaches may confuse these maturation-dependent anthropometrical and physical advantages with "talent", increasing the likelihood of selecting relatively older players, which represents a common relative age selection bias (27, 29). Nevertheless, it is important to note that relatively older players are not inherently more advanced in their maturation in comparison to their relatively younger peers because maturation individually varies in terms of

timing and tempo (11). Therefore, relative age and biological maturation are regarded as distinct constructs and should be treated as such (5, 9, 30). A substantial body of research has documented the existence of relative age selection biases in handball at the youth level. These studies involved players of both sexes on national teams, club teams, and tournaments across various countries, including Brazil (31, 32), Denmark (33), Germany (27, 34–37), Hungary (14, 20), Israel (38), Kosovo (39), Norway (40), and Spain (41–46). While an older relative age may provide certain advantages at the junior level, studies suggest that under certain conditions, athletes of younger relative age who successfully overcome the relative age selection bias could be superior to their peers on various performance indicators at the senior level (37, 47).

Given that both relatively older and early-maturing players are often favored in selection processes at the youth level, it could be assumed that relatively younger selected players born at the end of the selection year tendentially mature earlier and have a similar maturity status as their relatively older peers to compensate for their younger relative age. This phenomenon has been documented in soccer (9, 16, 18, 48–55), handball (14, 20, 24), tennis (56), swimming (57), and winter sports (54, 58, 59), although some conflicting results have also been reported (60). Three studies could be identified that investigated the associations between relative age and maturation in handball: Matthys et al. (24) reported no statistically significant differences in maturation timing between relatively older and younger 14-year-old male Belgium handball players. The studies conducted by Tróznai et al. (14) and Tróznai et al. (20) demonstrated descriptively, albeit not statistically significant, that relatively younger male players may exhibit greater differences between bone age and chronological age than relatively older players. This finding suggests that male selected players who are relatively younger may have an advanced maturity status. However, this was not evident in female players. In view of the inconclusive results obtained in handball, which did not statistically show the same effects as observed in other sports, it was deemed worthwhile to test a larger sample to achieve greater test power.

Accordingly, this study aimed to investigate three key areas: first, to examine potential maturation selection biases; second, to investigate potential relative age selection biases; and third, to examine the associations between maturation and relative age. Based on the findings presented above, we separately hypothesized that maturation and relative age selection biases would be present in the selection of handball players who were chosen to participate in the SelCamp (i.e., at the regional selection level), with earlier maturing players and relatively older players being in favor. It was further hypothesized that relatively younger selected players born in later birth quarters mature earlier to overcome potential relative age disadvantages. Given the potential influence of selection level on maturation and relative age selection biases (20), the subsequent selection for participation in the NomCamp (i.e., at the national selection level) was additionally considered, albeit in an exploratory manner.

2 Methods

The study employs an ex post facto design with a secondary data analysis, which is exempt from ethics approval because of the previously conducted collection and retrospective analysis of anonymized data. Good practice standards for conducting secondary data analyses were followed (61).

2.1 Subjects

The DHB provided a dataset comprising birthdate, body mass, body height, and sitting height of $n = 2{,}259$ female U15 players and $n = 2{,}340$ male U16 players who participated in the annual SelCamp from 2010 to 2020 [the mean chronological ages were 14.71 (0.28) years and 15.74 (0.28) years, respectively]. Of those players, $n = 498$ female players and $n = 489$ male players were eventually selected for participation in the NomCamp.

Players who were either younger or older than those in the regular cohort, which is U15 for girls and U16 for boys, were not included in the dataset. It is important to note that the players who participate in the SelCamp have been selected by the coaches of their respective regional handball federation (i.e., at the regional selection level). However, the player selections for participation in the NomCamp were determined by the national coaches (i.e., at the national selection level) (4).

2.2 Procedures

In German handball, annual age grouping is determined by the dates from 1st January to 31st December (34). Consequently, birth months were extracted from the birthdates and categorized as follows: January–March = birth quarter 1 (Q1), April–June = birth quarter 2 (Q2), July–September = birth quarter 3 (Q3), and October–December = birth quarter 4 (Q4). The chronological age was determined as the age at the date of the SelCamp.

Data of players' anthropometry (i.e., body mass, body height, and sitting height) and chronological age were utilized to noninvasively estimate maturity offset [time difference from peak height velocity (PHV)] based on the sex-specific (modified) (62) equations proposed by Mirwald et al. (63). The estimated APHV was calculated as the difference between the maturity offset and the chronological age. The maturity offset is considered the current maturity status, and the APHV represents the timing of the growth spurt, with a lower APHV indicating earlier maturation. Players' birthdates were known to the regional and national coaches, but only the national coaches had information on their maturity status.

2.3 Statistical analysis

Statistical analyses were performed with R 4.4.1, IBM SPSS Statistics (29.0.0.0, IBM, Armonk, NY, USA), and G*Power

3.1.9.7 (64). Owing to the large sample size, the statistical significance level was set to $\alpha = .001$. APHV and maturity offset were determined to be the operationalized dependent variables.

The presence of maturation selection biases was evaluated by conducting one-sample *t*-tests to compare the mean APHV of female and male players with the mean APHV of German girls of 12.00 (0.88) years and German boys of 14.07 (0.98) years (65). Hedges' *g* effect sizes with 95% CIs were calculated and interpreted as described below.

To examine relative age selection biases, chi-square goodness-of-fit tests were performed to determine whether the distributions of the birth quarters differed from the expected uniform distribution (26). The effect size Fei (פ) (66) and 90% CIs were calculated to determine the magnitude of difference in frequency counts and interpreted on the scale of a correlation coefficient according to the guidelines of Funder and Ozer (67) with thresholds of <.05, .05–.09, .10–.19, .20–.29, .30–.39, and ≥.40 as tiny, very small, small, medium, large, and very large effects, respectively. Odds ratios with 90% CIs for Q1 vs. Q4 were additionally calculated as a tangible effect size measure.

One-way analyses of variance (ANOVA) were performed to examine whether maturity offset and APHV differed between the birth quarters. Shapiro-Wilk and Levene tests were performed in advance to test for normal distribution and homogeneity of variance. Planned contrasts analyses were conducted for the APHV, with weights of 1, 1, −1, and −1 across the birth quarters to test the hypothesis that players born in later birth quarters mature at an earlier age than players born in earlier birth quarters. Effect sizes with confidence intervals were calculated. An orientation of small, medium, and large effects was based on η^2 values of .01–.05, .06–.13, and ≥.14 and Hedges' *g* values of 0.20–0.49, 0.50–0.79, and ≥0.80, respectively (68).

In an exploratory analysis, all statistical procedures were repeated with the players selected for participation in the NomCamp to ascertain whether any potential biases persist at the subsequent national selection level.

3 Results

3.1 Maturation selection biases

The APHVs of female and male players at the SelCamp and NomCamp are illustrated as half-eye plots in Figure 1. The mean APHV of 12.07 (0.39) years observed in female players at the SelCamp statistically significantly differed from the mean APHV of 12.00 (0.88) years observed in common German girls (65), but with an effect size below the "small" category, $t(2{,}258) = 8.36$, $p < .001$, $g = 0.18$, 95% CI [0.13, 0.22]. Conversely, at the NomCamp, the mean APHV of 11.95 (0.39) years was not statistically different from the reference sample (65), $t(497) = -3.02$, $p = .003$, $g = -0.14$, $1\text{-}\beta = .43$.

Whereas, the mean APHV of 13.16 (0.55) years in male players at the SelCamp was significantly lower than the mean APHV of 14.07 (0.98) years observed in a representative sample of German boys (65) with a large effect size, $t(2{,}339) = -80.77$, $p < .001$, $g = -1.67$, 95% CI [−1.73, −1.61]. Comparable results were found at the NomCamp, with a lower mean APHV of 13.00 (0.54) years, $t(488) = -44.16$, $p < .001$, $g = -1.99$, 95% CI [−2.15, −1.84].

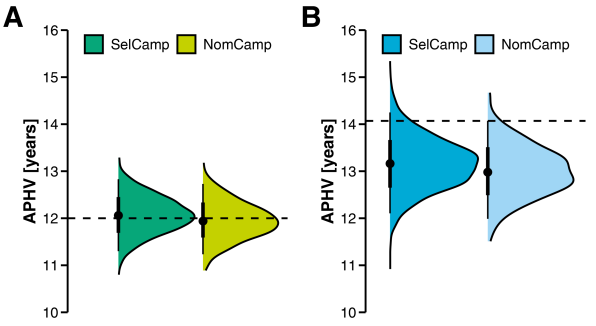


FIGURE 1
Age at peak height velocity (APHV) in female and male players. Panel (A): Selections of female players. Panel (B): Selections of male players. The dashed lines indicate the mean APHVs of German girls and boys (65). NomCamp = National Talent Nomination Camp of the German Handball Federation; SelCamp = National Talent Selection Camp of the German Handball Federation.

3.2 Relative age selection biases

Figure 2 illustrates the distributions of birth quarters for female and male players. Irrespective of sex and selection level, the majority of players were born during the first quarter, with the number of births declining in subsequent quarters. The distribution of birth quarters showed a significant difference from a uniform distribution in female players at the SelCamp, indicating a relative age selection bias with a small effect size, $\chi^2(3) = 168.30$, $p < .001$, פ = .16, 90% CI [.14, .18]. The odds ratio calculations revealed that the odds of being born in Q1 were more than twice as high as those of being born in Q4, $OR = 2.72$, 90% CI [2.41, 3.06]. Similar results were obtained at the NomCamp, $\chi^2(3) = 43.74$, $p < .001$, פ = .17, 90% CI [.12, .21], $OR = 3.13$, 90% CI [2.42, 4.05].

A relative age selection bias with a medium effect size was observed in male players at the SelCamp, as the birth quarter distribution significantly differed from the expected uniform distribution, $\chi^2(3) = 293.53$, $p < .001$, פ = .20, 90% CI [.18, .22]. The odds of being born in Q1 were more than three times as high as those of being born in Q4, $OR = 3.78$, 90% CI [3.35, 4.26]. The transition to the subsequent NomCamp slightly augmented the already existing relative age selection bias, $\chi^2(3) = 108.83$, $p < .001$, פ = .27, 90% CI [.23, .31], $OR = 5.36$, 90% CI [4.09, 7.01].

3.3 Association between maturation and relative age

The descriptive statistics and ANOVA results for the dependent variables are presented in Table 1 for female players

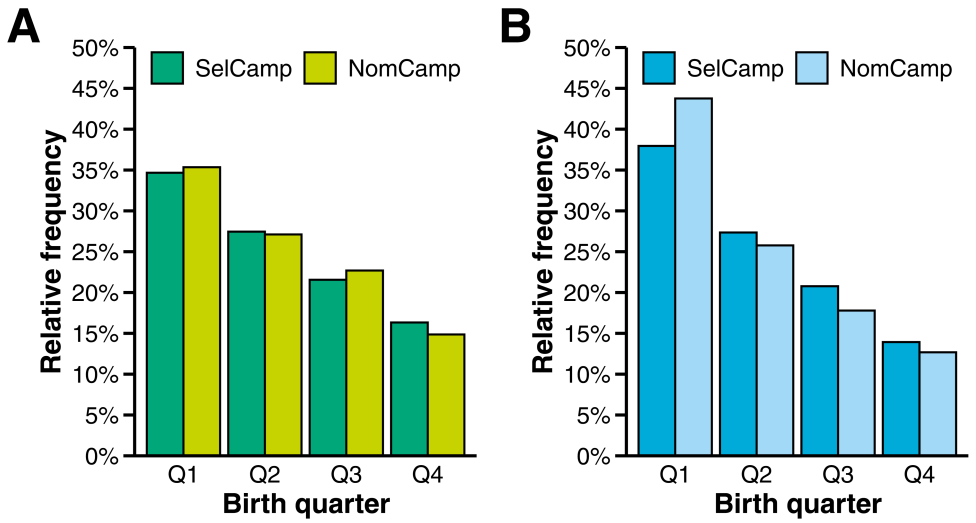


FIGURE 2
Birth quarter distributions in female and male players. Panel (A): Selections of female players. Panel (B): Selections of male players. NomCamp = National Talent Nomination Camp of the German Handball Federation; SelCamp = National Talent Selection Camp of the German Handball Federation.

TABLE 1 Descriptives and results of ANOVA for female players.

Camp	Variable	Q1		Q2		Q3		Q4		Total		F	p	η^2	90% CI
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*				
SelCamp	Count	$n = 783$ (34.66%)		$n = 620$ (27.45%)		$n = 487$ (21.56%)		$n = 369$ (16.33%)		$n = 2,259$					
	APHV [years]	12.17	0.38	12.10	0.38	11.99	0.37	11.91	0.39	12.07	0.39	49.98	<.001	.06	[.05, .08]
	Maturity offset [years]	2.84	0.38	2.66	0.38	2.53	0.37	2.36	0.40	2.64	0.42	149.37	<.001	.17	[.14, .19]
NomCamp	Count	$n = 176$ (35.34%)		$n = 135$ (27.11%)		$n = 113$ (22.69%)		$n = 74$ (14.86%)		$n = 498$					
	APHV [years]	12.04	0.39	11.96	0.36	11.87	0.36	11.81	0.42	11.95	0.39	8.27	<.001	.05	[.02, .08]
	Maturity offset [years]	2.97	0.39	2.81	0.37	2.65	0.36	2.45	0.43	2.78	0.42	37.30	<.001	.19	[.13, .23]

APHV = age at peak height velocity; NomCamp = National Talent Nomination Camp of the German Handball Federation; Q = birth quarter; SelCamp = National Talent Selection Camp of the German Handball Federation.

and in Table 2 for male players. The APHV and maturity offset were significantly different between birth quarters in female players at the SelCamp, with medium to large effect sizes, $F(3, 2,255) = 49.98$, $p < .001$, $\eta^2 = .06$, 90% CI [.05, .08], $F(3, 2,225) = 149.37$, $p < .001$, $\eta^2 = .17$, 90% CI [.14, .19], respectively. Similar results were observed at the NomCamp (please see Table 1). Planned contrast analysis revealed that younger relative age is accompanied by a lower APHV, $t(2,255) = 11.26$, $p < .001$, $g = 0.99$, 95% CI [0.81, 1.16], indicating that relatively younger players mature at an earlier age, as illustrated in Figure 3.

Significant differences in the APHV and maturity offset between birth quarters were detected in male players at the SelCamp, with small to medium effect sizes, $F(3, 2,336) = 17.19$, $p < .001$, $\eta^2 = .02$, 90% CI [.01, .03], $F(3, 2,336) = 92.24$, $p < .001$, $\eta^2 = .11$, 90% CI [.09, .13], respectively. Comparable outcomes were documented at the NomCamp (please see Table 2). The result of the planned contrasts analysis indicated that younger relative age was accompanied by reduced APHV, $t(2,336) = 6.36$, $p < .001$, $g = 0.56$, 95% CI [0.39, 0.74].

4 Discussion

This study was conducted to investigate three specific aims. The first and second aims were to examine maturation and relative age selection biases in the selections of players for participation in the SelCamp. The third objective was to determine whether maturation was associated with relative age in the selections. The hypotheses were that the selections are biased regarding maturation and relative age. It was further hypothesized that relatively younger players would mature earlier, thereby overcoming potential relative age disadvantages.

The main findings indicated the presence of a substantial maturation selection bias in male ($g = -1.67$), but not in female

TABLE 2 Descriptives and results of ANOVA for male players.

Camp	Variable	Q1		Q2		Q3		Q4		Total		*F*	*p*	η^2	90% CI
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*				
SelCamp	Count	*n* = 888 (37.95%)		*n* = 640 (27.35%)		*n* = 486 (20.77%)		*n* = 326 (13.93%)		*n* = 2,340					
	APHV [years]	13.24	0.55	13.17	0.53	13.07	0.55	13.03	0.54	13.16	0.55	17.19	<.001	.02	[.01,.03]
	Maturity offset [years]	2.78	0.55	2.60	0.53	2.44	0.56	2.24	0.53	2.58	0.58	92.24	<.001	.11	[.09,.13]
NomCamp	Count	*n* = 214 (43.76%)		*n* = 126 (25.77%)		*n* = 87 (17.79%)		*n* = 62 (12.68%)		*n* = 489					
	APHV [years]	13.10	0.55	12.98	0.50	12.85	0.54	12.89	0.51	13.00	0.54	5.61	<.001	.03	[.01,.06]
	Maturity offset [years]	2.93	0.56	2.79	0.51	2.66	0.54	2.39	0.49	2.78	0.56	17.93	<.001	.10	[.06,.14]

APHV = age at peak height velocity; NomCamp = National Talent Nomination Camp of the German Handball Federation; Q = birth quarter; SelCamp = National Talent Selection Camp of the German Handball Federation.

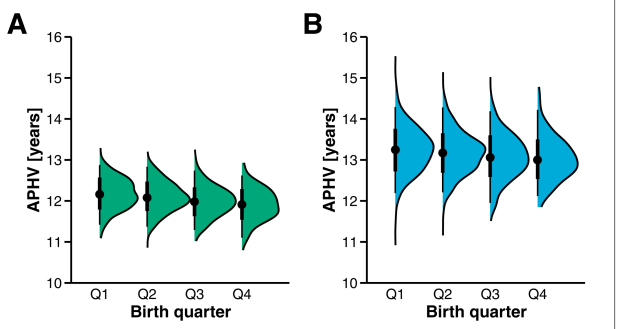


FIGURE 3
Age at peak height velocity (APHV) across birth quarters in female and male players. Panel (A): Female players. Panel (B): Male players.

players ($g = 0.18$). Furthermore, in the selection process, preference was given to relatively older players (i.e., born in earlier birth quarters), with a small effect size observed in female (ɒ = .16) and a medium effect size observed in male (ɒ = .20) players, indicative of relative age selection biases. As hypothesized, the players born in later birth quarters matured earlier to compensate for their younger relative age, with a large effect size observed in female players ($g = 0.99$) and a medium effect size in male players ($g = 0.56$).

Although the APHV of female players at the SelCamp was statistically significantly higher than in the reference sample, the magnitude of the difference was not of practical importance. Hence, the absence of a practically meaningful maturation selection bias in female players did not confirm our hypothesis and is contrary to the abovementioned results obtained by Tróznai et al. (14). The players at the NomCamp demonstrated only a slight tendency toward earlier maturation. The absence of meaningful maturation biases toward earlier maturation could be explained by the fact that, at the time of the selections, the players were already far beyond the average PHV. Consequently, later-maturing girls have potentially made up the leeway in their physical development, thereby diminishing the initial advantages of earlier maturation. In contrast to female players, considerable maturation selection bias was evident in male players, who matured almost one year earlier than the average German boy (65), confirming our hypothesis for males. This is consistent with the data obtained by de la Rubia et al. (19) and Tróznai et al. (14). The selection of the national coaches marginally increased the already substantial bias. The preference for more mature players in male selections clearly disadvantages later maturing players. Observations from a practical perspective in German handball indicate that early-maturing players are frequently placed in the subsequent higher age group within their club. It may be assumed that the training in these groups is typically at a higher performance level, characterized by enhanced quality, and led by coaches with higher expertise. Additionally, players may also encounter higher-performing teammates and more challenging opponents at tournaments. This exposure to high-level training and competition could provide early-maturing players with an edge (10), which may, in turn, promote maturation selection bias.

The presence of relative age selection biases in this study corroborates our hypotheses and lends further support to the plethora of studies that have reported such biases in youth handball (14, 20, 27, 31–46). In female players, the probability of being born within the first quarter (Q1) than that of being born within the final quarter (Q4) of the year aligns with the *OR* of 2.29 observed by Lidor et al. (38). The relative age selection biases were not exacerbated from the SelCamp to the NomCamp, which is consistent with previous findings (14, 20, 36). In male players, the odds of being born in Q1 than that of being born in Q4 are similar to the *OR* of 2.8 documented by Doncaster et al. (42). The already existing relative age selection bias was only slightly intensified at the subsequent NomCamp. Although sex is a known moderator of relative age effects (26), the relative age selection biases were only slightly stronger in male players, which is in line with previous research (34, 36, 37). Taken as a whole, players born earlier in the selection year benefit from their higher relative age in the selection process during childhood. However, the relative age effects in handball appear to decrease in the subsequent years into adulthood and further diminish across career stages in later adult years (34, 37).

A combined analysis of maturation and relative age revealed that relatively younger female and male players tend to mature at an earlier age than their relatively older counterparts do (please

see Figure 3), confirming the initial hypothesis. This phenomenon has been documented in numerous studies, albeit in sports other than handball. Previous studies conducted in handball (14, 20, 24) did not support these and present findings. In the current study, the mean APHV decreased from Q1 to Q4 by 0.26 years in female players and by 0.21 years in male players, representing the amount of compensation for relative age. Nevertheless, early maturation did not fully offset the relative age differences, and the absolute compensation was relatively modest. When the relative age difference between Q1 and Q4, which is 0.74 years in both sexes, is considered, early maturation compensates for approximately only one-third of this difference.

Given the existence of maturation and relative age selection biases at the SelCamp, the talent pool from which national coaches select their players is inherently biased. However, the rising selection level from the SelCamp to the NomCamp only marginally exacerbated maturation and relative age selection biases. These findings align with the results of recent studies in Hungarian handball that indicated that relative age selection biases did not significantly increase from the regional to the national level (14, 20).

In an effort to address the issues of maturation and relative age selection bias in elite German youth handball, measures have already been taken by the DHB, such as an early assessment of players' biological age (biannually, starting approximately two years prior to the SelCamp) and the sensitization of coaches regarding relative age effects. Further solutions are currently being developed in cooperation with the regional and national handball federations.

4.1 Limitations

Readers should be mindful of the limitations of this study. Although the method proposed by Mirwald et al. (63) to noninvasively estimate maturity status in the present study is an established one, it should be noted that, as with any estimation, there may be discrepancies between the estimated and actual maturity status. According to previous validation studies by Malina et al. (69) and Kozieł and Malina (70), the equations tend to overestimate the APHV when assessing early-maturing individuals. Furthermore, the estimated APHV increases with chronological age at prediction. Thus, the players may actually mature earlier than estimated, which would increase maturation selection biases.

4.2 Conclusions and practical implications

This investigation identified the existence of maturation and relative age selection biases in the selections of players for participation in the SelCamp. Relatively younger players (born in later quarters of the selection year) tended to mature earlier than their relatively older peers born in preceding quarters. This suggests that younger relative age was (partially) offset by early maturation. Consequently, it may be crucial for players born in later quarters to be early-maturing to increase their likelihood of overcoming relative age selection bias and being perceived as a "talent". Players who mature at a later age and are born in later quarters face a dual disadvantage when competing with more mature and relatively older players.

Eventually, regardless of whether players are not selected due to their later maturation or their younger relative age, players are unfavored probably based on current physical characteristics rather than their long-term potential (22). This initiates a vicious cycle for the non-selected players, as they do not receive the same level of support and competition as their selected counterparts, making it even more challenging for them to "catch up" and to (re)enter the TID system (35). As a result, misjudgments in selections can lead to potentials being overestimated and actual "talents" being overlooked (3, 22). Therefore, it can be recommended that coaches at all selection levels be provided with objective data on the biological age of players (e.g., through somatic estimation equations or skeletal age measures) to validly consider maturation in their selection decisions. Estimates of players' maturation based solely on the coaches' eye may not be sufficiently accurate (71). Furthermore, a number of proposed countermeasures to mitigate relative age and maturation selection biases are the subject of ongoing debate (72, 73), including the employment of more handball-specific selection tasks (24, 74), raising awareness of coaches/scouts (73), player labeling (75), (relative) age quotas (73), and bio and birthday banding (22, 76, 77). It is of paramount importance to identify the selection levels at which the largest proportions of biases emerge to deploy these countermeasures in a targeted manner and enable them to unfold their full potential. In this study, selections for the NomCamp only marginally amplified already existing maturation and relative age selection biases. Given that no practically significant relative age selection biases can be observed at the club level in German handball within the same age groups as examined in this study (78), it can be inferred that relative age selection biases emerge somewhere between the initial selection levels (i.e., county/district level) and the SelCamp. To the best of our knowledge, there is an absence of research addressing the issue of maturation selection bias below the SelCamp. Thus, further research at lower and middle selection levels is necessary to elucidate the accumulation and persistence of maturation and relative age selection biases within the TID system.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: the data that support the findings of this study are available upon reasonable request and only with the permission of the data proprietor Deutscher Handballbund e.V. Requests to access these datasets should be directed to Jochen Beppler, jochen.beppler@dhb.de.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this

study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements. This study is exempt from ethics approval because of the previously conducted collection and retrospective analysis of anonymized data. Good practice standards for conducting secondary data analyses were followed (61).

Author contributions

LT: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. JS: Conceptualization, Methodology, Writing – review & editing. JB: Data curation, Investigation, Project administration, Writing – review & editing. DB: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, 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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A qualitative analysis of female sport experiences in soccer

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Relative Age Effects (RAEs) have the potential to be counterproductive to sport participation rates given the associated selection (dis)advantages and inequitable access to development opportunities for individuals of varying relative age. Previous work has predominantly been quantitative in nature and focused on male athletes, with only a few qualitative studies in the published literature. Thus, the purpose of this study was to examine relative age and sport engagement and dropout issues by conducting a qualitative analysis of post-adolescent, female athletes' experiences. An invitation to participate in a semi-structured interview (via phone) or online questionnaire (via Qualtrics) was distributed to a targeted sample of post-adolescent (18–19 years of age), current and past female soccer participants from Ontario, Canada ($N = 15$). Questions focused on reasons for participation and dropout, aspects of programs and relationships that facilitated or discouraged participation, player recommendations for encouraging future participation or reuptake of the activity, perception of abilities at various stages, involvement in other sports, location considerations, and age issues. The three stages of Côté's Developmental Model of Sport Participation were used to structure the questions in order to explore experiences occurring during specific stages of the athlete's developmental years. Hierarchical content analysis was used to identify raw data themes, which were grouped into higher order sub-themes and categories. Half year comparisons (H1 vs. H2) revealed similar themes reported by relatively older and younger participants, suggesting relative age was not the most important factor with respect to the players' experiences and decisions to continue in the sport when examined from a qualitative lens, although study design may have been a contributing factor. Engaged athletes reported a greater number of themes related to specialization in sport, and dropout athletes reported more negative sport experiences. Sport sampling at young ages (<12 years of age) was associated with ongoing sport participation into the post-adolescent years, with engaged athletes reporting involvement in a greater number of additional sports (beyond soccer), vs. the dropouts. Community size/characteristics reportedly impacted sport experiences, although no clear trends were ascertained. General recommendations for sport practitioners and recommendations for future research are discussed.

KEYWORDS

relative age, sport participation, athlete engagement, sport dropout, birth advantage, sport sampling, community size

1 Introduction

Organized sport participation during childhood and adolescence has been associated with a variety of desirable outcomes including higher levels of cardiorespiratory fitness (1, 2), enhanced psychological and social health (3), and overall well-being (2). The benefits appear to extend beyond those attributable to

physical activity alone, some of which are reinforced by the social nature of sport competition (4, 5). Unfortunately, high rates of sport dropout have also been reported (e.g., 6–8) with lack of enjoyment, low perceived competence, an increase in family and intrapersonal pressure, and physical factors (maturation and injury) being cited as primary contributors (9). Young girls may be at increased risk of dropout from sport participation (5, 10), which is concerning given that females are at increased risk for insufficient levels of physical activity when examined globally (11).

Within the context of organized sport, children are often grouped by chronological age. These age divisions are intended to promote a developmentally suitable environment to practice sport by providing age-appropriate access to training/tasks and competition (12, 13). However, subtle differences in physical, psychological, and emotional development among children grouped in a same-age cohort can lead to selection advantages and playing opportunities for the relatively older individuals (14, 15), as determined by their birthdate position with respect to an arbitrarily imposed date used for age groupings. Relatively younger individuals may not have these same opportunities to develop (13, 16, 17) and consequently may be more likely to struggle with issues of competence and reduced self-esteem (18). Relative age effects (RAEs) describe these potential (dis)advantages experienced by members grouped within a same-age cohort (19), which ultimately pose a threat to ongoing sport participation, as individuals who are disadvantaged (typically, the relatively youngest) may withdraw from sport altogether (20, 21) resulting in a reduced pool of talent for advancement to higher levels of competition.

The RAE-related advantage conveyed to those who are relatively older is considered to be present when an over-representation of relatively older players is observed among sport participants. For example, a team roster containing more athletes born in the earlier months of January, February, March… compared to athletes born in October, November, December, in a system that uses December 31st as a cut-off to group participants. These disproportionate birth distributions have been observed across a variety of sport and cultural contexts in both male and female samples (for a review, see 14, 22). With respect to team invasion sports, the risk of RAEs is influenced by biological characteristics (particularly during the maturation period), the sport's popularity, coaches' perceptions, and level of competition (23). For instance, RAEs have been observed in ice hockey (e.g., 24), soccer (e.g., 25), and handball (e.g., 26), to name a few. Individual, but still physically demanding activities, may also be affected with RAE patterns documented in sports such as tennis (e.g., 27), skiing (e.g., 28), and sprinting (e.g., 29). In contrast, sports that are more skill-based in nature (vs. physical prowess) tend not to exhibit RAEs, including golf (30) and shooting (31). Relative age effects have also been observed in the collegiate system within the US and Canada [see (32) and (33), respectively], and participation at this level may also serve to motivate individuals at young ages to seek higher levels of training and competition in an attempt to obtain athletic scholarships.

In light of the potential benefits associated with organized sport participation, effective strategies are needed to encourage ongoing engagement for developing youth. Creating an environment where athletes can thrive may encourage them to stay in sport and increase their overall well-being (2). Relatively younger athletes may feel isolated from their peers due to perceived differences in skill level and expectations (or lack thereof) placed on them in comparison to their relatively older teammates (34, 35). These differences may lead to conflicts between relatively older and younger athletes, contributing further to the feelings of isolation (34, 36). Thus, relative age has the potential to be counterproductive to this objective and therefore, the continued study of the RAEs is necessary to gain a thorough understanding of the contributing factors and identify meaningful ways to reduce the adverse outcomes. Yet, existing work investigating RAEs has been predominantly quantitative in nature, which is limited for understanding the intricacies of this multi-faceted, complex phenomenon. There are many aspects that still need to be analyzed (23), and qualitative studies may provide new insights into RAEs and relative age-related dropout. Existing qualitative studies have primarily focused on the experiences of coaches with respect to talent selection (37, 38); and only a few athlete-focused studies are available for review. Furthermore, female sport contexts have also been habitually understudied with respect to RAEs[1], thus representing an important group for continued investigation.

Edwards and O'Donoghue (34) investigated the experiences of relatively older and younger (female) international-level netball players (ages 24–52 years; $N = 13$). The findings suggested that relatively older and younger athletes shared many motivations and obstacles, such as enjoyment of social and competitive aspects of sport, injury risk, and issues related to commuting. However, several factors were experienced more commonly and to a greater degree by the relatively younger athletes, including feelings of isolation from their team/governing bodies, being less developed and/or coordinated than older teammates, and conflicts with others on their team. These factors align with those reported to contribute to sport dropout by Andronikos et al. (36). Although their research was not tied specifically to RAEs, it was found that competing with teammates and receiving poor support from coaches and sport organizations was a significant contributor to dropout; issues that theoretically may be experienced to a higher degree by those who are relatively youngest across a variety of sport contexts.

A case study by Hancock (40) examined the experiences of relatively older and younger athletes, parents of both groups, and coaches from a youth (male) ice hockey team. Athletes were 14 and 15 years of age, born in the same calendar year. Several differences in the acknowledgment and acceptance of RAEs were noted in each individual's career. The relatively younger athletes

[1]The percentage of female studies (to male) has been estimated to vary between 2% (14) and 7.92% in team sports (39).

and their parents were generally more knowledgeable of RAEs prior to the study and acknowledged the impact on their athletes, while the relatively older athletes and their parents reportedly knew less about RAEs initially and were slow to accept the potential implications of being relatively older. Interestingly, regardless of their opinion on RAEs, all parties believed that they did not have an effect on their own (child's) career. Coaches were aware of RAEs and claimed they did not allow them to influence their decision-making, yet they also held opinions that were (unknowingly) biased towards relatively older athletes (40). Ultimately, more work is needed to examine the experiences of the athletes themselves, and this work should be expanded to female athletes due to variation in physical growth and maturational timing, and associated social expectations/pressures that might be experienced differently between the sexes during development.

Given the lack of qualitative research examining RAEs in general, and more specifically the experience of athletes with respect to relative age-related influence on sport participation, the objective of this study was to explore relative age and sport engagement and dropout issues by conducting a qualitative analysis of post-adolescent, female athletes' experiences. Côté's Developmental Model of Sport Participation (DMSP) has been widely used in the participation literature (41) and thus, the stages of this model were used to organize the questions for the participants in order to examine various timepoints during development. Briefly, these stages include sampling a variety of sports at a young age (less than 12 years of age), specializing in a smaller number of sports during the adolescent years (or continued sampling in some cases; between 12 and 15 years of age), and investment in post-adolescence (16+ years of age; 42). A cohort of female athletes was identified through a provincial level organization, in which RAEs were observed across the pre- to post-adolescent years in Canada's most popular youth sport [i.e., soccer; Canadian Heritage (43) report]. Comparisons of "engaged" and "dropout" players, and relatively older and younger athletes were planned to examine the impact of relative age on sport experiences.

2 Methods

2.1 Research paradigm

The current study was designed from a reality-oriented, post-positivism paradigm; that being, an objective reality exists but is only imperfectly achievable (44, 45). The RAE phenomenon is notably complex (15, 23) and while this domain of research often seeks to promote equitable development for all young athletes, it is acknowledged that a complete understanding of the factors involved in athlete success/expertise may not be attainable.

2.2 Study design and theory

Côté's (42) three stages contained within DMSP were used to organize the questions for the semi-structured interview/questionnaire in order to explore experiences occurring during specific periods of an athlete's career. Specifically, the wording and organization of questions referred the participants to experiences occurring before 12 years of age, between 12 and 15 years of age, and current experiences at the age of 18–19 years, in sequential order. Edwards and O'Donoghue (34) also used these stages to identify when different participation and attrition motives were experienced, and to conceal that the study was concerned with RAEs. Thus, this study expands on the work of Edwards and O'Donoghue (34) with female, international-level netball players, by distinguishing between dropout and engaged players at various levels of competition in the sport of soccer.

The content of questions included reasons for participation and dropout, aspects of programs and relationships (i.e., with coaches, parents, and/or peers) that facilitated or discouraged participation, player recommendations for encouraging future participation or reuptake of the activity, perception of abilities at various stages, involvement in other sports, location considerations (e.g., community size), and age issues. These themes align with factors that have been proposed to affect youth sport experiences in previous research (34, 36, 46–48), and also allowed exploration of issues related to relative age. Participants were asked for their month of birth at the end of the interview/questionnaire, so as not to bias responses towards relative age, but collecting this information allowed an analysis of relatively older and younger athletes as outlined in Section 2.5. The DMSP stages align nicely with what is known about the impact of relative age at each developmental stage (22). The interview guide/questionnaire was adapted from Edwards and O'Donoghue (34; please refer to Supplementary Appendix A).

2.3 Participants and recruitment

Recruitment began during an earlier phase of a longitudinal, multi-study project, which examined the role of relative age, community size/density, and positive youth development (PYD) on female youth soccer participation. Briefly, a 1-year cohort (i.e., same birth year) was identified by Ontario Soccer and followed from age 10–16 years. Individuals who maintained participation into the final 2 years under examination (i.e., until a minimum age of 15 years) were recruited directly by Ontario Soccer to participate in an online survey examining developmental assets (further details can be found in (21); and (49). Following the completion of the online survey, participants were subsequently invited to provide their contact information if interested in participating in a separate future study. Fifty-three individuals initially indicated they were interested in participation, and the target age range of these individuals at the time of data collection was 18–19 years of age. A subsequent/direct invitation to participate in semi-structured, interview (via phone) or online questionnaire (via Qualtrics) was extended to this targeted subsample of current/former post-adolescent, female soccer players.

2.4 Data collection

Participants, which included current and former female soccer players, were given the choice to complete their interview on the phone (at a mutually agreeable time with the first author) or through an online questionnaire using the Qualtrics platform, which provided enhanced anonymity and allowed greater time for reflection. These procedures were cleared by the University of Windsor Research Ethics Board (REB #18-184). One participant opted for the telephone interview and fourteen selected the online format, for an overall sample of fifteen ($N = 15$). This sample size aligns with previous research, which has ranged from four to 25 participants (48, 50). Individuals who selected the online questionnaire were asked if they could be contacted for follow-up questions via email (13 participants agreed, one declined), whereas follow-up questions were asked during the interview session for the participant selecting the phone option. The interview completed via the phone was 14.11 min in length and the average length of time to complete the questionnaire on Qualtrics was 10.77 min (overall average 10.99 min), and varied depending on the amount of information that each participant chose to share.

2.5 Data analysis

The procedural steps of hierarchical content analysis were followed, as outlined by Sparkes and Smith (51). The basic unit of analysis was the individual participant. However, relative age (half year comparisons) and current status (dropout vs. engaged) were taken into consideration when evaluating and comparing emergent themes between groups. A preliminary review of the data was conducted by the authors to achieve familiarity (i.e., immersion). Two authors (K.S. and N.E.) manually identified raw data themes (i.e., meaning units from the transcribed text that contain one distinct piece of information) and labelled these themes with tags (52). The tags were manually grouped together into higher order sub-themes and categories, which were modified reflexively to accommodate new insights when required to find the best fit for the data (51). Each unique tag (i.e., raw data theme) was recorded a maximum of one time per participant. Themes, sub-themes, and categories were then organized into a table based on their hierarchical nature, while ensuring heterogeneity between each category. The number of occurrences for each theme were then tallied for the group of relatively older participants (H1; born in January through June based on the Dec. 31st cutoff used to organize youth soccer in Ontario, Canada; $n = 8$) and relatively youngest (H2; born in July through December; $n = 7$) to allow comparison. Additional details about the participants can be found in Supplementary Appendix B.

2.6 Data quality and trustworthiness

Two of the three researchers (K.S., P.W.) were familiar with RAEs within the context of sport. At the time of data collection, K.S. (Ph.D. Candidate) and P.W. (Faculty Supervisor) had conducted multiple studies on RAEs, including several involving female samples. Thus, they were able to identify valid themes in the raw data. However, the potential for bias associated with this familiarity was also recognized. Thus, two authors coded the data: one familiar with relative age research and qualitative analysis (K.S.); and one who had a general understanding of RAEs and sport participation research following the completion of undergraduate studies, but who was also new to this area of study and able to offer a fresh perspective on the data (N.E.). One case was coded by K.S. and N.E. in collaboration to provide training on the identification of meaning units within the data. This was followed by a second case coded independently and then discussed to provide additional feedback. The remainder of the cases were then fully coded independently by each author before further discussion took place. Agreement rates were 96.77% and 94.17% for the engaged and dropout participants, respectively. Disagreements were resolved through discussion and the coding structure was revised accordingly. A final review of the data was completed by the third author (P.W.), who was also familiar with relative age research.

2.7 Interpretation of the data

Analysis and interpretation sought principles for successful athletic development that could inform similar populations of post-adolescent female athletes. Developmental age (according to the stages of DMSP; 42), competition level (competitive vs. recreational), and community size[2] (small/rural, mid-size, or large city) during participation were also taken into consideration. An exhaustive search of the literature was conducted following the final compilation of themes from the present study in order to compare it to any existing research that may be related. Findings were also compared to existing RAE-related hypotheses (e.g., maturation-selection hypothesis; 13, 14) and theoretical models (e.g., 35, 53).

3 Results

3.1 Overall findings

Raw data themes were compiled separately for "engaged" and "dropout" participants (i.e., participant status reported at the time of data collection, ~18–19 years of age), and further delineated based on whether the participant was considered to be relatively older (H1) or relatively younger (H2) within this

[2]Participants were asked to estimate the size of the community they currently lived in (1 = Rural/small town, e.g., less than 5,000 people; 2 = Medium-sized town or city, e.g., 5,000-500,000 people; 3 = Large city, e.g., More than 500,000 people; 4 = Not sure).

cohort. The hierarchical content analysis suggested 11 main categories in the data collected from engaged participants (comprised of 155 distinct meaning units) and 10 main categories for those classified as dropouts (representing 103 distinct meaning units). The themes, higher order sub themes, and categories are summarized in Tables 1, 2 for engaged and dropout participants, respectively.

3.2 Participation motives—initial motivation

Overall, there were more similarities than differences between engaged and dropout participants regarding their experiences and motives for participation. At younger ages, participation/engagement motives were the most commonly identified category. For the engaged participants these represented 48 of the identified themes. The top three higher order sub themes included enjoyment (e.g., fun, love of the sport/game), social (e.g., friends/relationships, playing with teammates), and personal improvement motives (e.g., goal setting, challenge). Similarly, for those identified as dropout, the top higher order sub themes were also similar in nature and represented 28 of the identified themes, with enjoyment being the most highly cited, and social, physical fitness, and personal improvement motives noted equally. Family was also noted as a motivator for sport participation.

> [EP14]:"My parents started me, but then I motivated myself. I liked being good at something and thought soccer could be the thing that was mine. The thing I enjoyed and I excelled at."

> [DP5]: "I liked playing and I got to hang out with my friends while I was there."

When these motives were examined based on half-year, the raw data themes were well-balanced between H1 and H2, with no distinct differences observed in any aspect of this category for both engaged and dropout participants.

3.3 Participation motives—future motivation

While initial participation motives were similarly focused, motives for future participation revealed differences between engaged and dropout. For engaged participants, the second most frequently identified category was ongoing/future participation with the higher order sub themes of motives and intentions capturing the data (number of occurrences = 22). Consistent with motives at younger ages, enjoyment and social aspects were commonly cited. Several participants indicated that they intended to continue because opportunities were available, with reference to several competitive levels [e.g., (competitive) varsity teams vs. (recreational) intramurals].

> [EP9]:"How fun it is. It's much less competitive in an intramural setting, and playing with friends who also have the primary goal of just having a good time is refreshing."

In contrast, only 5 themes emerged for future motives within the group of players that dropped out. These include continuing to play recreational/intramural soccer, continuing in a different sport and the social aspects.

> [DP5]:"No, I enjoy playing hockey more."

What set the two groups apart was that those who did not continue in soccer identified attrition motives with a total of 22 distinct meaning units and higher order sub themes comprised of sport-related issues (e.g., lack of a coach, unfair playing time), schedule conflicts (e.g., could not commit to travel schedule, games too late/too long), and change of focus [e.g., (switch to) alternate sport, school, other interests]. With respect to negative sport-related issues, they were experienced to a greater degree by the dropout participants (vs. engaged counterparts) as expected, but there were a variety of themes captured as opposed to common/reoccurring issues experienced by multiple participants. Notably, Participant #12 expressed significant adversity with respect to a coach's expectations and pressure to specialize/train for soccer…

> [DP12:]"I had some crazy coaches who took it too seriously. It got to a point where I no longer enjoyed it due to the screaming coach, rude girls, and ridiculous winter training expectations. Coaches should NOT expect children to focus on one sport in their teen years, especially because I didn't struggle on the team, I was one of the best. I was sad quitting but my coach gave me no choice. I cannot stress enough the importance to allow teenagers to explore other sports as training tends to be universal. Please tell coaches children should be allowed to play other sports regardless of what they are missing in the offseason as a result of it. In fact, they should encourage players to try other sports, or else too much of one sport just ruins the fun, as it did for me."

Barriers to continued participation for the engaged participants included negative relationships, sport politics and issues related to other sports. For instance, Participant #9 stated…

> [EP9:] "Becoming competitive in soccer did not leave any time for sports outside of soccer."

In terms of future motivations and attrition motives/barriers to participation, two distinct differences emerged between H1 and H2 participants. For the engaged participants, four of five H1 participants mentioned "loving the sport" as compared to zero (of three) H2 participants. For the participants who dropped out, attrition motives related to sport (e.g., pressure, off-season expectations, coaching) and schedule conflicts were identified more frequently by the older players, while a change of focus

TABLE 1 Athletes who were engaged at age 18–19 years (i.e., at time of data collection).

Theme[a]	H1 (n = 5)	H2 (n = 3)	Higher order sub theme	Category
Parents enrolled	3	3	Family influence	Initiation Determinants
Sibling(s) participated	2			
Family valued sport sampling		1		
Delayed engagement	1		Self/personal choice	
Friend played	1		Social network	
Invited to participate	1			
Low/negative perception of soccer specific skills	2	1	Soccer specific	Skill Perception vs. Peers (sampling years, age <12 years)
Average/neutral perception of soccer specific skills	1	2		
High/positive perception of soccer specific skills	1			
Not concerned with skill level	1			
(Hindsight) highly skilled	1			
Increasing confidence/skill level	3	1	Soccer specific	Skill Perception vs. Peers (specialization years, age 12–15 years)
Average skill	1			
Improved due to practice	1			
Comparison to other (talented) athletes		1		
Played with heart		1		
Increased level of competition	2	1	Specialization	Sport Progression (transition from sampling to specialization)
Increased training/practice	2			
Increased travel	1			
Year-round participation	1			
Increased investment	1	1		
Leadership role		1	Other	
Attrition of other players/reduced commitment of others	1			
Enjoyment	2	2	Enjoyment	Participation/Engagement Motives (at younger ages/past)
Fun	2	2		
Loved the sport/game	2	2		
Loved to play		2		
Observation of (older) others' enjoyment	1			
(Enjoy) being active/running	2		Physical fitness motives	
Exercise/fitness		1		
Friends/relationships	4	3	Social motives	
Playing with a team/teammates/teamwork	2	1		
Family		1	Family motives	
(Older) sibling(s)	1			
Parent support/parents provided motivation	2	1		
Skill improvement/desire to improve	3	3	Personal improvement motives	
Goal setting		1		
Challenge		1		
Self-exploration		1		
Experience of success (e.g., score goal)		1	Success motives	
Excelled/skilled		1		
Competitive/competition	1			
Future aspirations (i.e., varsity team membership)	1			
Consistent coach	1		Coach related motives	
Coach support	1			
(Pressure due to) influence of/relationship with parents of teammates		1	Sport related issues	Potential Barriers to Participation
(Negative) sport politics		1		
Other sports (more enjoyable/fun)	1			
Dropout from other sports, due to…			In other sports	
- Injury	1			
- Travel issues	1			
- Time commitment	1			
- Loss of interest	1			
- Investment in soccer		2		
Skilled/confident	1	1	Self-awareness of skill	Current Skill Perception (at time of data collection 18–19 years of age)
Know (self) potential	1			
Room to improve		1		

(*Continued*)

TABLE 1 Continued

Theme[a]	H1 (n = 5)	H2 (n = 3)	Higher order sub theme	Category
Maintained skill, but not as refined (due to reduced play)	1	1		
Reached peak/stagnant (due to reduced practice/play)	1			
Average (due to injury)	1			
Reduced skill level (because aged out)	1			
Reduced importance of skill (replaced by fitness/fun)	1	1	Reduced emphasis on skill	
Enjoyment	1	1	Motives	Ongoing/Future Participation
Fun		1		
Love of the sport	4			
Love running	1			
Love competition	1			
Friends/relationships	3	2		
Being active/fitness	2	1		
Part of self-image/identity		1		
Transition to a less competitive context (e.g., Women's league, intramurals)	1	1	Intentions	
Only sport (thus, will continue)	1			
Opportunities available (current league, varsity team)		1		
Team constraints			Time constraints	Potential Barriers to Future Participation
- Work	1			
- School	1			
- Travel	1			
Surgery	1		Miscellaneous	
Academic goals (as a back-up)		1		
Uncertainty about future opportunities		1		
School success/pride		2	Experiences of success	Memorable Experiences
Winning games	2			
Scoring game winner/scoring goals	1	1		
Winning tournament	1	1		
Recognition/accolades (e.g., MVP)	1			
Team captain/leadership role		1	Leadership roles	
Co-captain with friend		1		
Disagreement with coach	1		Negative experiences	
Community support (lots of parents)	1		Network	Impact of Developmental Community (size, characteristics, etc.)
Friends as opponents		1		
Small town community/familiarity		1		
Always fun (with reference to small town)		1		
Lack of facilities	1		Resources	
Proximity to facilities		1		
(Positive) access to resources/environment		1		
Dispersion of talent (community size could not support # of clubs)	1			
(Negative) impact on recruitment (for varsity level	1			

[a]Each theme captured a maximum of one time per participant.

(e.g., switch to new sport) were exclusively identified by the relatively younger H2 players.

3.4 Comparison of relatively oldest vs. youngest with respect to DMSP stages

Overall, there were more similarities than differences when comparing relatively older (H1) vs. younger (H2). There were no clear trends with respect to perceived skill level during the sampling years (i.e., less than 12 years of age); but the relatively older (engaged) members of this sample may have been more inclined to perceive themselves as skilled and reported opportunities for specialization between ages 12–15 years. Supporting this, within the category of Sport Progression, themes for engaged H1 participants included increased practice, competition, travel, and year-round training, which is commonly associated with early specialization in sport. For instance, Participant #2 reported the following…

> [EP2]:"…it [soccer] got more competitive, more practices, I found myself travelling more to play on higher level teams where as when I was a kid it was closer to home…"

TABLE 2 Athletes who had dropped out at age 18–19 years (i.e., at time of data collection).

Theme[a]	H1 (n = 3)	H2 (n = 4)	Higher Order Sub Theme	Category
Parent enrolled	2	2	Family influence	Initiation Determinants
Parent (as coach)		1		
Sibling(s) participated	1			
Interested in sport	1		Self/personal choice	
Knew others who played		1	Social network	
Program availability		2	Programming	
Low/negative perception of soccer specific skills	1	1	Soccer specific	Skill Perception vs. Peers (sampling years, age <12 years)
Average/neutral perception of soccer specific skills		1		
High/positive perception of soccer specific skills	1	1		
High/positive perception of general motor abilities (e.g., fast runner)	1	1	General abilities	
Superior skill level/lack of challenge	2	1	Soccer specific	Skill Perception vs. Peers (specialization years, age 12–15 years)
Improving/improved	1	2		
Average/appropriate skill level		3		
Declining skill level		1		
Rising to challenge (able to push themselves)		1		
Increased intensity/level of competition	1	3	Specialization	Sport Progression (transition from sampling to specialization)
Increased expectations from coaches	1		Coaching	
Familiarity (with other athletes)		1	Other	
Late start	1		Age issues	Age issues
Fun	2	1	Enjoyment	Participation/Engagement Motives (at younger ages/past)
Enjoyment	2	2		
Love of sport/soccer	1			
Love of competition	1	1		
(Enjoy) being physically active		1	Physical fitness motives	
Exercise/fitness	2	2		
Friends	2	3	Social motives	
Family influence	1		Family motives	
Playing with sibling(s)	1			
Quality time with parent (as coach)		1		
Opportunities to improve skill/skill improvement	3		Personal improvement motives	
Goal setting	1			
Superior abilities (provided motivation to focus)	1			
Lack of coach		1	Sport-related issues	Attrition (Dropout) Motives
Lack of teammates/participants		1		
Unfair playing time/coach decisions (at rec level)	1			
Lack of teams (for competition)	1			
Loss of engagement (boring)	1			
No team available (at older age)		1		
Feelings of not belonging to team	1			
Pressure to specialize in soccer (from coach)	1			
Off season training expectations	1			
Conflict with teammates	1			
Inappropriate coach	1			
Time constraints			Schedule conflicts	
- Work	1	1		
- School		1		
- Couldn't commit to travel	1			
Games too late	2			
Games too long	1			
Focus on different sport			Change of focus	
- Skill based reasons		1		
- Enjoyment		1		
(Choose to) focus on school		1		
Other interests		1		
Intramurals (at post-secondary institution)		1	Availability of opportunities	Future Participation (Intentions)
Recreational	1			
(For fun) with friends	1	1	Enjoyment	

(*Continued*)

TABLE 2 Continued

Theme[a]	H1 (n = 3)	H2 (n = 4)	Higher Order Sub Theme	Category
In other sports (because more enjoyable)		1		
Tournaments			Tournaments	Memorable Experiences
- Winning		1		
- Fun		1		
- With friends	1			
Making friends/playing with friends	2	1	Social/team	
(Being part of) newly established team		1		
Practice		1		
Playing with sibling(s)	1		Family	
Network/friends who play	1	2	Network	Impact of Developmental Community (size, characteristics, etc.)
Play at school (recess)		1		
Status within the community	1			
Quality of team		1	Team	
(Explicitly stated) no impact of community	1		Other	

[a]Each theme captured a maximum of one time per participant.

However, caution is needed when interpreting this data due to the low number of engaged H1 participants reporting within this sample (i.e., three of five H1 participants). These themes were not reported to the same degree among the dropout participants.

Interestingly, engaged participants were found to be greater samplers of sport at young ages when compared to the cohort of dropouts. Briefly, the DMSP (41, 42) recommends that children younger than age 12 years participate in a variety of activities before selecting their preferred sport(s) in later years. Engaged participants reportedly participated in an average of 3.25 other sports during the sampling years (range 0–6; two participants reported 6 other sports and both were H2). Further, engaged participants reported involvement in an average of 1.5 sports other than soccer during the specialization years (12–15 years; range 0–3 additional sports). By comparison, athletes who were reported dropouts at time of data collection participated in an average of 1 other sport (range 0–2) during the sampling years (<12 years), and an average of 1.14 sports other than soccer (range 0–2) during the specialization years (12–15 years). This suggests engaged participants sampled three times as many sports at age <12 years vs. the dropouts based on the average. Engaged participants were also more likely to report playing at a competitive level vs. dropouts.

3.5 Community size findings

With respect to community size, participants were primarily from a medium-sized community (overall, $n = 11$) as opposed to small ($n = 3$) or large ($n = 1$) communities. Themes related to social network (e.g., community support) and aspects of the built environment (e.g., proximity to facilities) were noted by both the relatively older and younger, with no clear trends. One participant discussed the negative impact of living in a (smaller) medium-sized community with respect to two issues: 1. Dispersion of talent and 2. Varsity-level recruitment, as evidenced in the following quotes from Participant #15:

> [EP15]:"…we had two separate clubs…which I don't think our city was big enough to have, so that meant that you were splitting up the best players to each club depending on where you lived in the city and I think that that kind of hindered our success. If we had one club, we would have different levels of teams in the same age group and one super team of all the best players. We could pick and choose which kid would play at which level, but because we had two clubs, we split up where we were going."

Her club team was not competitive against larger clubs and consequently, she would have preferred a combined, more competitive group of players to select from.

> [EP15]:"…with the smaller/medium-sized city thing…I had wanted to play…I was interested in playing at the university level but with the smaller clubs, we didn't have access to the university coaches but if I had been playing at a larger club – it would have been easier to get in contact with the university coach…like I feel the university coaches are more invested in finding players at the larger clubs and it wasn't something that our club was ever like…hey, if you guys want to play at the university level, we'll tell you how to get in touch with coaches, we'll tell you the steps you need to be doing in order to have that opportunity."

With respect to recruitment, the participant felt disadvantaged with respect to opportunities for participation at the post-secondary level and responsible for promoting herself as an athlete.

4 Discussion

4.1 Overall of findings related to participation

The purpose of this hierarchical content analysis was to examine relative age and factors contributing to sport engagement/dropout in a post-adolescent, subsample of female soccer players from Ontario, Canada. Additional determinants of youth sport participation (e.g., community size) were also explored, with consideration of the developmental stages outlined in the DMSP (42). Eleven categories emerged from the data provided by engaged participants ($n = 8$), and ten categories for dropouts ($n = 7$). The categories for each of the two groups were similar, although a few distinct differences were noted in the raw data themes. For instance, both engaged and dropout athletes reported similar influences related to initiation of the sport (e.g., parents, siblings), and similar variation with respect to skill perception vs. peers at young ages (less than 12 years).

Differences were noted within the transition from sampling to specialization (12–15 years) category, with engaged athletes reporting a higher number of themes related to specialization in sport (e.g., increased training/year-round training, increased travel). This may suggest that an increased level of commitment to sport during this period of development ultimately results in greater longevity/engagement as an athlete. This proposition is further supported by the reported participation trends of these athletes: that is, all engaged athletes were reportedly playing at a competitive level from ages 12–15 years; and 50% (four of eight) were still playing at a competitive level at the time of data collection which corresponds with 18–19 years of age (three reported participation at the recreational level, and the status of one participant was unknown).

Many participation motives were also shared between the two groups of engaged and dropout athletes, and the themes identified were consistent with previous research. For instance, enjoyment and support from parents, coaches, and/or peers have been found to be predictors of continued sport engagement (for a review, refer to 54). However, despite these similarities, the shared themes were not influential enough to keep the dropout group engaged. Perhaps for some, these motives to participate were overridden by negative experiences (discussed further in the following paragraph). Engaged and dropout participants also shared similar motives for ongoing and future participation, respectively, and similar themes related to their most memorable experiences in sport.

While both groups identified potential barriers to participation (for engaged) and attrition motives (for dropouts), differences were noted with respect to dropout players reporting a greater number of themes related to negative sport experiences (e.g., pressure to specialize, an inappropriate coach, conflicts with teammates). A lack of necessary sport-related resources was also noted [i.e., insufficient number of teammates/participants (to form a team), lack of a coach, no team available for older participants]. Andronikos and colleagues (36) reported similar contributions to sport withdrawal, including poor communication, inappropriate support, excessive pressure, and a win-focused environment. Likewise, Persson et al. (10) identified negative experiences, lack of suitable options within the sports club, high competitiveness/seriousness of training, and illness or injury as deterrents to continued participation. Additional factors contributing to dropout identified by Crane and Temple's review (9) include a lack of enjoyment, competing pressures, injuries, and perceived competence; these themes are consistent with the potential barriers and attrition motives reported by the participants in the current study.

4.2 Relative age-related differences (H1 vs. H2)

When the frequency of reported themes was examined based on relative age (H1 vs. H2) within the engaged and dropout groups, very few differences emerged. This may not be surprising given that participants were not explicitly asked about relative age-related experiences, nor were they informed that RAEs were under examination as part of study objectives. Furthermore, month of birth was intentionally requested at the end of the interview/questionnaire, so as not to bias the participant toward RAE-related themes during data collection. This procedure is consistent with the protocol used by Edwards and O'Donoghue (34). The engaged H1 participants did report a greater number of themes that may be connected to opportunities for early specialization (e.g., increased level of competition or travel, year-round training). Specifically, there were seven raw data themes that exemplified aspects of specialization reported by relatively older (H1) participants and only two instances provided by the relatively youngest (H2). These findings may be consistent with the maturation-selection hypothesis (e.g., 13, 14, 55) which suggests that those who are relatively older and consequently, further along in physical and psychological development, may be more likely to garner coaches' attention and be selected to higher level sport opportunities at earlier stages of development. However, it is difficult to ascertain the consistency of this trend in the current sample.

In general, the similarity of reported experiences mirror the findings of Edwards and O'Donoghue (34); however, they also found that relatively younger athletes experienced feelings of isolation from their team/governing bodies, being less developed and/or coordinated than older teammates, and conflicts with others on their team more often and to a greater degree than the relatively older athletes in their sample. These differences might be explained by the demographic characteristics of the two samples and/or context-related differences between the sports/regions examined in each study. Edwards and O'Donoghue (34) examined high-level (adult) netball players who had competed for one of two countries at some point during their careers; while the current sample included (post-adolescent) athletes from a variety of competitive levels across the province of Ontario, Canada.

The lack of relative age differences may suggest that RAEs are not an important determinant of athletes' experiences when examined from a qualitative perspective. Furthermore, relative

age did not appear to be influential for identifying/predicting who would drop out in this sample; there was no evidence that RAEs impacted the players' experiences and decisions to continue in/disengage from the sport. However, it is also possible that RAEs are a less salient aspect of youth sport experiences, and these differences did not emerge as a result of the study design which aimed to explore youth sport experiences without biasing athletes towards relative age issues. A significant volume of literature has reported RAEs using quantitative methods across a wide variety of age groups, competitive levels, and sport contexts. But this quantitative work has not been able to answer the question why or fully unravel the underlying mechanisms contributing to observed trends that favour those with the earliest birthdates. Future qualitative work in this area will need to carefully consider how to explore RAEs as part of the lived experience of young athletes. Past relative age research has also been limited by the use of birth halves/quartiles and the associated loss of information with respect to participant outcomes (53); and the results of this study may be limited in the same manner.

4.3 The importance of sport sampling

The DMSP recommends that children participate in a variety of sports between the ages of 6–12 years, with an emphasis on motor development and fun (41, 42). This early diversification in sport has been suggested to foster fundamental skills for lifelong involvement and prolonged sport enjoyment (56, 57). This study supports the claim that sampling is important for ongoing engagement, with engaged participants reportedly sampling an average of three times more sports at age <12 years vs. the dropouts.

4.4 Community size

As outlined in the Results section, there were no clear trends between groups with respect to community size. However, ten of the fifteen participants contributing to this study acknowledged that community size/characteristics did impact their athlete experience in some manner (whether it be positive or negative). Further, a separate quantitative analysis of participation trends using the provincewide cohort associated with this subsample revealed participation differences based on community size and density categories (see 58). However, individual variation within community size and community density categories was evident upon detailed analysis. This area of study would greatly benefit from further qualitative work to determine how various community characteristics influence athlete experiences and associated decisions regarding participation.

4.5 General recommendations for sport

The findings of this study suggest that coaches have a significant role to play in athlete wellbeing. Reports of poor or inappropriate support, differing goals and expectations, and unfair/inappropriate behaviour from coaches were observed in the current data, and align with factors that have been found to contribute to decreased athlete enjoyment, engagement, and wellbeing with respect to sport (10, 34, 36). Coaches should employ developmentally appropriate strategies to provide athlete support and promote ongoing engagement (at any level) for the overall well-being of participants (59). With respect to RAEs, coach education has also been recommended and while additional work is needed to assess the empirical validity of specific interventions (60), it is likely important that coaches adjust their selection criteria to avoid relative age biases, and change the way athletes are categorized to promote equitable access to opportunities for all young athletes (23, 40).

4.6 Strengths, limitations, and future directions

This work contributes to an understanding of female sport experiences within the context of North American, developmental-level soccer. The sample size provided a detailed dataset for analysis within this particular sample of post-adolescent athletes; however, it was somewhat limiting when comparing subgroups (i.e., H1 vs. H2, community size, competition levels). Questions about past experiences may have been limited by memory biases, and responses in general may have been subject to limitations inherent in any type of self-report questionnaire, such as social desirability bias. Furthermore, verbal cues were available for the telephone interview, but not for the online Qualtrics questionnaire which may have negatively impacted the richness of the data that was collected from the participants who selected this method. This study also highlights the limitations of existing quantitative analyses when examining athlete experiences and RAEs; while it is certainly plausible that relative age differences impact sport participants in some manner during childhood and youth, the broader, multi-dimensional nature of sport participation needs to be considered when examining participation-related experiences (3, 53). Further, the perspective of participants who dropped out from soccer at younger ages (i.e., before age 15 years) were missing from this analysis and should be considered in future work to ascertain whether these athletes experience RAEs to a greater degree than the current sample.

4.7 Conclusions

This qualitative analysis has provided important insights with respect to the athletes' lived experiences and dropout/engagement behaviour within the sport of soccer. Relative age was not the most important factor with respect to the players' experiences and decisions to continue in the sport when examined from a qualitative lens, with relatively older and younger participants reporting similar themes. Consistent with the tenets of the DMSP (42), sampling a variety of sports before 12 years of age appears to promote continued engagement into the post-adolescent years. Community size/characteristics impacted sport experiences, although no clear trends were ascertained.

Data availability statement

The datasets presented in this article are not readily available because access is not permitted due to privacy concerns. Requests and queries can be directed to smith43@uwindsor.ca.

Ethics statement

The studies involving humans were cleared by University of Windsor Research Ethics Board. The studies were conducted in accordance with the local legislation and institutional requirements. Consent to participate in the telephone interview was confirmed verbally and documented in the interview notes at the time of the interview. Clicking on the link and proceeding to answer the survey questions was considered consent to participate for the online option.

Author contributions

KS: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. NE: Formal analysis, Writing – original draft, Writing – review & editing. PW: Conceptualization, Methodology, 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.

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The author(s) declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

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The Royal Netherlands Football Association (KNVB) relative age solutions project—part two: an adapted e-Delphi study

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Introduction: Following the lack of widely implemented interventions to mitigate Relative Age Effects (RAEs) in sports, the Royal Netherlands Football Association (KNVB) called on stakeholders to propose relative age solutions in youth soccer (Part One). This initial study yielded 13 lower-order potential solutions, many of which remain hypothetical. Therefore, this study aimed to evaluate these solutions to overcome RAEs in youth soccer using a two-round adapted e-Delphi study.
Methods: Fifteen international experts, including both researchers and practitioners, rated (out of 9) each solution on how likely it is to directly and indirectly mitigate RAEs (Round 1) and how feasible it is to implement (Round 2).
Results: Findings indicated that "rotating cut-off dates" was perceived as the most effective solution to mitigate direct and indirect RAEs (6.2 ± 1.6), although it was not rated particularly feasible (4.6 ± 2.5). In comparison, while "cueing differences in age" was perceived as the most feasible solution (6.7 ± 2.1), it was deemed less useful for mitigating RAEs (5.2 ± 2.3). Taken together, "cueing differences in age" was considered the most viable solution across both rounds (5.8 ± 2.3).
Discussion: Interestingly, highly rated solutions perceived to effectively moderate RAEs were generally expected to be more challenging to implement. Results also showed regular disagreement amongst the international experts, highlighting that creating consensus on possible relative age solutions may be difficult to achieve in youth soccer. Moving forward, the highest rated solutions should be designed, implemented, and evaluated based on their effectiveness and feasibility in practice.

KEYWORDS

relative age effects, talent identification, talent development, athlete development, youth soccer, youth football

Introduction

Over the last four decades, there has been widespread research attention on Relative Age Effects (RAEs) in sport. Following the seminal works of Grondin et al. (1) and Barnsley et al. (2), several reviews [e.g., (3–5)], books [e.g., (6, 7)], and a substantial amount of empirical studies in different sports have been published since; ranging from chess [e.g., (8, 9)] to basketball [e.g., (10, 11)] and cricket [e.g., (12, 13)] to synchronized swimming (14). Youth soccer has emerged as a regularly researched area where RAEs are highly prominent and persistent [e.g., (15–18)]. Such studies consistently show that age differences resulting from cut-off date eligibility (e.g., U12,

U13, U14, etc.) favour relatively older players (i.e., those born near the start of the cut-off date), while simultaneously disadvantaging relatively younger players (i.e., those born near the end of the cut-off date). During this time, however, there is a lack of proposed solutions that have been designed, implemented, and evaluated to test their effectiveness and feasibility to mitigate RAEs (19). Given its worldwide popularity coupled with the early selection procedures often applied in high performance environments (e.g., academies), soccer provides an important context to evaluate the effectiveness and feasibility of relative age solutions.

Research in sport has emphasised multiple potential implications of RAEs, including higher dropout rates and exclusion of relatively younger athletes at higher competitive levels. These inferences are manifested in the skewed birth date distributions of athlete populations and are likely limiting the pool of potential talent. Any attempt to implement solutions into practice to mitigate RAEs requires a thorough understanding of the fundamental mechanisms of what exactly causes them (20). To date, research has put forward several theoretical frameworks that aim to explain the emergence of RAEs in sport [e.g., (3, 12, 21, 22); see Part One for an overview, (23)]. While these frameworks offer different views, the general consensus is that RAEs arise from an interaction between various factors, such as superior physiological capacities, an older training age, and advanced cognitive development. This coincides with the evaluation of these advantages by social agents (i.e., coaches, parents, and peers), whereby coaches (and other scouts/recruiters) who act as gatekeepers to future developmental opportunities often misinterpret physiological advantages, prolonged training, and/or enhanced cognitive abilities as talent (3, 21). This bias seems to underpin RAEs by creating a self-fulfilling prophecy, as those initially considered as more talented (i.e., relatively older players) are provided access to better coaches and more resources, further increasing their opportunities for future selections.

Given the theoretical mechanisms, it becomes apparent why RAEs are especially prevalent across youth levels in sport, and particularly soccer. In soccer, it is common to group players based on chronological age (4). As a result, 12- or 24-month age differences might occur between the youngest and oldest player in an age-grouped team. Especially across the youngest age groups (e.g., U8, U9, U10, etc.), such an age difference represents a substantial part of a player's developmental career. For instance, up to the age of 10 years, a 12-month age gap represents more than 10% of the player's total lifespan. When combined with selection and grouping procedures involving the evaluation or judgement of performance and potential, which generally already begins during childhood (e.g., aged 8, 9, 10, years) (24), these age differences result in a substantial overrepresentation of relatively older players at representative levels such as academy teams (25).

In an attempt to simplify how RAEs arise, Mann (26) classified two general working mechanisms as "direct" effects (i.e., benefits experienced by relatively older players themselves) and "indirect" effects (i.e., benefits experienced by relatively older players through others). Although this distinction supports the practical implementation of solutions, there remains a lack of research that has tested solutions to mitigate RAEs in practice. Webdale et al. (19), for example, provided a valuable synopsis of the possible benefits and drawbacks for proposed relative age solutions in sport. Importantly, though, the utility of many of these solutions remains largely generalised and mainly hypothetical, as very few have been implemented or empirically studied across different sports. Indeed, it is important to recognise different sports require different approaches to RAEs. For instance, grouping based on chronological and biological age may be more suitable for team sports (e.g., basketball, rugby, soccer), whereas birthday-banding, corrective adjustments, and proficiency level-based competition may be more useful for racket (e.g., badminton, squash, tennis), timed (e.g., cycling, sprinting, swimming), and combat (e.g., boxing, judo, taekwondo) sports, respectively (27). Further research is required, however, to better understand sport-specific relative age solutions and substantiate these examples.

In an attempt fill the relative age solutions void and fulfill the need for sport-specific measures, the Royal Netherlands Football Association (KNVB) created a project to better understand potential approaches to mitigate RAEs in soccer, with the long-term goal of designing, implementing, and evaluating viable interventions in Dutch youth soccer settings. As a first step in this project, stakeholders were invited to propose relative age solutions in youth soccer, which resulted in 13 lower-order solutions from three higher-order themes: (a) altering the behavior of observers ($n = 3$), (b) implementing rules when selecting teams ($n = 6$), (c) adjusting competition structures ($n = 4$) [see Part One (23);]. Interestingly, no new suggestions outside the existing literature were proposed in any of the participants' submissions. Whilst no new proposals were suggested, to our knowledge, only two have been empirically tested in soccer to date [i.e., "cueing differences in age", (28); "grouping based on chronological and biological age", (29)]. Out of the 143 proposed solutions, results showed the most frequent higher-order theme that was put forward by the participants was "adjusting competition structures" ($n = 78$), with "modifying age bands" ($n = 25$) the lower-order solution that was suggested most often.

The second step of this project, and the corresponding aim of this present study, was to evaluate the direct and indirect "effectiveness" (i.e., the likelihood that a solution would be successful in mitigating the direct and indirect RAEs in soccer) and the "feasibility" (i.e., the practicality and possibility to design and implement a solution in youth soccer) of these 13 potential solutions. Using "direct" and "indirect" as distinctions for effectiveness provided a useful framework to classify solutions that might be effective based on the underlying mechanisms of RAEs they address, serving as a useful input as part of a modified electronic Delphi (e-Delphi) approach. The e-Delphi technique is commonly used to increase the understanding of complex phenomena without much conclusive information (30). As it became apparent in Part One of the current project, many solutions have been suggested to mitigate RAEs. To date, though, there is a lack of a systematic evaluation of their utility and

currently limited to the context of a single sport or country [e.g., (28, 29)]. Typically, evaluating such interventions would involve scientific techniques such as systematic reviews and meta-analyses; however, the relative lack of empirical investigations on the utility of RAEs solutions limits this approach. As such, given the lack of empirical evaluations across multiple contexts, we deemed the e-Delphi approach as a particularly useful method to evaluate the utility of potential interventions that could mitigate RAEs in youth soccer. The Delphi technique, and the e-Delphi in particular, enables to gather the judgments across a wide pool of international experts, given that all communication is online. Indeed, gathering a mixed pool of experts from different backgrounds enables the simultaneous evaluation of the conceptual mechanisms and practical implications of each solution beyond the national youth soccer contexts in which it has been examined so far.

Methods

Participants

Given the global importance of RAEs and our objective to evaluate both the effectiveness and feasibility of proposed solutions, we aimed to create an international expert panel that reflected these areas of expertise. As such, panel members of the e-Delphi were selected through purposeful sampling, considering several aspects to construct the panel (31). With regards to the size, heterogeneity, and expertise level of the panel, we invited 25 researchers who were (co-)authors (excluding the current research team) from book chapters in two published books on RAEs [e.g., (6, 7)], as well as 15 practitioners working within youth soccer who had publicly discussed the impact of RAEs in practice, to participate. This size of the expert panel was considered adequate for the specific topic of RAEs in sport (32). In addition, the heterogeneous sample of both researchers and practitioners reduced the risk of response bias, while also offering a broader picture of the utility of potential RAEs solutions. Based on these criteria, it was anticipated that these participants would have a certain level of interest in the topic, which would motivate them to participate in the e-Delphi study.

After invitations were administered, 15 participants took part in the e-Delphi survey. First-round data from three participants who did not complete the second-round survey were retained to help capture the wider expertise. All participants were informed of the study procedures and provided electronic consent prior to participation. This study received ethical approval from the Health, Education, and Life Sciences Faculty Academic Ethics Committee at Birmingham City University, United Kingdom (ethics code #9524).

Measures and procedures

The Delphi technique is a systematic method, consisting of a series of surveys, to develop consensus amongst a designated panel of domain-specific experts. While there are no clear guidelines for the design of a Delphi study, typical elements include anonymity amongst the panel members, several iterative rounds, and the analysis of group results (33, 34). In the present study, we used a modified e-Delphi approach, consisting of an electronic approach with *a priori* defined maximum of two rounds. The e-Delphi is particularly suited for expert panels that include international participants from multi-stakeholder groups, enabling them to complete this online at their own convenience.

For the initial round of our e-Delphi, we created an online survey in Microsoft Forms (Microsoft Corp., Redmond, WA, USA) and invited all participants to take part in the study. Here, they were required to rate the direct and indirect "effectiveness" of each of the 13 solutions to mitigate RAEs in youth soccer, derived from the first part of this research project (see the list of solutions in Table 1). In the invitation, participants were asked to provide consent to participate in the e-Delphi and were made aware that their responses would be processed anonymously. Each solution was evaluated using 10 items, resulting in 130 items within the first round. Each item was phrased as a presumption in the following way: "This solution … [mitigates a specific (in)direct effect]". Thereby, the items were divided into their effectiveness to mitigate "direct" (6 items) and "indirect" (4 items) effects of RAEs. This distinction involved addressing different (dis)advantages considered to arise from RAEs. For instance, "This solution decreases the likelihood of relatively older players experiencing greater levels of self-efficacy" was based on the hypothesised "Galatea Effect", whereby unjustly raised self-efficacy of relative older players can subsequently enhance performance (21). This distinction enabled the examination of how certain solutions might act on the different mechanisms underlying the emergence of RAEs, whereby the items related to the direct effects are (dis)advantaged experienced through enhanced maturation, whereas indirect effects are disadvantages experienced through the behaviour of social agents. Additionally, it enabled the possibility for hybrid approaches to appear (e.g., complementary approaches where one solution targets direct effects, the other mitigates indirect effects), as well as aggregates the overall mean effectiveness score. Instead of discussing solutions as mutually exclusive, potential solutions could now be considered as complementary because they might differ in effectiveness on either direct or indirect RAEs.

Following the first e-Delphi round, participants could immediately commence the second e-Delphi round. While a typical feature of the Delphi methodology is the provision of feedback amongst panelists, we adapted this to reduce participant burden and to lower attrition rate (35). If participants did not begin the second Delphi round two weeks after completion of the first, they received an email invitation that included the results of the first e-Delphi round and a link to commence the second e-Delphi round. This feedback included a bar chart describing the distribution of (anonymous) responses from the first round. The second (final) e-Delphi round aimed to evaluate the "feasibility" of each of the 13 solutions. In line with the first e-Delphi round, ten items were formulated as a presumption reflecting the practical feasibility of that solution to be

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TABLE 1 Descriptive statistics for each solution over the two e-Delphi rounds. These are listed from highest to lowest based on the overall rating.

Solution	Direct Effectiveness			Indirect Effectiveness			Combined Effectiveness			Feasibility			Overall Rating[c]			
	M ± SD	Mdn	KAlph[a]	M ± SD	Mdn	KAlph	M ± SD	Mdn	KAlph	M ± SD	Mdn	KAlph	M ± SD	Mdn	KAlph	Con[b] (*n*)
Cueing Differences in Age	4.7 ± 2.2	5	−0.01	5.9 ± 2.3	7	0.30	5.2 ± 2.3	5	0.19	6.7 ± 2.1	7	0.15	5.8 ± 2.3	6.5	0.29	5
Grouping Based on Chronological and Biological Age	6 ± 2.2	6	−0.04	5.8 ± 2.1	6	−0.04	5.9 ± 2.2	6	−0.04	5.2 ± 2.5	5.5	0.27	5.6 ± 2.3	6	0.12	
Submitting Entry Exemption	5.5 ± 2	6	0.04	5.3 ± 1.6	6	−0.01	5.4 ± 1.8	6	0.03	5.6 ± 2.3	6	0.19	5.5 ± 2.1	6	0.12	
Rotating Cut-off Dates	6.3 ± 1.6	6	−0.03	6.2 ± 1.6	6,5	−0.03	6.2 ± 1.6	6	−0.03	4.6 ± 2.5	4.5	0.15	5.5 ± 2.2	6	0.17	
Capping the Average Team Age	5.6 ± 2.1	6	0.01	5.7 ± 2.1	6	0.05	5.7 ± 2.1	6	0.02	4.8 ± 2.1	5	0.19	5.3 ± 2.1	6	0.13	
Categorising on Characteristics Other than Age	6.3 ± 2	7	−0.04	5.9 ± 2.1	6	−0.03	6.1 ± 2.1	7	−0.02	4.4 ± 2.3	4	0.19	5.3 ± 2.3	6	0.21	1
Modifying Age Bands	6.1 ± 2	6	−0.04	5.4 ± 2.1	6	−0.06	5.8 ± 2	6	−0.01	4.8 ± 2.6	5	0.08	5.3 ± 2.4	6	0.07	
Applying Player Selection Quotas	4.7 ± 2.3	5	0.00	5.2 ± 2.3	6	0.12	4.9 ± 2.3	5	0.05	5.6 ± 2.5	6	0.09	5.2 ± 2.4	6	0.10	
Delaying Selection and Deselection	5.1 ± 2.3	5,5	−0.03	5.8 ± 2.2	6	0.17	5.4 ± 2.3	6	0.08	4.9 ± 2.7	5	0.12	5.2 ± 2.5	5	0.11	2
Raising Awareness of Relative Age Effects	4.4 ± 2.2	5	0.00	4.7 ± 2.3	5	0.07	4.5 ± 2.2	5	0.03	6.1 ± 2.5	7	0.08	5.2 ± 2.5	6	0.17	
Testing Objective Skills	5.9 ± 1.8	6	−0.02	5.7 ± 1.7	6	0.01	5.8 ± 1.7	6	0.00	4.1 ± 2.4	4	0.31	5 ± 2.3	5	0.29	3
Using Corrective Adjustments	5.1 ± 2.2	5	−0.07	5.8 ± 2.2	6	0.05	5.4 ± 2.2	5	0.01	4.5 ± 2.7	4	0.17	5 ± 2.5	5	0.12	
Shifting Cut-off Dates	3.5 ± 1.8	3	−0.06	3.6 ± 2	4	−0.05	3.6 ± 1.8	3	−0.06	5.3 ± 3	5	0.39	4.3 ± 2.6	4	0.29	1

[a]Krippendorf's Alpha.
[b]the items that reached consensus (≥80%).
[c]the overall rating is the average of all items together, M = Mean, SD = Standard Deviation, Mdn = Median.

implemented in the context of youth soccer. Each item was phrased as a presumption in the following way: "This solution … [mitigates a specific (in)direct effect]". Items included question such as "This solution requires significant financial resources (e.g., extra teams) at an individual club level" and "This solution is expected to yield positive results on a short timescale (i.e., within one season)".

For both rounds, participants were asked to evaluate the likelihood that the presumption for that specific solution is true, ranging on a Likert scale from 1–9 (1: Not Very Likely; 9: Very Likely). The use of a nine-point rating scale aligns with the established consensus-criteria used in Delphi research and is recommended in the process before establishing definitive consensus, aligning with our study's aim (36, 37). If participants could not reliably evaluate the likelihood of that solution mitigating RAEs, they were instructed to give a score of 0, which were subsequently treated as missing values. In addition, if participants were not fully familiar with the proposed solutions hypothetical working mechanisms, they could revert to a brief one-page summary of each solution that was provided by the research team. Lastly, participants were encouraged to provide qualitative justification for their rating via an optional open textbox provided at the end of each assessment, enabling panellists to comment on the solution as a whole. See Supplementary File S1 for the complete survey.

Data analysis

Following the conclusion the second e-Delphi round, using the R base package [version 4.4.0; (38)], mean (M) ratings with standard deviations (SD) as well as median (Mdn) and interquartile ranges (IQR) were compiled on items related to their perceived: (a) direct effectiveness to mitigate RAEs, (b) indirect effectiveness to mitigate RAEs, (c) combined effectiveness to mitigate RAEs, (d) feasibility to be implemented in youth soccer, and (e) overall rating, of which was used to rank order the solutions. To examine the consensus amongst the e-Delphi panel, we calculated the percentage agreement among the panellists for each solution. Consensus was defined as 80% of the panellists rating the items between either 1 and 3 (the statement is not true for this solution) or 7 and 9 (the statement is true for the solution). In addition, we also computed Krippendorf's Alpha with the "irr" package in R (39) to assess the inter-rater agreement on each of the items related to RAEs solutions (40). These statistics provided an overview of the variability in expert opinions, and, as such, also served as an indicator of consensus.

Qualitative responses that the panellists provided were also collated, which were analysed by one member of the research team (last author) and then reviewed by another (first author). This included coding the qualitative comments as "nuance" (i.e., the panellist provided opposing arguments to make their quantitative response more nuanced) or "justification" (i.e., the panellist provided supporting arguments to strengthen their quantitative response). The comments were subsequently analysed based on the specific content of their argumentation (e.g., significant need for extra resources, limited applicability in

soccer), summarising comments that referred to the same arguments. These data were used in the final analysis to provide insight on the (lack of) consensus for specific solutions, and are included as examples in the results to provide support for the mean group ratings (41). Comments that did not include any information from the panellist on the potential benefits and drawbacks of each solution were not considered further in the analysis.

Results

Descriptive statistics (i.e., mean, standard deviation, and median) from the panelists during the first (effectiveness) and second (feasibility) e-Delphi rounds are presented in Table 1. Table 1 also presents Krippendorfs alpha as an indicator of the consensus amongst panel members for each of the e-Delphi statements related to each proposed solution. The interquartile ranges for each of the statements are shown in Figure 1 (round one) and Figure 2 (round two). In both figures, the subplots are ordered according to the overall interquartile range for each proposed solution. The perceived benefits and drawbacks for each of the 13 proposed solutions are presented in Table 2. Since it is beyond the scope of this study to provide an in-depth overview from each of the 13 proposed solutions, the qualitative results in this section are presented below for "cueing differences in age", "rotating cut-off dates", "categorising on characteristics other than age", "grouping based on chronological and biological age", and "submitting entry exemption". This is because these solutions were considered the most effective to mitigate direct and indirect RAEs as well as the most feasible to be implemented in youth soccer.

The highest overall ranked solution was "cueing differences in age". Participants reached consensus on 5 items, and strongly agreed that this solution decreases the likelihood of a selection bias caused by relatively older players being judged as more talented by coaches and/or talent scouts (7.2 ± 1.8; IQR = 1; $\%_{agree} = .87$). Related to this, consensus was reached amongst participants that this solution would to some extent address "the likelihood of relatively older players being selected" (6.7 ± 1.7; IQR = .5; $\%_{agree} = .80$). For example, Participant 4 stated: "Additional information (such as shirt numbering) will provide greater clarity and a truer picture of ability, so would prove useful for assessment and selection". Relatedly, the study of Mann and van Ginneken (28) suggested that when presented with information regarding the relative age of players while simultaneously assessing performance by means of age-ordered shirt numbering, coaches and/or talent scouts were able to reduce the relative age bias in their assessments. As such, cueing differences in age might be especially appropriate for mitigating indirect effects, which typically emerge through social agents' behaviours.

Regarding feasibility, the majority of participants commented that "cueing differences in age" can be implemented "quickly and effectively" (Participant 2). Indeed, participants agreed that it is likely that it can be implemented immediately ($\%_{agree} = .92$) without considering the macro sporting context (e.g., league structures and regulations) (7.8 ± 1.9; IQR = 1.5). However, given

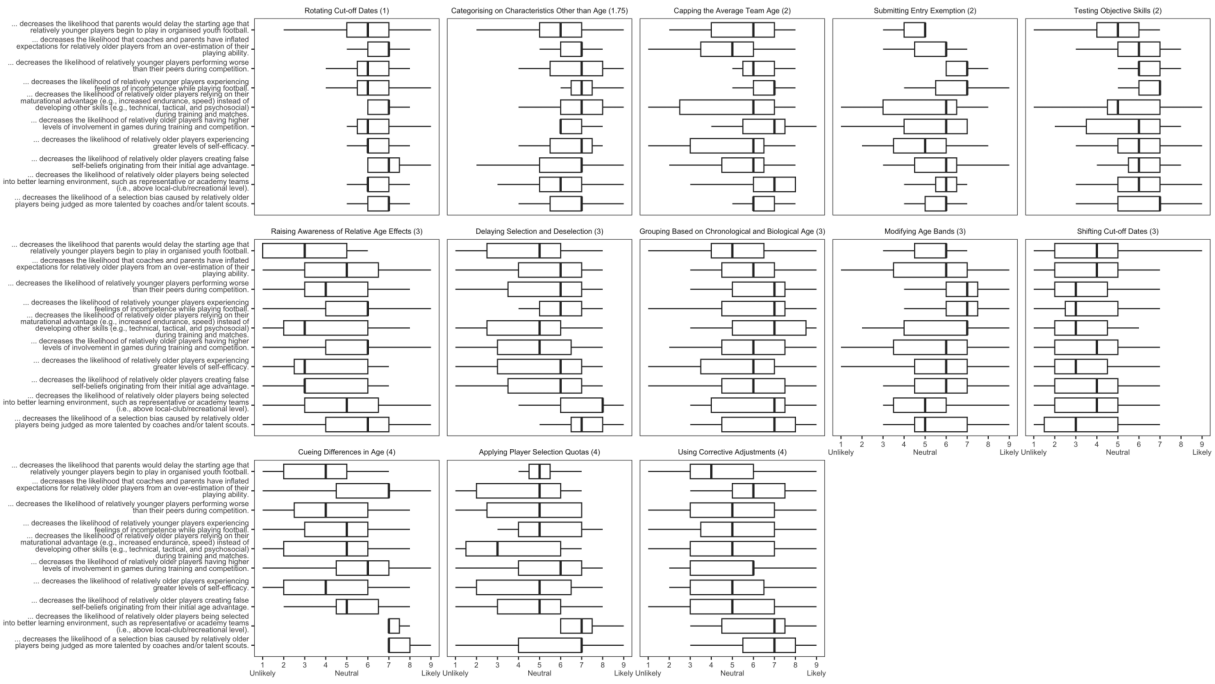


FIGURE 1
The interquartile ranges for each of the statements for round one (effectiveness), with the subplots ordered according to the overall interquartile range for each proposed solution.

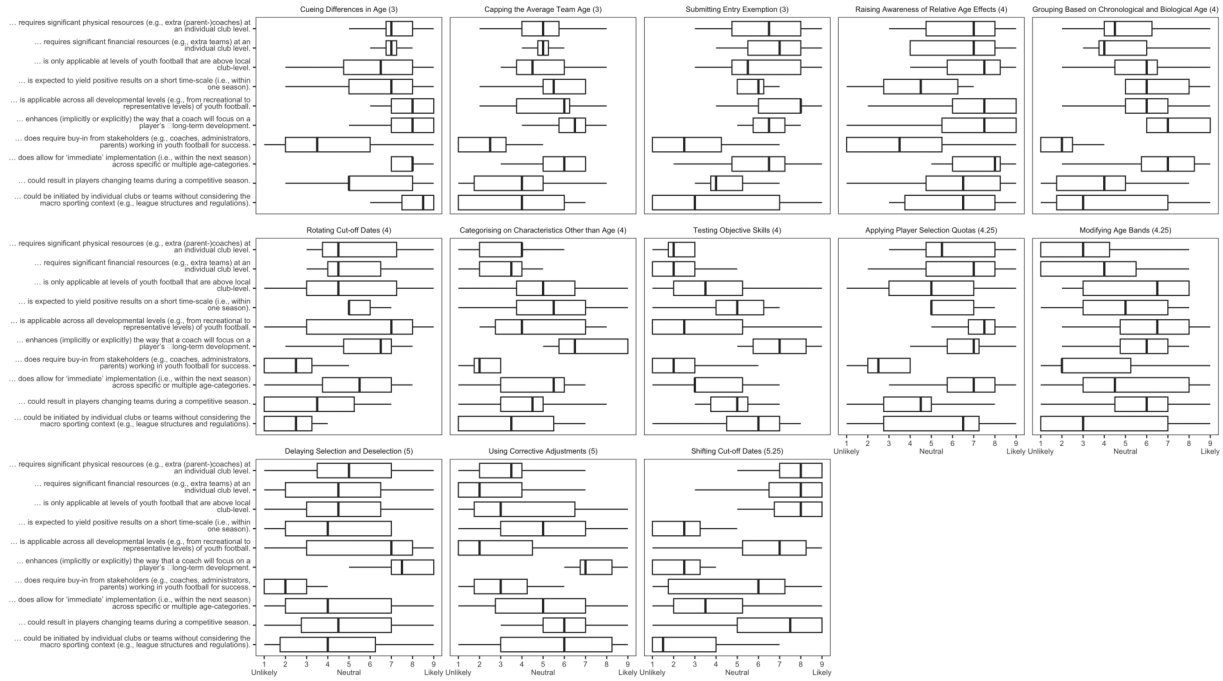


FIGURE 2
The interquartile ranges for each of the statements for round two (feasibility), with the subplots ordered according to the overall interquartile range for each proposed solution.

that these solutions mainly target the selection of players, which typically takes place on an annual basis, it might not address the direct advantages of being relatively older. For instance, Participant 2 also stated that: "It may not prevent certain players being disadvantaged during the game", highlighting that the direct effects attributed to age-related differences are likely not addressed by this solution. This is also reflected in the relatively higher disagreement about cueing difference in age decreasing "the inflated expectations of player's ability from coaches and parents" (5.9 ± 2.3; IQR = 2.5). Therefore, it may be a more beneficial solution to use during momentary talent identification and selection activities (e.g., trials, talent identification events) rather than routine training and competition; or alternatively, in conjunction with other solutions to mitigate more direct effects. However, further research is required to substantiate these suggestions.

The most effective overall solution was "rotating cut-off dates". This solution aims to balance RAEs by rotating the selection cut-off date (e.g., changing the cut-off date 3-months every year). This way, each player would spend some time as the oldest player amongst an age group, and some time as the youngest. Participants suggest that it does not address the age advantage *per se*, but does alter "player experiences of being the youngest and oldest on the team" (Participant 7). As such, participants generally agreed that this solution might decrease "the likelihood that relatively older players created false self-beliefs" (6.7 ± 1.7; IQR = 1.5) and "stakeholders over-estimating the playing ability of relatively older players" (6.3 ± 1.6; IQR = 1). As stated by Participant 5, this solution could potentially increase relatively younger players self-image, "as the peer group being used for comparisons would always be changing". Although such statements remain hypothetical as rotating cut-off dates have not been researched of widely implemented in soccer, lessons could be learnt from the "birthday-banding" approach (i.e., athletes competing with and against those of the same age and move up to their next birthdate group on their birthday) used in the England Squash Talent Pathway, which has been attributed to the encouraging absence of RAEs across their cohorts (42). Importantly, however, while participants indicated that "the idea that players experience being the oldest and youngest at some point is one worth considering further" (Participant 4), they were hesitant and in disagreement regarding its feasibility ($M = 4.6 \pm 2{,}5$, $K_{alpha} = .15$). In particular, participants were doubtful about the logistics that "would have to be well thought out and communicated and understood very clearly" (Participant 2), as well as requiring buy-in from stakeholders (e.g., coaches, administrators, parents).

Although "submitting entry exemption" was ranked equal third with the same overall score as "rotating cut-off dates", there was generally less agreement amongst the panellists regarding its utility ($K_{alpha} = .17$ vs. $K_{alpha} = .12$). Entry exemption enables players to "play-down", which means that a player competes in competitions designed for younger age groups (43). Typically, eligibility criteria (e.g., youth league policies) do not allow players to play down, resulting in relatively younger players born closer to the cut-off date fixed to play with and against relatively older players. This solution, however, proposes easing the eligibility criteria, particularly for relatively younger players (e.g., players

TABLE 2 The perceived benefits and drawbacks for each of the 13 proposed solutions. These are listed based on the three higher-order approaches to correspond with Part One of this project [see Figure 1 in (23)].

Approaches	Solutions	Perceived Benefits	Perceived Drawbacks
Changing the Behaviour of Observers	Raising Awareness of Relative Age Effects	I think it is good as an additional concept. The underdog-concept also shows that children can also develop more skills by competition with relative older children. So, I think that a combination of both is good (Participant 10).	Maybe causes another issue where players are being selected on the basis of age rather than actually technical and tactical ability and potential, which really should be the focus. While it would address the RAE issue, I am not sure that it is the best approach to ensuring players are selecting on the factors that are most important (Participant 1).
	Cueing Differences in Age	This is a way to implement something quickly and effectively to raise the age differences that will occur. It may not prevent certain players being disadvantaged during the game, but it will raise awareness of age and possible maturity differences (Participant 2).	This solution looks very promising, although I would love to see some replication of these findings in different labs and contexts to establish the robustness of these effects (Participant 3).
	Testing Objective Skills	I think this is a good call. Having standards where players can be judged not just for their age groups but for their relative age would be good. Equivalent systems, but for variance in maturation and fitness tests, are already in place with the English Premier League academy system allowing coaches to better evaluate strength and weakness of players from a developmental perspective (Participant 1).	For physical attributes, a clear link with relative age has been found. However, for other important attributes like cognitive maturation, the link is far from clear. As a result, skill-testing can only be done for a limited number of attributes (Participant 6).
Implementing Rules when Selecting Teams	Submitting Entry Exemption	The flexibility of our pathways is extremely important due to the non-linear nature of development so yes, I would favour this. There would need to be a lot of player and parental supports available while navigating "playing down"—counteracting perceptions of failure/lack of ability (Participant 6).	A key question here is what criteria are used to allocate a youth player to a higher or a lower team: is it just by month of birth or is also the developmental age considered (Participant 5)?
	Applying Player Selection Quotas	Raising awareness by coaching and scouting staff is important, but many studies show that it is not enough to decrease RAE- and maturity-related bias in soccer. I think it is good to involve in the further education program from coaching and scouting staff. But more solutions are necessary (Participant 10).	The value of this solution lies in the assumption that coaches don't already know about this effect. In my experience, most are aware of it and so education, while feasible and relatively inexpensive, may not be that helpful (Participant 3).
	Delaying Selection and Deselection	I like the idea of delaying the selection/deselection aspect in favour of a focus upon development and managing the journey through puberty more effectively (Participant 2).	Delaying selection is a good idea, but the problem is that the RAE is present from 6 years and holds pretty steady through to mid adolescence (i.e., 15 to 16 years). Even if you select at this point you are still selecting from a biased sample. The impact of RAE upon developmental differences will be arguably less at this time, but the academies are still full of BQ1s (Participant 1).
	Capping the Average Team Age	This option could begin to level out the playing field but may prove difficult across all levels of the game. The idea behind it is a good one (Participant 4).	Bio-banding has absolutely nothing to do with the RAE so while it may be effective at addressing maturational differences it will have no impact whatsoever. Part of the problem with addressing the RAE has been the fact that people are quick to attribute it to differences in maturation when this is clearly not the case (Participant 1).
	Grouping Based on Chronological and Biological Age	This reallocation concepts would be a very good solution for RAE- and maturity-related bias in soccer. Comparing with the concept of bio-banding, we see that the age-differences in different age categories are becoming smaller and better, more realistic (Participant 10).	I don't see throwing in maturation as a viable approach to address the RAE as you are talking about two completely different issues here. Plus, RAE effects are present from early childhood and maturation related biases and advantages do not kick in until approximately 11 years of age (Participant 1).
	Using Corrective Adjustments	As an additional tool in player evaluations then yes, all data should be examined. But how to incorporate it into a score for team selection or to remove performance (dis)advantages is complex (Participant 6).	As mentioned before, it is not clear what this method will look like for team sports. For individual sports, it is clear that there are sprinting times for example that are very representative of the overall performance. In team sports, however, the performance is multi-dimensional, which makes it very hard to understand how this kind of adjustment would be applied (Participant 1).
Adjusting Competitive Structures	Modifying Age Bands	The smaller the age range, the smaller the RAE (Participant 7).	If you just reduce the age band or extend it, then the RAE will still remain [..] it simply shifted from BQ1 and BQ2 to BQ1 and BQ3 (Participant 1).
	Rotating Cut-off Dates	Each player experiences being the youngest and oldest on the team. The overall average of these experiences should minimize, if not eliminate, the RAE. Overall, a very effective proposal (Participant 7).	Cut-off date modification and birthday-banding will not be enough to encounter the RAE bias, as showed in different studies. It's also difficult to implement it organizational in daily life, different systems use different cut-off dates (Participant 10).

(*Continued*)

TABLE 2 Continued

Approaches	Solutions	Perceived Benefits	Perceived Drawbacks
	Shifting Cut-off Dates	This is an interesting idea. Players who are disadvantaged in both education *and* sport may benefit from this approach and as such it deserves further investigation, particularly if it supports the social and emotional development of players due to more appropriate peer grouping (Participant 2).	Varying cutoff dates for the same sport in different leagues would be effective, however, varying cutoff dates for different sports will still maintain RAE (Participant 7).
	Categorising on Characteristics Other than Age	These initiatives definitely have merit, although I fear that they'd have to delivered in conjunction with coach education, as changing the mindset for some (i.e., winning at all costs at youth level) will be necessary for successful adoption of such worthy initiative (Participant 6).	Its success will be largely dependent on the clubs having a balanced distribution of players coming into the academy in the first place (Participant 1).

born in the second half of the selection year). As such, these children could potentially avoid the associated disadvantages of being younger, whilst also providing a more challenging environment for the older birth quartiles in the younger age group. Although yet to be empirically evaluated, anecdotal evidence has showed how some England international players played down in academy soccer during their development (44). Some participants, however, issued possible warnings regarding the stigma surrounding playing-down. For instance, Participant 1 suggested: "We would have to change the cultural interpretation associated with playing-up or playing-down. Playing-up is seen as good, playing-down as bad".

Another solution that was ranked high on its effectiveness to mitigate direct RAEs was "categorising on characteristics other than age". In particular, the participants considered grouping players on alternative criteria as a viable solution to address "feelings of incompetence while playing football for relatively younger players" (6.7 ± 2.0; IQR = 1.0), although disagreed more on the solution mitigating "the reliance of relatively older players on their maturational advantage" (6.7 ± 2.2; IQR = 2.0). Given the hypothesised developmental advantages that influence RAEs and the fact that relatively older players have had more time to grow and physically develop [e.g., (45–47)], it is expected that controlling for anthropometric and/or physical characteristics could mitigate RAEs. As such, alternative grouping criteria that have been suggested are height/weight categories or initiatives such as "bio-banding", whereby players are grouped according to their level of maturation, often using their percentage of predicted adult height (48).

Closely related to using height and weight categories as a grouping strategy was "grouping based on chronological and biological age". This solution suggests using the height of players relative to their peers as a criterion for grouping. Although, on average, this solution was rated more feasible (5.2 ± 2.5) and panel members were more in agreement ($K_{alpha} = .27$) compared to "categorising on characteristics other than age" (4.4 ± 2.3), some participants were cautious to try and solve temporary, maturational advantages together with relative age differences. As one participant stated: "Maturity and RAE share about 8 percent variance in academy football" (Participant 1). In addition, for both "grouping based on chronological and biological age" (IQR = 1.5) and "categorising on characteristics other than age" (IQR = 1.25; $\%_{agree} = .92$), participants perceived the buy-in from stakeholders (e.g., coaches, administrators, parents) working in youth soccer necessary. This was also the case for "delaying selection and deselection" (IQR = 2.0; $\%_{agree} = .83$) and "testing objective skills" (IQR = 2.0; $\%_{agree} = .83$).

Discussion

The aim of this present study was to evaluate the potential direct and indirect effectiveness and feasibility of 13 proposed solutions to mitigate RAEs in youth soccer that were gathered in Part One of this project. Based on our modified e-Delphi approach, "cueing differences in age" was considered the most viable solution across both rounds. "Grouping based on chronological and biological age" and "rotating cut-off dates" were also perceived highly to mitigate direct and indirect RAEs as well as the most feasible to implement into youth soccer. Interestingly, these three solutions are from three different higher-order categories according to the taxonomy of Mann (26), which perhaps underscores the importance of designing hybrid approaches that target multiple aspects of RAEs.

Overall, "shifting cut-off dates" was rated the lowest solution, with "using corrective adjustments" and "testing objective skills" also rated lower than other approaches. With regards to effectiveness, "raising awareness of RAEs" was rated low but rated high on feasibility, whilst "cueing differences in age" and "modifying age bands" were rated differently on their effectiveness for direct and indirect RAEs, respectively. With regards to feasibility, on average, overall ratings were lower compared with effectiveness, highlighting some of the practical barriers that are associated with implementing relative age solutions. As an example, "rotating cut-off dates" was deemed effective in terms of mitigating RAEs, but rated lower on its feasibility. Taken together, our study suggests that potentially effective solutions to mitigate RAEs were generally considered less feasible to implement, whereas those that are possibly more feasible were generally considered less effective. This may highlight that a range of different approaches may be required to combat RAEs in soccer.

Results perhaps also suggest that the current organisational structures in youth soccer and its related activities (i.e., talent identification, selection, training, and competition) are a contributing factor to the ongoing presence RAEs. As such, any

attempt to mitigate RAEs in youth soccer should also, at least to some extent, address the manner in which common practices in youth soccer are executed, whether through altering observer behaviour or adjusting competition structures. This might explain the lack of solutions that have been empirically tested or implemented. Moreover, this could potentially provide a rationale for the common disagreement between experts and the proposed solutions (i.e., only five out of 13 solutions reached consensus on more than one aspect regarding the effectiveness and feasibility of the respective solution).

To our knowledge, "cueing differences in age" is one of only two proposed solutions that have been empirically assessed to date in youth soccer (28). Through age-ordered shirt numbering, Mann and van Ginneken (28) showed that during a soccer selection task, scouts were able to control for the relative age of players when assessing their potential. In the study, players competed in an 8 vs. 8 match and wore shirt numbers that corresponded to their relative age (i.e., oldest player wearing number "1", and the youngest wearing number "8"). Results indicated that when scouts were aware of the age-ordered shirt numbering, it successfully reduced the relative age bias of their player potential rankings. Interestingly, this approach has also been previously shown to moderate maturation biases between soccer players when scouts are assessing their potential (49). This suggests that when individuals are explicitly provided with important information on a player, it can positively support their decision making.

Explicitly cuing relative age could also go beyond age ordered bibs, such as listing player registers in chronological age order and clearly providing relative ages on player observation reports, although further research is required to test how effective this could be. While the methodology of Mann and van Ginneken (28) has, so far, only been applied with scouts having to rank youth players, the solution might also address other direct or indirect RAEs. Regularly playing with age-ordered shirt numbers could make players, parents, coaches, and other stakeholders aware that differences in ability might result from differences in age (26). As such, this could mitigate the inflated expectations from coaches and parents, or the false self-beliefs amongst relatively older teammates and peers, although these expectations remain mostly hypothetical to date and require further research.

To directly address the possible growth advantages of relatively older players (50, 51), results from our study suggest that grouping on alternative characteristics besides chronological age might be effective. However, given the plethora of indicators to group players (e.g., height and weight, cognitive and social maturity) and the accompanying burden of objectively assessing these indicators, this solution was rated low in terms of feasibility. A closely related solution that was rated higher for its feasibility, however, was "grouping based on chronological and biological age". This solution proposes the use the "developmental birth dates" to group players. Developmental birth dates are estimated by comparing a player's stature with the normative growth curves for the player's population (e.g., Dutch boys aged 1–21 years). In a preliminary study by Helsen et al. (29), this method was applied to reallocate a group of Belgium youth soccer players. In their study, the traditional chronological age-grouping resulted in significant RAEs amongst these players, with most players born in the first quarter of the selection year. Importantly, however, following the reallocation of players based upon their developmental birth dates, the overrepresentation of players in birth quartile one (i.e., those born in the first three months of the annual selection year) disappeared, with player's birthdates almost evenly distributed across each birth quartile (~25%). While this study shows promising results in terms of removing RAEs when grouping players, it is yet to be tested within competitions, and as a maximum age difference could exceed more than three years, it could prove difficult to implement and gain stakeholder buy-in.

It is also important to acknowledge that relative age and biological age are two independent constructs that can impact individuals differently (52). More specifically, relative age remains fixed whereas biological age can differ up to five years between those within the same chronological age group (53). In fact, a recent commentary warned that, while relative age and maturity differences are two important biases that play a role in talent development, they should be considered two separate processes (54). Each occurring at different timepoints in a player's developmental career, operating independent from another, and impacting individuals differently, thus two distinct solutions may be important to consider when implementing solutions to mitigate both RAEs and maturation biases (e.g., RAEs occur from entry into soccer at childhood, whereas biological age differences in boys occur during adolescence) (55). It is important to remember, though, that research on the interconnectedness between relative age and biological age is still limited, while exploration of possible independent and combined solutions of these phenomena is still in early stages.

Both "cueing differences in age" and "grouping based on chronological and biological age" can be readily implemented at an individual club level, and do not necessarily require adjusting competition structures. In addition, both solutions can coexist due to their different methods, which creates the possibility for a hybrid approach, whereby multiple solutions are implemented to mitigate RAEs (19). Both these solutions target a different approach to mitigate RAEs and are considered to vary in their effectiveness to alleviate direct and indirect effects (26). "Cueing differences in age" is expected to primarily mitigate indirect effects by clarifying relative age differences for individuals to adjust their assessment of players. In contrast, "grouping on chronological and biological age" introduces constraints beyond traditional birthyear grouping and, as such, attempts to mitigate the developmental advantages of relatively older players (i.e., direct effects). Despite the relative autonomy that comes with implementing both solutions, it has not yet been widely adopted. Although there are anecdotal cases of sports teams using age-ordered shirt numbering during their selection procedures (26), it will be important to evaluate these attempts to build on the current evidence.

Our results highlight that while several solutions to mitigate RAEs have been put forward, many of these were perceived difficult to implement. This might explain the relative lack of

empirical work that has tested these solutions in real-world youth soccer settings. For instance, despite being the highest rated solution on effectiveness to mitigate both direct and indirect RAEs, "rotating cut-off dates" was only ranked tenth in terms of feasibility. One of the main reasons for this is the associated complexity for coaches and other stakeholders that occurs when regularly changing the cut-off date to group players into teams. Nevertheless, the Football Flanders [Voetbal Vlaanderen] (56) has recently announced that, from July 2025, they will introduce "rotating cut-off dates" within the calendar-year, by alternating the cut-off dates between January 1st to July 1st every six months. While the barrier to implementing this approach might be solved with clear communication and administration, other solutions carry potential unforeseen risks for athlete development. For example, solutions such as "submitting entry exemption" or "capping the average team age" might increase injury risk or break-up age group friendship groups (57, 58). Therefore, it is important to consider the unintended consequences that could come with widely implementing relative age solutions without evaluating their effectiveness and feasibility beforehand.

Although it is beyond the capacity of this discussion to critically review all 13 relative age solutions [see Part One for an overview of each proposed solution; (23)], there is some additional feedback from the experts to consider. With regards to the lowest rated solution, whilst "shifting cut-off dates" in different sports would make it possible for all children to experience a favourable cut-off date, it might not solve RAEs in soccer *per se*. In 1997, for example, the Belgian Soccer Federation changed the start of their cut-off date from August 1st to January 1st. This shift prompted an investigation from Helsen et al. (59) who explored the changes in the birthdate distributions throughout youth competitions for 1996–1997 compared to 1997–1998. Their findings revealed a shift of RAEs corresponded with the new cut-off dates, thus "shifting cut-off dates" will likely just shift the relative age distribution. Finally, "raising awareness of RAEs" was suggested as a highly feasible solution that requires minimal resources. However, considering the effectiveness, this solution was rated relatively low overall. Indeed, Helsen et al. (60) demonstrated that, over a period of 10 years, the magnitude of RAEs did not decrease in European soccer. As such, the authors concluded that, assuming education and attention regarding RAEs in soccer had taken place in that period, raising awareness may not be effective in mitigating RAEs.

Related to the relative lack of solutions that have been applied in practice is the concept of knowledge mobilisation (KMb). This concept refers to the process of taking research beyond the academic domain to have an impact in real-world settings (61). While many models and frameworks have been developed to describe the process of KMb, most strategies to translate knowledge from research to practice use three approaches (62). The first strategy entails "connecting" knowledge stakeholders, such as researchers and practitioners via "knowledge brokers" (63). These could be, for instance, sport's governing bodies that mobilise knowledge through coach education. For example, following interviews with seven talent identification experts, Andronikos et al. (64) showed how "raising awareness of RAEs" for the likes of coaches, scouts, and clubs, was perceived to be part of the controllable features available to eradicate them. The second strategy entails "disseminating" knowledge via (online) resources and easily accessible documentation. As an example, as part of this project, we have already shared our results via the KNVB website in an attempt to widely disseminate key findings (65). Lastly, a strategy to translate knowledge would be to facilitate "interactions", such as participatory research. Specifically, actively involving all stakeholders (e.g., researchers, coaches, recruiters, policy makers, players, parents) seems a particularly fruitful approach to design, implement, and evaluate potential relative age solutions (19), which could prove a useful next step for the Royal Dutch Football Association (KNVB) Relative Age Solutions Project. Overall, researchers and practitioners should consider a KMb approach when seeking to moderate RAEs in youth soccer.

Limitations and future directions

One of the limitations of this study is related to the e-Delphi design. Typically, the e-Delphi method consists of several iterative rounds with controlled feedback to achieve consensus. However, given the diverse group of panelists and the risk of participant attrition often occurring with Delphi studies (66), we aimed to minimise participant burden by priori setting the number of e-Delphi rounds to two. In addition, we reduced the duration of the study by enabling participants to immediately commence the second e-Delphi round, whereas panelists typically receive feedback from the previous rounds, which might alter their perspective. It is also important to understand the contextual variances of different youth soccer environments across the world. This may have resulted in variations in effectiveness and feasibility depending on the likes of resources available, knowledge uptake, and sport popularity. Therefore, those working in soccer are encouraged to recognise that there is no "copy and paste" template when it comes to solving RAEs, and that they should seek to comprehend potential solutions based on the contextual complexities of cultures, communities, and individual circumstances (67). However, since RAEs are pervasive in youth soccer across the world, attempts to minimise or remove them could be considered universal, with a range of different approaches proving useful to test and evaluate in different contexts.

Regarding future directions, as a first step, researchers, coaches, and policymakers can use our findings as a list of options that might moderate RAEs. As such, the outcomes of our study can serve as a starting point for governing bodies and soccer academies to test different options, whilst also providing considerations of the potential effects when implementing these solutions. For instance, the panellists highlighted the requirement of buy-in from different stakeholders for several solutions to be successful. We would, therefore, recommend that before adjusting competition structures, stakeholders should be informed about the potential changes and challenges. In

addition, while the experts reached consensus on some of the items regarding the effectiveness and feasibility of potential RAEs, there was regular disagreement between them. This highlights the need for more empirical research to validate expert opinions. As such, we recommend creating real-world experiments to test the utility of these solutions. While such experiments are complex and require significant resources, the results of our study can be used to prioritise certain solutions. Relatedly, we recommend testing these solutions in a range of youth soccer settings, with researchers and universities working collaboratively with soccer organisations and industry stakeholders to support improved KMb (68).

Conclusion

There are many empirical studies on RAEs in soccer that highlight its existence and emphasise the need mitigate such effects. However, only a few researchers have attempted to analyse ways in which RAEs can truly be moderated or removed. In light of the expert consensus and feedback regarding the effectiveness and feasibility of the 13 proposed relative age solutions presented in this study, an important next step will be to design, implement, and evaluate the highly rated solutions in practice. This will help capture the most effective and feasible approaches based upon the needs and context of different youth soccer environments.

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 project was endorsed by the KNVB and ethically approved by the Health, Education, and Life Sciences Faculty Academic Ethics Committee at Birmingham City University (ethics code #9524). 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

AK: Conceptualization, Data curation, Supervision, Writing – original draft, Writing – review & editing. FZ: Funding acquisition, Resources, Supervision, Validation, Writing – review & editing. DM: Data curation, Investigation, Project administration, Visualization, Writing – review & editing. JV: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Writing – original draft, Writing – review & editing.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2025.1565819/full#supplementary-material

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Relative age effect in the 2022–2023 World Fencing Championships

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Introduction: This study aimed to investigate the presence of relative age effect (RAE) in the World Fencing Championships of the 2022–2023 season across three age categories.
Methods: Data from the participants of the World Fencing Championships were collected from the International Fencing Federation, resulting in a total of 2,791 participants distributed according to the age categories: 713 cadets, 1,048 juniors, and 1,030 senior athletes. The data collected included the athletes' birthdate, birth quartile, sex, weapon, age category, country, continental area, and world championship result. An athlete's relative classification was computed using their competition classification and the total number of participants in the event. The chi-square goodness-of-fit test was performed to assess the presence of RAE, examining differences in birth quarter distribution across the total sample, for each sex, and for the 18 events. Follow-up analyses included standardized residuals, Cramér's *V* effect size, and odds ratios. In events where RAE was detected, the Kruskal–Wallis and Quade's non-parametric ANCOVA tests were used to compare athletes' relative classification across birth quarters.
Results: RAE was present, in the overall sample [$\chi^2(3) = 16.142$, $p < 0.001$, $V = 0.044$], according to sex [female: $\chi^2(3) = 10.349$, $p = 0.016$, $V = 0.053$; male: $\chi^2(3) = 7.987$, $p = 0.046$, $V = 0.041$], and was inconclusive when focusing on each event.
Discussion: The complexity of results in individual sports and the lack of research in fencing makes it difficult to understand the relevance of RAE in this sport. Despite the lack and inconsistency of results in fencing, coaches should be aware of this effect.

KEYWORDS

relative age effect, fencing, talent identification, athlete development, youth sports

1 Introduction

Sport is often organized into age groups based on cutoff dates, which, in the case of fencing, start on 1 January (1). These cutoff dates place individuals who may differ in age by 1 year or more into the same category (2), leading to the relative age effect (RAE). In fencing, the age gap can be up to 2 years in the cadet category and 3 years in the junior category. The RAE refers to age-related differences between individuals born in the same calendar year, where those born earlier tend to have an advantage over those born later (2–4). The advantages to older individuals include their physical growth, maturation, or experience (4).

The RAE was first reported by Barnsley and Thompson (5) in ice hockey players. Three main theories have been proposed to explain the RAE (6): (1) the "Matthew effect" suggests that parents are more likely to enroll their older children in sports first, giving them an early advantage in training and experience that compounds over time; (2) the "Pygmalion effect" refers to the expectations coaches place on more physically mature players, leading to preferential selection and increased opportunities; and lastly, (3) the "Galatea effect" occurs when expectations placed on a player are internalized, influencing them to perform in line with those expectations (6). Supporting these theories is the maturation hypothesis, which states that older children are more physically and cognitively mature (7).

The prevalence of RAE depends on the sport, competitive level (e.g., recreational to elite level), athlete's age, sex, and physical characteristics (8). It is more common at elite levels (9, 10), in highly competitive environments where many athletes compete for limited opportunities (11), in younger age categories (12, 13), and in male sports (10, 14, 15). RAE is a well-documented phenomenon in team sports, particularly in popular and physically demanding disciplines such as football, basketball, and ice hockey (3, 10, 12, 16, 17). In contrast, its presence in individual sports varies depending on the sport's physical and competitive demands. For example, it is generally absent in low-contact, less physically demanding sports like shooting (18), but more prevalent in physically demanding disciplines such as skiing (7), and certain track and field events, where RAE increases with performance level (8, 15). In addition, some sports like swimming show event-specific RAE patterns (14), while others, such as gymnastics and figure skating, tend to exhibit an inverse RAE (19).

In individual opposition and combat sports like fencing (20–22), RAE was observed among the top 100 female tennis players (23) as well as across different weight classes and age groups in judo (13). Despite being a combat sport, fencing is one of the few sports in this category that does not have weight classes. Sports like wrestling, judo, or taekwondo have been the focus of previous research on RAE (24). Although some researchers argue that weight classes can be a moderator against RAE (25–28), others still observed it (21, 24, 29). Adding to the inconsistency of findings in combat sports (30, 31), fencing studies have shown a noticeable lack of research on RAE. Fencing is an Olympic sport of individual opposition (20), where psychomotor and perceptive skills prevail (32, 33). In fencing, performance has been related mainly to perceptual, neuro-physiological characteristics, and body composition, such as the amount of lean body mass (34, 35), or power and speed (22, 33, 34, 36). This contrasts with sports like judo or wrestling, where performance relies more heavily on isometric strength (24). These reported functional and anthropometric characteristics (speed, power, and lean body mass) are normally related to age and to the maturation of athletes (37). However, the relationship between the anthropometric characteristics of athletes and fencing performance is still unclear (37, 38). To the best of our knowledge, only two studies assessed RAE in fencing. One study reported that Swiss recreational female fencers exhibited RAE, while an inverse RAE was observed in the competitive level (39). Another study about the top 20 Brazilian fencers reported a RAE for several age categories using different weapons (21).

The issue of RAE in individual sports remains a subject of ongoing debate, and this study aims to contribute to that discussion. To this end, we investigated the presence of the RAE in the World Fencing Championships events of the 2022–2023 season, across cadet, junior, and senior categories. We hypothesized that: (1) RAE would be evident in the overall sample; (2) RAE would be more prevalent in male athletes than in female athletes; and (3) RAE would be more prevalent in younger age categories and in male events.

2 Materials and methods

2.1 Study design

The aim of this study was to examine the presence of the RAE in top-level fencing competitions, specifically at the 2022–2023 World Fencing Championships. For this purpose, a cross-sectional observational design was employed, using official athlete data obtained from the International Fencing Federation database (1).

First, we assessed the presence of RAE in the total sample, as well as separately for male and female athletes. Then, RAE was investigated separately for each of the 18 fencing events (divided by sex, weapon, and age group) that took place during the 2022–2023 World Fencing Championships.

2.2 Data collection

All the data were collected from the International Fencing Federation website (1). The data related to the 2022–2023 season and included the cadet (U17), junior (U20), and senior athletes who participated in the World Fencing Championships. The recorded variables included the following: the participants' date of birth, competition date, weapon, sex, age category, final result at the world championship, and number of participants in the event. Decimal age was calculated as the difference between the date of competition and the date of birth of the athlete.

In fencing, age groups start on 1 January and end on 31 December (1); therefore, to determine the distribution of birthdates by quarter, we adopted the following cutoff periods: first quarter (January to March), second quarter (April to June), third quarter (July to September), and fourth quarter (October to December).

The relative result was calculated as the ratio between an athlete's final classification in the World Fencing Championship event and the total number of participants in the corresponding event.

2.3 Participants

Data were collected from 2,791 participants (mean decimal age: 20.4 ± 4.4 years). The sample comprised 1,216 female athletes (mean age: 20.1 ± 5.4 years) and 1,575 male athletes (mean age:

20.6 ± 5.5 years), distributed across three age categories: 713 cadets, 1,048 juniors, and 1,030 seniors. The mean ages of cadets, juniors, and seniors were 16.2 ± 0.8 years, 18.1 ± 1.5 years, and 25.6 ± 5.7 years, respectively. There were 785 saber fencers, 1,103 épée fencers, and 903 foil fencers.

Fencers were from 119 different countries. Each country was allowed to participate with a maximum of 66 fencers across the three World Fencing Championships (cadets, junior, and seniors), distributed as follows: 18 cadets (three per weapon and sex), 24 juniors (four per weapon and sex), and 24 seniors (four per weapon and sex).

2.4 Statistical analyses

The Statistical Package for the Social Sciences (SPSS software version 29.0, 241, IBM SPSS, Chicago, IL, USA) was used for the statistical analysis and the significance level was set at 5%. A chi-square goodness-of-fit test was used to examine whether the distribution of athletes' birthdates across the four birth quarters deviated from an expected uniform discrete distribution (i.e., 25% in each birth quarter). This analysis was conducted for the total sample, as well as for each sex and for each one of the 18 events. Typically, in RAE studies, the observed birthdate distribution is compared to a theoretically expected one, ideally that of the underlying population. However, in studies that analyze data from multiple countries, such as the present one, obtaining official birth statistics can be challenging. Therefore, a uniform discrete distribution is commonly used as a simplified alternative for data analysis (40). In addition, a chi-square test for homogeneity was employed to compare the distribution of birth quarters between male and female athletes.

Follow-up analysis of the chi-square goodness-of-fit test included standardized residuals, Cramér's V for effect size, and odds ratios (OR). When significant differences were observed in the distribution of birth quarters, the standardized residuals (R_i) were used to interpret the direction of the effect: values of $R_i \geq 1.96$ indicated overrepresentation, while $R_i \leq 1.96$ indicated underrepresentation (41). The effect size was assessed using Cramér's V. With three degrees of freedom, the effect was considered negligible if $V < 0.058$, small if $0.058 \leq V < 0.173$, medium if $0.173 \leq V < 0.289$, and large if $V \geq 0.289$ (42).

To estimate the likelihood of athletes being born in each birth quarter compared to a reference population, binary logistic regression was applied. For this purpose, a new dataset was created by combining the observed distribution of athletes with a hypothetical reference population, assuming a uniform discrete distribution across the four birth quarters. The dependent variable represented group membership (1 = athlete; 0 = reference population), and birth quarter was entered as the independent variable. The fourth quarter (Q4) served as the reference category, in line with standard practice in RAE research (16). Odds ratios and 95% confidence intervals (95% CI) were calculated. A relevant RAE was considered present when the confidence interval of the OR did not include the value 1. The OR comparing quarter Qi to Qj reflects how much more (or less) likely athletes born in Qi are to be represented in the sample relative to those born in Qj, in relation to the reference population, with OR >1 indicating overrepresentation and OR <1 indicating underrepresentation.

In the competitions where the RAE was detected, the Kruskal–Wallis test was applied to compare the athletes' relative results across birth quarters. In addition, Quade's non-parametric ANCOVA test followed by multiple comparisons with Bonferroni correction was conducted to compare relative results across birth quarters while controlling for the effect of decimal age.

3 Results

The overall sample showed significant differences in the distribution of birth quarters [$\chi^2(3) = 16.142$, $p < 0.001$], though the effect size was negligible ($V = 0.044$). The first three quarters had a higher proportion of births (Q1: 26.4% and $R_i = 1.49$, Q2: 25.4% and $R_i = 0.43$, Q3: 26.4% and $R_i = 1.49$) compared to Q4 (21.8% and $R_i = -3.40$). According to the odds ratio analysis, the likelihood of competing at the World Fencing Championships was 1.21, 1.17, and 1.21 times higher for athletes born in Q1, Q2, and Q3, respectively, compared to those born in Q4. The distribution of birth quarters is shown in Figure 1. Significant differences were also seen across birth months [$\chi^2(11) = 38.012$, $p < 0.001$, $V = 0.034$], with January showing a higher number of births (10.2% and $R_i = 3.50$), and November (7.1% and $R_i = -2.27$) and December (6.5% and $R_i = -3.32$) showing fewer births.

According to sex, significant differences in the birth quarter distribution were observed for both male ($n = 1{,}216$) and female ($n = 1{,}575$) athletes (Figure 2). For female athletes [$\chi^2(3) = 10.349$, $p = 0.016$, $V = 0.053$], the distribution for Q1, Q2, Q3, and Q4 was 26.6%, 26.6%, 25.7%, and 21.1%, respectively. Athletes born in Q4 were underrepresented (R_i: Q1 = 1.02, Q2 = −0.44, Q3 = 1.52, Q4 = −2.10). Based on odds ratios, the likelihood of competing at the World Fencing Championships was 1.26, 1.27, and 1.22 times higher for athletes born in Q1, Q2, and Q3, respectively,

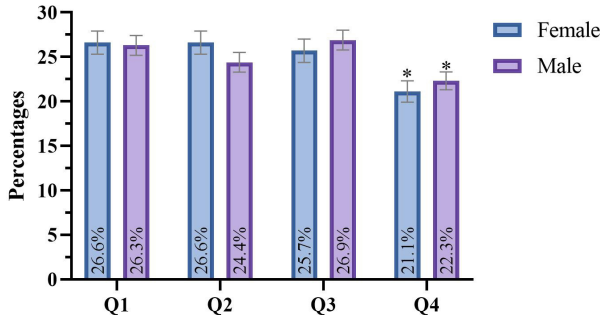


FIGURE 1
Birth quarter distribution on the overall sample of participants in the 2022–2023 World Fencing Championships. Note: Q1: first birth quarter; Q2: second birth quarter; Q3: third birth quarter; Q4: fourth birth quarter; *standardized residual ≥1.96 or ≤−1.96.

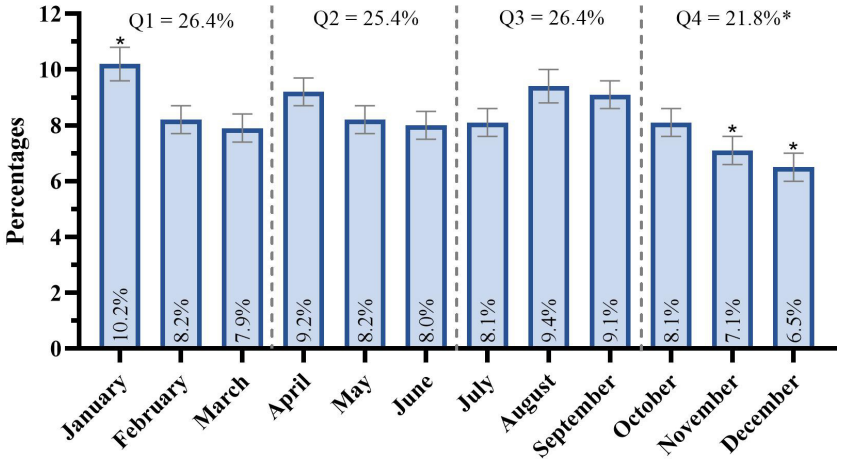


FIGURE 2
Birth quarter distribution by sex. Note: Q1: first birth quarter; Q2: second birth quarter; Q3: third birth quarter; Q4: fourth birth quarter; *standardized residual ≥1.96 or ≤−1.96.

compared to Q4. For male athletes [$\chi^2(3) = 7.987$, $p = 0.046$, $V = 0.041$], 26.3%, 24.4%, 26.9%, and 22.3% of athletes were born in Q1, Q2, Q3, and Q4, respectively. There was an underrepresentation of athletes born in Q4 (R_i: Q1 = 1.09, Q2 = 1.15, Q3 = 0.52, Q4 = −2.75). Based on odds ratios, the likelihood of competing at the World Fencing Championships was 1.18, 1.09, and 1.20 times higher for athletes born in Q1, Q2, and Q3, respectively, compared to those born in Q4. Furthermore, no significant differences were found in birth quarter distribution between sexes [$\chi^2(3) = 2.219$, $p = 0.529$, $V = 0.028$].

Birth quarter distribution was also examined by event (Table 1). Significant differences were found in junior men's saber [$\chi^2(3) = 8.602$, $p = 0.035$, $V = 0.131$] and cadet men's foil [$\chi^2(3) = 9.471$, $p = 0.024$, $V = 0.152$). In junior men's saber, the distribution was 31.9%, 16.9%, 28.3%, and 22.9% for Q1, Q2, Q3, and Q4, respectively (Figure 3a). Athletes born in Q2 were underrepresented (R_i: Q1 = 1.79, Q2 = −2.09, Q3 = 0.85, Q4 = −0.54). In the cadet men's foil event, the birth quarter distribution was 24.3%, 28.7%, 32.4%, and 14.7% for Q1, Q2, Q3, and Q4, respectively (Figure 3b). Q4 had the lowest number of births ($R_i = -2.40$), while the remaining birth quarters were neither over- or underrepresented (R_i: Q1 = −0.17, Q2 = 0.86, Q3 = 1.71). No significant differences in birth quarter distribution were observed in any of the female events or the remaining male events.

When comparing the athlete's relative results across birth quarters, no significant differences were observed in the junior men's saber category ($H = 2.389$, $p = 0.496$), nor in the cadet men's foil category ($H = 0.224$, $p = 0.974$). When accounting for the decimal age effect, since older athletes are expected to be more experienced (43), the results were still not significant. In the junior men's saber category, no significant differences were observed [$F(3, 162) = 1.292$, $p = 0.279$], nor in the cadet men's foil category [$F(3, 132) = 0.567$, $p = 0.638$].

In the analysis of the overall top eight athletes per event, RAE was identified, albeit with a small effect [$\chi^2(3) = 9.056$, $p = 0.029$, $V = 0.145$]. However, the *post hoc* analysis using standardized residuals revealed no quarters outside the range of −1.96–1.96 (R_i: Q1 = −1.50, Q2 = 1.67, Q3 = 1.33, Q4 = −1.50). However, when analyzing each sex and each event, no significant differences in birth quarter distributions were observed (Table 2).

4 Discussion

4.1 General discussion

Our study examined the presence of the RAE at the 2022–2023 World Fencing Championships. As hypothesized, RAE was evident in the overall sample, with a notable underrepresentation of fencers born in the fourth quarter. An analysis of birth months revealed that the fewest athletes were born in November and December. When analyzed by sex, both male and female participants showed fewer births in the fourth quarter. However, contrary to our expectations, no significant differences in birth quarter distribution were found between sexes. RAE was identified in only two specific events: junior men's saber and cadet men's foil. In junior men's saber, there was an underrepresentation of athletes born in the second quarter, whereas in cadet men's foil, those born in the fourth quarter were underrepresented. Notably, these patterns were not associated with final rankings in either event. When considering only the top eight fencers per event, the overall sample showed a trend toward RAE, with a higher proportion of athletes born in the second and third quarters. However, no clear evidence of RAE was found when analyzing the birth distribution of the top eight athletes in each individual event.

According to Musch and Grondin (11), the presence of RAE depends strongly on the competitiveness of the sport. A sport with increased popularity, few available playing spots, and more physically driven tends to have a greater RAE, since the most developed and athletic individuals are chosen (11, 44, 45). The

TABLE 1 Birth quarter distribution (%) of participants in the 2022–2023 World Fencing Championships and comparison between birth quarters.

Event	*N*	Birth quarters (%)				Chi-square			Odds ratio (95% CI)		
		Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	χ^2	*P*	*V*	OR Q1 VS. Q4 (95% CI)	OR Q2 VS. Q4 (95% CI)	OR Q3 VS. Q4 (95% CI)
Female	1,216	26.6	26.6	25.7	21.1	10.349	.016	0.053	1.26 (1.00, 1.59)	1.27 (1.01, 1.59)	1.22 (0.97, 1.54)
Saber											
Cadet	92	32.6	25.0	25.0	17.4	4.261	.241	0.124	1.88 (0.81, 4.33)	1.44 (0.61, 3.40)	1.44 (0.61, 3.40)
Junior	124	22.6	29.0	27.4	21.0	2.194	.539	0.077	1.08 (0.52, 2.24)	1.39 (0.68, 2.81)	1.31 (0.64, 2.67)
Senior	127	22.0	32.3	22.8	22.8	3.614	.314	0.097	0.97 (0.47, 1.97)	1.41 (0.71, 2.80)	1.00 (0.49, 2.04)
Epée											
Cadet	120	30.0	23.3	23.3	23.3	1.600	.668	0.067	1.29 (0.63, 2.61)	1.00 (0.48, 2.07)	1.00 (0.48, 2.07)
Junior	174	29.9	23.0	23.6	23.6	2.230	.538	0.065	1.27 (0.71, 2.28)	0.98 (0.53, 1.79)	1.00 (0.55, 1.83)
Senior	184	25.0	26.1	27.2	21.7	1.217	.748	0.047	1.15 (0.64, 2.07)	1.20 (0.67, 2.16)	1.25 (0.70, 2.24)
Foil											
Cadet	110	30.0	27.3	25.5	17.3	3.964	.266	0.110	1.74 (0.80, 3.76)	1.58 (0.72, 3.45)	1.47 (0.67, 3.24)
Junior	156	25.6	25.6	29.5	19.2	3.385	.344	0.085	1.33 (0.70, 2.55)	1.33 (0.70, 2.55)	1.53 (0.81, 2.91)
Senior	129	23.3	29.5	26.4	20.9	2.132	.555	0.074	1.11 (0.55, 2.27)	1.41 (0.70, 2.82)	1.26 (0.62, 2.54)
Male	1,575	26.3	24.4	26.9	22.3	7.987	.046	0.041	1.18 (0.96, 1.44)	1.09 (0.89, 1.34)	1.20 (0.99, 1.47)
Saber											
Cadet	106	27.4	30.2	26.4	16.0	4.261	.188	0.116	1.71 (0.76, 3.82)	1.88 (0.85, 4.18)	1.65 (0.73, 3.70)
Junior	166	31.9	16.9	28.3	22.9	8.602	.035*	0.131	1.39 (0.77, 2.54)	0.74 (0.38, 1.41)	1.24 (0.67, 2.27)
Senior	170	24.7	22.9	25.9	26.5	0.464	.926	0.030	0.93 (0.51, 1.70)	0.87 (0.47, 1.59)	0.98 (0.54, 1.77)
Epée											
Cadet	149	33.6	24.2	20.8	21.5	6.195	.103	0.118	1.56 (0.83, 2.95)	1.13 (0.58, 2.17)	0.97 (0.50, 1.90)
Junior	233	24.5	26.6	25.3	23.6	0.459	.931	0.026	1.04 (0.62, 1.74)	1.13 (0.67, 1.88)	1.07 (0.64, 1.80)
Senior	243	23.0	27.6	29.6	19.8	5.774	.124	0.089	1.17 (0.69, 1.97)	1.40 (0.84, 2.33)	1.50 (0.90, 2.50)
Foil											
Cadet	136	24.3	28.7	32.4	14.7	9.471	.024*	0.152	1.65 (0.79, 3.43)	1.95 (0.95, 4.00)	2.20 (1.08, 4.48)
Junior	195	23.1	23.1	30.3	23.6	2.887	.415	0.070	0.98 (0.55, 1.73)	0.98 (0.55, 1.73)	1.28 (0.74, 2.23)
Senior	177	27.7	20.9	22.6	28.8	3.136	.375	0.077	0.96 (0.54, 1.70)	0.73 (0.40, 1.31)	0.78 (0.44, 1.41)
Total	2,791	26.4	25.4	26.4	21.8	16.142	<0.001	0.044	1.21 (1.04, 1.41)	1.17 (1.00, 1.36)	1.21 (1.04, 1.41)

Q1: first birth quarter; Q2: second birth quarter; Q3: third birth quarter; Q4: fourth birth quarter; *V*, Cramer's *V*; OR, odds ratio; CI, confidence intervals.
*Significant difference.

remaining individuals can remain practicing at less competitive levels, change for a less popular sport, or even drop out completely from sport (16, 46). For example, in French boxing, the RAE is absent at the amateur level where there is low selection pressure (28).

Fencing is not very popular despite being an Olympic sport since the first modern Olympic Games in 1896 (1). This may explain why the RAE was absent in most World Fencing Championships' events, with the only exceptions being the junior men's saber and cadet men's foil events. Another possible explanation is that fencing does not depend, as it might appear, on physical characteristics to obtain good results, as in football or basketball (12, 17), but on combined mental, tactical, and technical skills (9, 33, 39, 47–49). Fencing competitions involve moments of high-intensity efforts, relying heavily on anaerobic metabolism during exchanges, interspersed with longer pauses dominated by aerobic activity (33, 47, 48). During a match, fencers rely on perceptual and technical skills to succeed, whether by creating touch opportunities or responding to an opponent's actions (33, 39). In addition, since the cadet and junior categories span 2 and 3 years, respectively, there is considerable age variability as well as morphological variability, such as height and weight. Therefore, the significant presence of RAE in only two of the 18 events analyzed, along with the underrepresentation of fencers born in the second quarter at the junior men's saber event, may be attributed to chance. Similar patterns have been observed in other technical sports, such as artistic gymnastics, rhythmic gymnastics, and figure skating, where the RAE is not observed (7, 9, 19).

The RAE observed in our overall sample is in line with the results of Joyner et al. (50), who analyzed Olympic athletes from 1896 to 1996 and reported an RAE in the Summer Olympics, in both non-ball sports and individual sports, with more births observed in the first quarter (50). We then observed the results in more detail, by sex and event, since the presence of RAE may vary across factors. These analyses revealed some inconsistencies. On one hand, RAE was significantly present among both male and female fencers, consistent with findings by Smith et al. (45), who studied elite female athletes across several sports, and by Almeida-Neto et al. (21), who focused on Brazilian fencers. However, we found no significant difference in the birth quarter distribution between sexes, as was reported in studies by Baker et al. (7) and Brustio et al. (8) in sports such as skiing, figure skating, and athletics, as well as in the meta-analyses by Smith et al. (45) and Cobley et al. (16). In addition, the absence of RAE in the senior age group aligns with the findings reported by Cobley et al. (16) and Smith et al. (45).

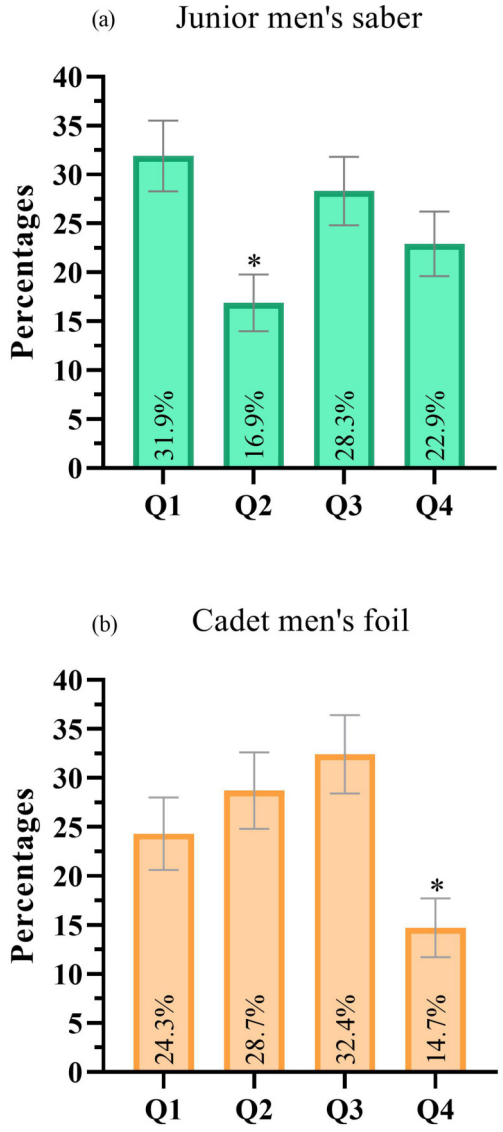


FIGURE 3
Birth quarter distribution in junior men's saber (**a**) and cadet men's foil (**b**). Note: Q1: first birth quarter; Q2: second birth quarter; Q3: third birth quarter; Q4: fourth birth quarter; *standardized residual ≥1.96 or ≤−1.96.

When comparing our findings with previous research on RAE and fencing, of which, to the best of our knowledge, there are only two studies, some inconsistencies were revealed. Romann et al. (10), who studied Swiss athletes, found no evidence of RAE among Swiss male fencers, whereas our results indicate a significant RAE in male fencers overall and specifically in two male events (junior men's saber and cadet men's foil). For female athletes, Romann et al. (10) reported the presence of RAE only at lower competitive levels and, in contrast to our findings —which identified RAE in the overall female sample—an inverse RAE at higher levels of competition. Almeida-Neto et al. (21). who examined Brazilian fencers, observed RAE in age groups younger than the cadet category. They also observed the presence of RAE among female cadets involved in the saber, epée, and foil events, as well as in the male epée category, differing from the results reported in this study. Fencing is unique among other combat sports, in that it does not employ weight classifications. Sports such as judo, wrestling, taekwondo, and boxing have often been mentioned when studying RAE in combat sports; however, to date, findings remain inconsistent. In grappling sports, such as judo and wrestling (24), Albuquerque et al. (26) reported RAE only in heavier Olympic judo categories, while Fukuda et al. (13), examining Olympic and World Championship participants, observed RAE among male athletes from cadet to senior levels across all weight classes, and RAE in female judokas competing in the heavy categories. Albuquerque et al. (24) identified RAE among male wrestlers in both Greco-Roman and freestyle disciplines. In contrast, Latyshev et al. (25) reported the absence of RAE from cadet to senior levels. In striking sports, which rely heavily on power and speed, as in fencing (24), the presence of RAE is not consistent. For example, RAE was observed in taekwondo among the top 20 Brazilian athletes (21) and at the 2018 Buenos Aires Youth Olympic Games (51); however, the absence of RAE in a sample of Olympic athletes was attributed to the sport's low popularity (27). In boxing, Kim et al. (29) reported RAE in the youth male category but not at the senior level. In contrast, RAE was evident in both male and female French boxers within the 14–15 year age categories, though it was absent at the professional level (28).

Similar to our findings, several studies on combat sports have found no association between competitive performance and the RAE (24, 25, 28, 29). This means that coaches and supporting staff should not overlook younger athletes when selecting for major competitions.

4.2 Practical implications and possible solutions

RAE is a consequence of grouping athletes based on chronological age. In youth sports, there can be an age difference of up to 23 months (2), as shown in the cadet age group; however, in the junior category, it can reach a difference of 35 months, since it covers a 3-year span. Consequently, at the cadet level, RAE should be more prevalent in male athletes, since most of the female athletes are already mature by the age of 16–17 years, while male athletes may still be growing (52).

Despite the inconsistency of our results and the lack of alignment with the findings of Almeida-Neto et al. (21) and Romann and Fuchslocher (39), it remains important to alert coaches to the topic of the RAE. Much of the research on RAE reports a lack of stimulation among older athletes and overstimulation at younger ages (53, 54). In fencing, training typically involves athletes of different ages and body sizes sparring with one another, which naturally counteracts the effects of the RAE. However, during competitions, athletes compete against their own age group.

One possible solution for this might be to implement a hybrid training structure, where on some days fencers are organized according to their biological age (bio-banding or estimated

TABLE 2 Birth quarter distribution (%) of the top eight fencers in the 2022–2023 World Fencing Championships and comparison between birth quarters.

Event	*N*	Birth quarters (%)				Chi-square			Odds ratio (95% CI)		
		Q1	Q2	Q3	Q4	χ^2	*P*	*V*	Q1 VS. Q4	Q2 VS. Q4	Q3 VS. Q4
Female	72	20.8	33.3	26.4	19.4	3.444	.348	0.126	0.93 (0.35, 2.48)	0.58 (0.23, 1.48)	0.74 (0.29, 1.91)
Saber											
Cadet	8	50.0	25.0	25.0	0.0	1.000	.744	0.204	–	–	–
Junior	8	0.0	62.5	25.0	12.5	3.250	.296	0.368	–	0.20 (0.01, 3.66)	0.50 (0.02, 11.09)
Senior	8	37.5	37.5	12.5	12.5	2.000	.654	0.289	0.33 (0.02, 6.65)	0.33 (0.02, 6.65)	1.00 (0.03, 29.81)
Epée											
Cadet	8	0.0	12.5	12.5	75.0	6.250	.059	0.510	–	6.00 (0.34, 107.42)	6.00 (0.34, 107.42)
Junior	8	37.5	12.5	37.5	12.5	2.000	.654	0.289	0.33 (0.02, 6.65)	1.00 (0.34, 29.81)	0.33 (0.02, 6.65)
Senior	8	37.5	25.0	25.0	12.5	1.000	.962	0.204	0.33 (0.02, 6.65)	0.50 (0.02, 11.09)	0.50 (0.02, 11.09)
Foil											
Cadet	8	12.5	25.0	50.0	12.5	3.000	.551	0.354	1.00 (0.03, 29.81)	0.50 (0.02, 11.09)	0.25 (0.01, 4.73)
Junior	8	12.5	37.5	25.0	25.0	1.000	.962	0.204	2.00 (0.09, 44.35)	0.67 (0.05, 9.47)	1.00 (0.06, 15.99)
Senior	8	0.0	62.5	25.0	12.5	3.250	.296	0.368	–	0.20 (0.01, 3.66)	0.50 (0.02, 11.09)
Male	72	16.7	30.6	34.7	18.1	7.000	.074	0.180	1.08 (0.39, 3.01)	0.59 (0.23, 1.52)	0.52 (0.20, 1.33)
Saber											
Cadet	8	12.5	37.5	25.0	25.0	1.000	.962	0.204	2.00 (0.09, 44.35)	0.67 (0.05, 9.47)	1.00 (0.06, 15.99)
Junior	8	37.5	0.0	50.0	12.5	1.750	.552	0.270	0.33 (0.02, 6.65)	–	0.25 (0.01, 4.73)
Senior	8	12.5	12.5	37.5	37.5	2.000	.654	0.289	3.00 (0.15, 59.89)	3.00 (0.15, 59.89)	1.00 (0.08, 12.56)
Epée											
Cadet	8	25.0	25.0	25.0	25.0	0.000	1.000	0.000	1.00 (0.06, 15.99)	1.00 (0.06, 15.99)	1.00 (0.06, 15.99)
Junior	8	25.0	62.5	12.5	0.0	3.250	.296	0.368	–	–	–
Senior	8	12.5	37.5	50.0	0.0	1.750	.552	0.270	–	–	–
Foil											
Cadet	8	12.5	25.0	50.0	12.5	3.000	.551	0.354	1.00 (0.03, 29.81)	0.50 (0.02, 11.09)	0.25 (0.01, 4.73)
Junior	8	12.5	37.5	25.0	25.0	1.000	.962	0.204	2.00 (0.00, 44.35)	0.67 (0.05, 9.47)	1.00 (0.06, 15.99)
Senior	8	0.0	37.5	37.5	25.0	0.250	1.000	0.102	–	0.67 (0.05, 9.47)	0.67 (0.05, 9.47)
Total	144	18.8	31.9	30.6	18.8	9.056	.029	0.145	1.00 (0.49, 2.03)	0.587 (0.30, 1.14)	0.614 (0.32, 1.19)

Q1: first birth quarter; Q2: second birth quarter; Q3: third birth quarter; Q4: fourth birth quarter; *V*, Cramer's *V*; CI, confidence intervals. When no athletes were present in a given birth quarter, the odds ratio and its 95% CI could not be calculated.
*Significant difference.

development age) (53, 55) or, since body dimensions might be relevant to performance, according to their height. This approach could help coaches not to overtrain athletes when they show better results, mainly due to their size, and reduce the dropout rate due to overtraining, injury, burnout, or even boredom (16).

4.3 Limitations and future directions

To the best of our knowledge, this is the first study focusing exclusively on RAE within the sport of fencing. Since there is very little or no previous research on this specific topic, this limitation could also serve as an opportunity to identify gaps in the literature and highlight further areas of study and development. This study, like many others, assumes an equal distribution of births across trimesters. While this approach is commonly used in research involving international samples, it may not accurately reflect real-world birth patterns, which can vary across quarters. A valuable direction for future research would be to analyze birth distributions on a country-by-country basis, allowing for more accurate assessments of the RAE in different contexts.

Our interpretation of the RAE as a causal factor may be limited by the absence of key variables related to maturation status, such as height and weight. The inclusion of these measures could have provided a more accurate understanding of the role of biological maturity on the observed patterns.

Although our primary aim was not to examine the relationship between the RAE and competitive performance, we addressed this relationship in the events where the RAE was observed. Nevertheless, we believe this topic warrants further investigation. In our findings, performance did not appear to be related to either the athlete's birth quarter or decimal age. However, other factors, such as maturation, and social, economic, political, and emotional (SEPE) influences (56), might be important.

This study highlights that RAE is less consistent in individual than in team sports, as stated by Baker et al. (7). The aim of our study was to contribute to the understanding of the RAE in fencing, as our results differ from related research. To further understand the RAE in fencing and the results presented in this study, further research is needed on the sport, examining the anthropometric characteristics and physical performance, especially strength and power, of fencers according to different weapons.

Coaches should consider the overall RAE results and provide equal opportunities to every athlete, as this can increase their chances of long-term success, as mentioned by Tascioglu et al. (17). According to Gil et al. (9) and Brustio et al. (8), younger

athletes (those born later in the year) who are given the opportunity have a higher chance of a successful transition to the senior level. By taking the RAE into account, coaches can more easily ensure equal playing opportunities for all athletes, tailor training with appropriately challenging exercises for both older and younger fencers, and postpone talent selection (16, 53, 54), thereby helping to mitigate the RAE.

5 Conclusions

Although the RAE was present in the overall sample and when analyzed by sex, it was not consistently observed across individual World Championships events, except for junior men's saber and cadet men's foil. This suggests causality may partially explain the observed RAE, making its presence in each event uncertain. The complexity of findings in individual sports, combined with the limited research on fencing, makes it difficult to understand the significance of RAE in this sport. However, it is important to recognize that coaches can benefit from considering the relative age of athletes. Further research is needed to draw more definitive conclusions.

Data availability statement

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

Author contributions

FB: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. JV: Writing – original draft, Writing – review & editing. JT: Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing. LF: Methodology, Writing – original draft, Writing – review & editing. XI: Writing – original draft, Writing – review & editing. MIF: 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.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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"More players can reach national and international levels": coaches perceptions of "birthday-banding" in youth squash and its potential for minimising relative age effects

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Relative age effects (RAEs) are common across many youth sports that use age group structures to band athletes. This creates a significant overrepresentation of those who are born near the start of the selection cut-off date across talent pathways compared to those born towards the end. In an attempt to identify, select, and develop the most talented squash players based upon their long-term potential, England Squash designed and implemented the "birthday-banding" approach (i.e., athletes compete with and against those of the same age and move up to their next birthdate group on their birthday), which has indicated promising results for moderating RAEs across their player pathway. However, little work has focused on the perceptions of interest-holders on this approach. For this reason, the purpose of this study was to use semi-structured interviews with fifteen England Squash Talent Pathway coaches, to better understand the mechanisms of the birthday-banding approach as well as its potential benefits and limitations. Using thematic analysis, three higher-order themes were found that comprised of six lower-order themes: (a) considering organisational structures (e.g., understanding selection processes, and reflecting on competition structures and performance outcomes), (b) building appropriate settings (e.g., promoting flexibility and fluidity in groups, and creating an environment that fosters long-term development), and (c) facilitating individual athlete development (e.g., encouraging holistic development and progression, and evaluating physical and skill development). Overall, coaches spoke highly of the implementation of birthday-banding, noting the value in creating fairness for athletes who might have been removed due to their birthday and maturation levels. Coaches also reported appreciating seeing athletes having varying competition within and across a year, as sometimes athletes would be relatively older and younger than their peers within the same 12 months. Some considerations and concerns were also raised about implementing a birthday-banding approach, which have been highlighted to inform continued improvements for both athletes and coaches in the system.

KEYWORDS

athlete identification, athlete selection, athlete development, talent identification, talent selection, talent development

Introduction

The purpose of talent development systems is to provide young athletes with a suitable learning environment to accelerate or realise their potential (1). However, when identifying (i.e., recognising individuals with the potential at an earlier age to become high performers in the future) and selecting (i.e., ongoing process of identifying individuals at various stages of development who demonstrate prerequisite levels of performance) athletes into these systems (2), there can be a range of personal- and system-level challenges that can result in biases and inaccurate decisions (3). One such bias that can influence these key processes is reflected in the well-known relative age effects (RAEs). This phenomenon refers to the overrepresentation of relatively older athletes (i.e., those born near the start of the cut-off date, such as January 1st) and underrepresentation of relatively younger athletes (i.e., those born near the end of the cut-off date, such as December 31st) in team rosters when individuals compete in fixed annual age groups in youth sport (e.g., U10, U11, U12, etc.), (4, 5). Such effects are evident from early in the pathway, as recreational and developmental leagues and programs often use age cut-offs (6). This has a pronounced knock-on effect on those who are subsequently recruited into talent development systems at young ages where RAEs become even more significant (7).

Relative age effects are almost ubiquitous throughout talent development systems [see (8, 9) for reviews]. Indeed, research has showed they are prevalent across many team sports [e.g., handball; (10)] and individual sports [e.g., swimming; (11)], as well as in physical education [e.g., academic achievement and school sport representation; (12)] and in comparatively less physically active domains [e.g., cognitively demanding tasks such as chess; (13)]. As an example, a systematic review on RAEs in female sport (9) showed that, across 57 studies ($n = 646{,}383$), athletes born in birth quarter one (BQ1; i.e., those born in the first 3 months of the annual selection year) were significantly overrepresented (26%) compared to those born in birth quarter four (BQ4; i.e., those born in the last 3 months of the annual selection year) who were significantly underrepresented (22.6%).

Although RAEs have been shown across a range of ages, competition levels, countries, and playing positions in both female and male sports, the mechanisms driving these effects remain mostly hypothetical (14–16). The current consensus is that they occur due to a combination of task (e.g., sport), performer (e.g., playing position), and environmental (e.g., country) constraints (17). These influences are co-dependent on a single cut-off date, which can differ depending on the sport, country, and organisational policies (12, 18). For instance, volleyball in The United States has 17 different cut-off dates alone depending on state regulations; however, RAEs shift according to these timepoints, which has been shown in other sports (18–20, 60). This helps to highlight how a single cut-off date can significantly impact an athlete's identification and selection into a talent development system (16), shedding light on how the current chronological age group system has questionable effectiveness, efficiencies, and ethics in developing talented young athletes.

The same trends can be seen in youth racket sports, with research showing how RAEs are generally consistent across different countries and genders in tennis [e.g., (21–24)], table-tennis [e.g., (25–27)], and badminton [e.g., (6, 28, 29)]. In tennis, for example, relatively older players within an age group are more likely to be selected for development programs (e.g., national team training camps), receiving more training and competition opportunities, which contributes to their continued development and success (21). Similarly, in table tennis, Faber et al. (26, 27) reported consistent relative age patterns across European youth competitions, where earlier born players were more likely to follow higher performance trajectories, whereas fewer relatively younger players reached these elevated levels. Likewise, Bilgiç and Devrilmez (30) showed comparable results in badminton, where RAEs favoured relatively older athletes across both singles and doubles categories during three consecutive European Badminton Championships, with players born in BQ1 and BQ2 over five and four times more likely to reach the podium than those born in BQ4, respectively. Collectively, this research emphasises the inefficiencies of current talent development systems, with age group structures often favouring those who are relatively older and disadvantaging those who are relatively younger.

Although findings are consistent at the youth levels, they appear more variable at senior levels. For instance, Zháněl et al. (24) and Bilgiç and Güvenç (25) showed significant RAEs at senior levels in tennis and badminton, respectively. As an example, Zháněl et al. (24) examined senior female tennis players ranked in the world top 100 from 2007 to 2016, showing RAEs for those born earlier in the year (e.g., BQ1 and BQ2), with further significant RAEs present among the world top 10 players. Interestingly, significant RAEs were also observed in older age subgroups (e.g., aged 19–36 years), suggesting that the impact of RAEs may intensify and persist into later stages of an athlete's career (24). In comparison, however, Ulbricht et al. (23) and Romann et al. (6) showed no RAEs at senior levels in tennis and table tennis, respectively. Ulbricht et al. (23), for instance, found little evidence of RAEs in senior ranked (56% born in the first half of the year) and senior recreational (49% born in the first half of the year) German tennis players.

These inconsistent findings are likely due to a combination of factors, including gender and sport popularity. For example, gender has been shown to moderate RAEs, with males generally experiencing stronger effects than females, which is possibly a result of higher competition levels and greater selection pressure in male sports (6, 8). Relatedly, Romann et al. (6) conducted a nationwide analysis of youth athletes across 68 male and 63 female sports in Switzerland, revealing RAEs were more pronounced in male athletes, especially in sports with higher participation and competitive depth. Conversely, RAEs in female sports were small and largely consistent across selection levels. Moreover, sport popularity has been shown to influence the extent to which RAEs are prevalent, whereby the more popular the sport is and the more competition there is for the limited competitive places at the highest levels of engagement in the sport, the higher RAEs become, and vice versa [e.g., (6, 8, 31)].

For instance, Romann et al. (6) showed a "residual bias" (i.e., the persistent overrepresentation of relatively older athletes in adult sport, where the expected or obvious effects of relative age should have faded) in Olympic sports compared to non-Olympic sports. This was attributed to the greater popularity, visibility, and funding of Olympics sports, thereby attracting larger athlete pools and creating higher selection pressures ultimately intensifying RAEs more at youth levels compared to non-Olympic sports, which has a subsequent knock-on effect in the longer-term (i.e., at adulthood).

There is one racket sport, however, that has shown no RAEs to date, across both youth and senior cohorts as well as for male nor female talent pathways—squash (32). Squash is an important sport to monitor from a relative age standpoint, since it is played globally and is particularly popular in England, where two players are, at the time of writing (33), ranked in the top 20 internationally for both women and men. Due to its popularity and international success, a greater emphasis has been placed on structured development for athletes at an early age. This has led to the creation of the England Squash Talent Pathway, which prioritises the identification, selection, and development of the best players in the country to help them succeed on the international stage. Interestingly, when examining RAEs across the five steps of their England Squash Talent Pathway, no effects were found across their mixed-gender pathway (BQ1 = 21% vs. BQ4 = 24.7%) or across genders (total female BQ1 = 21.4% vs. BQ4 = 23.8%; total male BQ1 = 20.3% vs. BQ4 = 25.2%). Its growing interest from a participation and spectator standpoint, combined with the recent news of its debut in the 2026 Olympics, make for an important case study to examine.

The encouraging absence of RAEs across the England Squash Talent Pathway is likely attributed to their novel grouping approach, referred to as "birthday-banding" (34). Birthday-banding involves athletes competing with and against those of the same age (i.e., all the 13-year-olds compete together, all the 14-year-olds compete together, etc.) and move up to their next birthdate group on their birthday, rather than competing in fixed chronological age groups (i.e., U13, U14, U15, etc.). The aim of birthday-banding is to remove specific selection time-points, maintain recruitment on a continual basis, and ensure there is an equal opportunity for all players to be selected during the entire selection year (32). The birthday-banding strategy also affords more diverse experiences, by allowing individuals to be both relatively older and relatively younger throughout their development. As a practical example, if a young athlete was born in August in England and competed in fixed chronological age group structures, they would be a BQ4 throughout their entire youth development. In contrast, if the same athlete was to compete in birthday-banding structures, they would start as a BQ4 in August (on their birthday), and then gradually progress towards being the oldest (i.e., BQ1) until the end of their 12-month development (on their next birthday) where they would again become the youngest (see Figure 1 for a visual representation) (34). In addition to its potential positive impact on mitigating RAEs, birthday-banding may provide additional benefits such as drawing unique benefits from mixed age play (35), enabling different types of social comparison environments (36), and moderating other identification and selection biases such as relative growth effects (37, 38).

Importantly, however, many of these suggestions remain hypothetical, as perceptions of birthday-banding are yet to be explored from various interest-holders. For example, Bilgiç and Güvenç (25) reported no significant RAEs among senior squash players in Turkey, attributing this to the relatively low popularity of squash in the country and the smaller athlete pool compared to other racket sports. The limited competition for places likely reduced selection pressures, thereby minimising the impact of RAEs. Moreover, qualitative methodologies in relative age research is generally lacking (39, 40). To fill this void, the purpose of this study was to better understand the perceived operational mechanisms of "birthday-banding" as well as the perceived player development outcomes associated with the birthday-banding approach. Using semi-structured interviews, coaches working throughout the England Squash Talent Pathway were invited to share their experiences and ideas with respect to the birthday-banding practices in squash. It was hypothesised that coaches would view birthday-banding in a positive manner with respect to its effect on the player development environment, emphasising its ability to create more diverse settings that focus on each individual's needs, and, in turn, highlight its ability to moderate RAEs during identification, selection, and development processes.

Methodology

Research paradigm

The current study will be guided through a constructivism research paradigm with a relativist ontological position and subjectivist and transactional epistemological position. Within a relativist ontological position, it is assumed that there is no single external reality independent of the individuals, rather reality is seen as multiple individual mental constructions about the world, shaped through lived experiences (41). A subjectivists and transactional epistemological position assume that knowledge is co-created through interactions between the researcher and the participant, whereby the researchers bring their past experiences and interpretations to the study (42). This theoretical perspective was fitting for our research question under examination because it allowed us to explore how birthday-banding is perceived by key interest-holders (i.e., coaches), through their lived experiences and interpretations. Rooted in the subjective realities of coaches, our study seeks to understand how their knowledge and experiences shape their perceptions, while also acknowledging the role of the researchers in guiding discussions, and interpreting and constructing meaning from the data (43).

While guided by these philosophical and theoretical positions and values, the chosen method for knowledge gathering was though qualitative interviews with coaches who have experience using, working within, and applying the birthday-banding in their work with athletes. To do so, semi-structured interviews

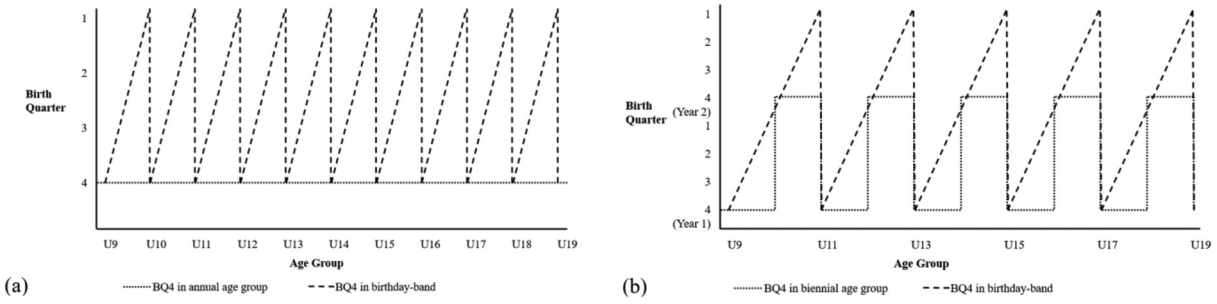


FIGURE 1
The U9 to U19 birthday-banding developmental trajectories compared with (a) annual age grouping, and (b) and biennial age grouping. Note, the example comparisons use a BQ4 athlete for the annual age group and biennial age group [adapted from (34)].

were utilised as a way to illicit storytelling, experience sharing, and conversations between the coaches and the interviewer. The dynamic nature of semi-structured interviews allowed participants a degree of freedom to discuss experiences most relevant to them with the birthday-banding approach as a coach (44). This technique also allows for greater flexibility and creativity in the interview process compared to an approach like a structured interview, as appropriate times during the interview, the interviewer (MF) was able to probe with related questions, to further unpack insightful details from participants' responses to questions. Using this method aligns with our guiding paradigm that amplifies the many voices and perspectives of a phenomena such as a birthday-banding (and more generally talent selection) in the context of sport.

Positionality

Bourke (45) describes how researchers often co-develop knowledge with research participants based on their positionality in association with the given questions within a project. In fitting with our philosophical position of constructivism with subjectivists and transactional views, the experiences and knowledge of the interviewer coming into (and during) the knowledge gathering process through interviews was celebrated rather than diminished. In this case, the primary interviewer, did not have any experience within the sport of squash and the practices of birthday-banding.

Participants

After obtaining ethical approval from the Health, Education, and Life Sciences Faculty Academic Ethics Committee at Birmingham City University (reference code: #3293), the authors used purposeful sampling to recruit 15 England Squash Talent Pathway coaches from United Kingdom, aged 29–49 years. All 15 coaches were emailed invitations and accepted to participate. Amongst the 15 coaches who participated in this study, 14 identified as male, and one identified as female. All coaches had extensive experience in squash coaching with years of experience ranging from 10 to 32 years. Among the participants, nine individuals held the England Squash Level 4 qualification and six participants had achieved the England Squash Level 3 qualification, demonstrating advanced expertise in coaching in squash at high performance levels. The coaches worked with athletes of various ages, ranging from as young as 3 years old to adults in their 70s, and coach players at different competitive levels, including beginners to professional and international levels. The average weekly squash coaching hours ranged from 15 to 40 h per week. Importantly for this study, all coaches had experience either being directly involved in, or working within the England Squash Talent Pathway that used the birthday-banding approach.

Figure 2 provides an overview of the England Squash Talent Pathway. ASPIRE provides the first stepping-stone onto the England Squash Talent Pathway for those who are mostly selected from aged 11 to 16 years, offering the most promising young players an environment to develop across eight English regions. This feeds into the Potential group, focused on providing the first national level squad for the younger and developing talent in England. This develops and leads individuals into the Development group, which supports individuals towards a world class level for the England Academy and England Senior Team (46). Training time varies across the five selection levels: (a) ASPIRE = 3–6 h/week; (b) Potential = 5–10 h/week; (c) Development = 7–14 h/week; (d) Academy = 15–20 h/week; and, (e) Senior Team = 15–20 h/week.

Data collection

An interview guide was developed with inspiration from the work of Goldman et al. (47), whose interview examined athletes' perceptions of "playing-up" (i.e., athletes competing in an older age group) in youth football. The interviews began with some broader opening questions to set an inclusive and friendly environment (i.e., "Tell me about your role in the organisation and how you started coaching squash"). They then progressed to an introduction into the relevance of birthday-banding within

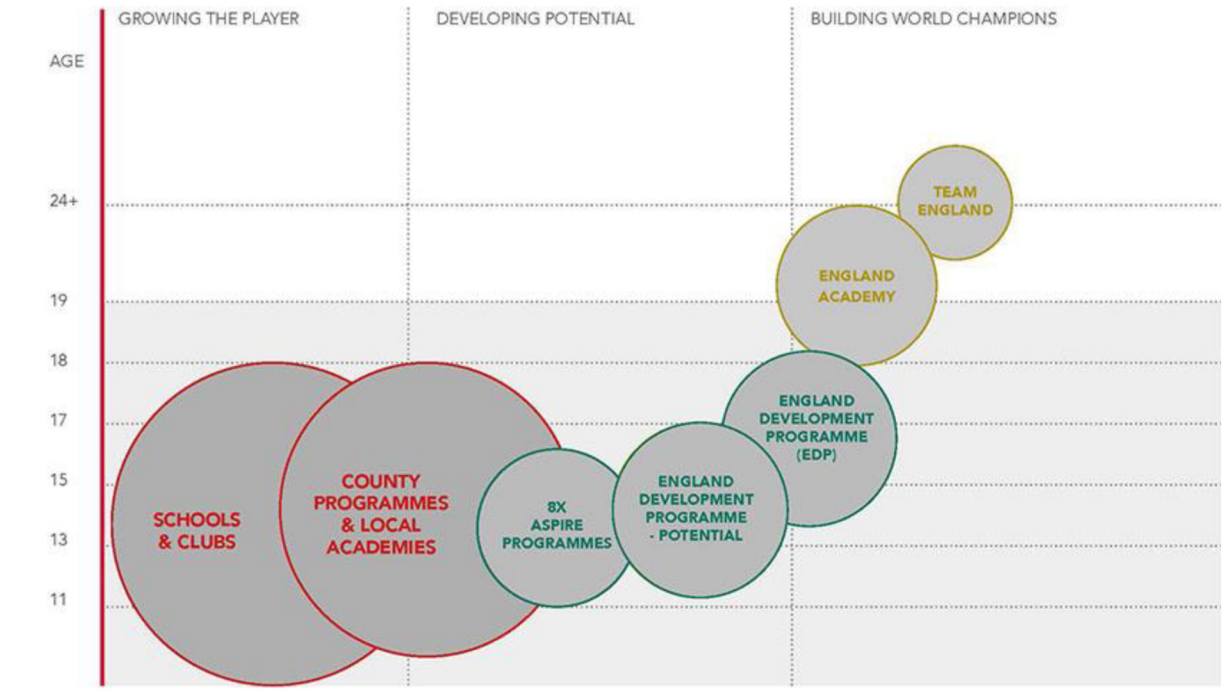


FIGURE 2
The England squash talent pathway [adapted from (32)].

the England Squash Talent Pathway specifically (i.e., "How is the concept of birthday-banding relevant to your organisation?"). An introduction to the topic was then followed by the general discussion of birthday-banding, which entailed various aspects including its implementation (i.e., "How was birthday-banding put into practice in your organisation?"), and evaluation (i.e., "What was the impact of using birthday-banding?"). The interviews were then concluded with a closing statement, thanking the coach for their participation in the interview, as well as allowing the opportunity for the participant to ask any questions or add any relevant information which may have not been covered through the interview questions (i.e., "Is there anything that you would like to mention that we haven't covered already?"). Using this approach, the third author facilitated participants' insights of experiences and perceptions on the birthday-banding approach in their own coaching environments. Before commencing main interviews, two pilot interviews were conducted with two squash coaches from the England Squash Talent Pathway. These pilot interviews were not included in the data analysis as they served to refine the interview approach, ensuring clarity and relevance of the questions in order to yield rich data for the analysis.

As part of the data collection process, the interviewer video and audio-recorded 15 interviews with 15 unique squash coaches as part of the data collection process. All interviews took place online via Microsoft Teams (Microsoft Corp., Redmond, WA, The United States), with only the interviewer and the respective participants present. On average, the interview length was 39.87 (SD = 14.26) minutes. Upon completion of all interviews, the interviewer transcribed the interviews using Microsoft Teams Transcriber (Microsoft Corp., Redmond, WA, The United States). Confidentiality of coaches who participated in the interview was maintained by assigning a random participant number to each coach to de-identify the transcribed audio data collected.

In addition to the interview transcripts, the interviewer kept a reflexive journal. Throughout each interview, observation of the coaches' and notes were made (e.g., tone, body language, ease or difficulty when participants responded to questions). Upon the completion of each interview, key messages, and overall thoughts of the interview were recorded by the third author through his notes which were ultimately synthesised to form the reflexive journal. This process is particularly important for qualitative research to maintain transparency and sincerity during the data analysis process and to document and reflect on personal assumptions (48).

Data analysis

Once participant interviews were transcribed, the second author conducted an inductive thematic analysis of the transcripts to identify and categorise emerging themes from participants' interviews (49). Informed by Braun et al.'s (49) six-step process, the second author conducted the thematic analysis on Microsoft Word (Microsoft Corp., Redmond, WA, The United States). To begin (i.e., step 1), the second author familiarised themself with the data by reading over the transcripts. Next (i.e., step 2), using the comment function on

Microsoft Word, the second author "tagged" pieces of the text that were relevant to the research purpose with one or more code. Then (i.e., step 3), to begin constructing lower-order themes, they examined codes and associated data to cluster them into bigger codes or provisional themes to capture meaningful patterns in the transcripts. Following this (i.e., step 4), they reviewed the provisional lower-order themes. This included ensuring all codes were representative of the lower-order theme and the lower-order themes were relevant to the research question. To capture an idea of an underpinning group of lower-order themes, higher-order overarching themes were also developed. Subsequently (i.e., step 5), they defined and named these themes. Finally (i.e., step 6), they compiled and revised all analytic writing to integrate it into a final report.

Methodological rigor

To ensure effective and ethical qualitative research practices, the authors employed a study design in accordance with criteria for excellent qualitative research [see (48)]. Tracy (48) proposed a model entailing eight key indicators of quality in qualitative research. Based on this work, the following criteria contributed to rigor in this study: worthy topic, significant contribution, sincerity, meaningful coherence, and credibility. Given the scarcity of literature surrounding the birthday-banding approach in youth sports, the present study covered a worthy topic. To the authors' current knowledge, the coaches' perception of birthday-banding approach in youth sports (within any sport) has yet to be examined. Indeed, the coach is a pivotal interest-holder in the birthday-banding approach, as they are often the ones responsible for identifying athletes, making (de)selection decisions, and subsequently working with those athletes in a training and competition environment Understanding the perceptions of the coaches may help to inform theory, shape coach education, challenge and inform selection policies, and support coaching practices within (and perhaps beyond) the sport of squash.

The authors recognise they are coming into this work with preconceived notions and experiences that will shape the way the study is conducted, and have try to stay transparent and sincere throughout the work. Throughout the data collection and analysis process the interviewer utilised the reflexive journal to record any personal assumptions. To accomplish meaningful coherence (i.e., ensuring the study aligns its aims, methods, and findings), the authors collaborated to ensure the construction of an effective interview guide that aligned with the purpose of the study. Lastly, to accomplish credibility, interviews were held with as many coaches as possible given the purposeful sampling. Having 15 coaches who were experienced and knowledgeable on the topic, working with some of the most elite athletes for their age in the country, helps to illuminate an important perspective on how birthday-banding is used. These coaches were directly involved with the birthday-banding approach in England youth squash, leading to rich data informed by coaches with lived experiences. In addition, a degree of alignment in the labelling and coding was achieved (i.e., triangulation), through multiple iterative consensus meetings among the authors. These meetings focused on reviewing and refining the coding and thematic structure from the data analysis based upon the contents from the interview transcripts.

Results

Participant discussions centred around the operational mechanisms of birthday-banding and its associated player development outcomes, highlighting three higher-order themes comprised of six lower-order themes: (a) considering organisational structures (e.g., understanding selection processes, and reflecting on competition structures and performance outcomes), (b) building appropriate settings (e.g., promoting flexibility and fluidity in groups, and creating an environment that fosters long-term development), and (c) facilitating individual athlete development (e.g., encouraging holistic development and progression, and evaluating physical and skill development) (see Figure 3). These higher-order themes reflect organisational, environmental, and individual outcomes inherent with youth sport development, respectively.

Considering organisational structures

Participants frequently highlighted the importance of considering organisational structures as a critical factor with the implementation of the birthday-banding approach. These considerations reflected the selection processes as well as competition structures and performance outcomes.

Understanding selection processes

Participants believed the birthday-banding approach held important implications for the selection processes in England Squash. Participants mainly highlighted the more inclusive and development-focused opportunities for younger players available through selection processes. Several participants spoke positively about how the birthday-banding approach allows interest-holders involved in the selection process to identify and nurture the potential of young players beyond traditional age-grouping constraints. For example, Participant 12 highlighted the flexibility associated with birthday-banding, which allowed younger players who may be overlooked to have the opportunity to be involved in high performing environments:

> "I'd say that birthday banding provides a lot of flexibility in squad selection processes, especially for youth players. It opens up opportunities for young players with potential to be involved in these environments, which is a real positive. I've seen many players develop rapidly and gain confidence. Coaches can select players based on attributes that they believe will help long-term development rather than being constrained by a ranking system" (Participant 12).

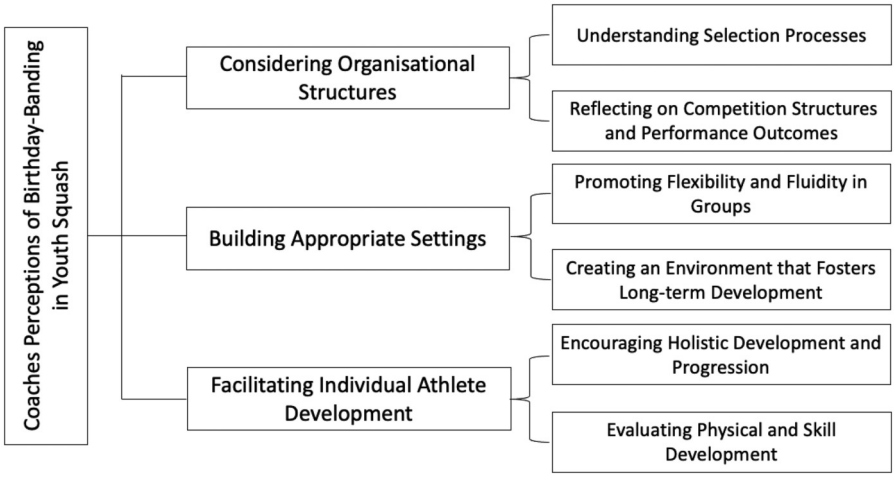


FIGURE 3
The three higher-order themes comprised of six lower-order themes based upon coaches' perception of birthday-banding in youth squash.

This example highlights the strong perceptions participants held on the positive association between birthday-banding and the selection process, specifically relating to the opportunities for young players who may be overlooked to be selected into further developmental or high-performance programmes. As Participant 12 noted, birthday-banding allowed for the emphasis on selecting players based on attributes indicative of high potential, rather than focus on the current performance and outcomes, which can be skewed by relative birth advantages such as maturation and growth.

With focus shifting to players' abilities within a birthday band rather than their immediate performance in selection processes, multiple participants believed this approach created greater opportunities for later developers or relatively younger players. Specifically, participants 5 and 8 believed that if relatively younger players demonstrated high potential through key attributes relevant to squash (e.g., effective use of different strokes), they were more likely to be recognised and given a chance to develop within a birthday-banding system rather than a traditional age-grouping system.

Whilst positive advantages in the selection process were mainly highlighted by participants when discussing the birthday-banding approach, some also believed that unique disadvantages existed for players in the selection process existed depending on their specific date of birth. For example, Participant 14 noted that when athletes try and represent England, some interest-holders may tend to favour the selection of players born towards the end of the season (i.e., April to July) due to the timing of international events and players born in this specific time range being at the peak of their performance. Participant 15 added, "It would be a shame for someone to miss out on an invitation to a national squad simply because they were a couple of weeks short of qualifying. I know of players who have just missed cut-offs for events and end up missing out on opportunities because of timing". This example highlights participants 14 and 15 believed certain players had unique advantages in the selection process, especially if their date of birth closely aligned with timing of key competition events.

Participants 2, 5, 8, 12, 14, and 15 believed if coaches and key interest-holders involved in the selection processes understood and were aware of these advantages, it would help minimise barriers in the selection process for players not born in these optimal time ranges. Participant 15 added "players born closer to competition dates may have more chances to gain ranking points. This could open doors to more squads, but we must be careful about how we assess potential based on timing". Indeed, participants 14 and 15 agreed that certain advantages may exist in the selection process for players born at an optimal time (e.g., being born closer to competition dates), however, they also noted to minimise the impact of a player's birthdate influencing selection opportunities, coaches and those involved in the selection process need to be aware of such biases and reflect on their selection criteria and process accordingly. Additionally, most participants strongly believed that biases related to a player's birthdate (i.e., RAEs) or relative birth advantages, such as maturation and growth, were more easily recognisable within a birthday-banding approach. This increased awareness enables coaches to make more informed selection decisions, ultimately minimising the negative effects associated with birthdate disparities.

Despite the potential negative impact of birthday-banding on the selection process as highlighted by a few participants, most believed these challenges could be addressed. Participants suggested that if coaches can understand the selection process and established possible barriers (e.g., unfavourable birthdays), they could adopt a more flexible approach. By integrating players based on their potential, recognised through key attributes or characteristics rather than immediate performance, the limitations of the birthday-banding system could be minimised. Overall, the examples and positive perceptions shared by participants about the impact of the birthday-banding approach

on selection processes suggest that it is seen as a valuable tool for talent identification.

Reflecting on competition structures and performance outcomes

Participants noted that the birthday-banding approach was mainly put into practice through competition structures and performance settings, offering a unique approach for player development as it can provide a longer developmental window within an athlete's relevant birthday-band compared to rigid annual age group classifications. This extended period was perceived by participants to allow players more time to develop, compete, and progress within their age group before moving up. For example, a player born later in the selection year may benefit from competing against similar aged peers for an extended period before transitioning to the next age category, rather than being disadvantaged by strict 1-year age classifications.

A key advantage specifically highlighted by participants 1, 2, 4, 7, 12, and 13 with the implementation of birthday-banding approach in competition structures is the opportunities players have to compete against others at different developmental stages, given the biennial birthday-band groups (i.e., U11, U13, U15, etc.). Although the early time spent in a birthday band may be challenging for some players due to greater age differences coupled with physical and maturational variances, this structure and performance outcomes could foster psychological skills, such resilience and motivation. Participant 1 noted:

> "Sometimes at tournaments, you'll see a 13-year-old getting completely outmatched by a 15-year-old, simply due to the physical differences. But because this system is in place from an early age, the kids get used to it. They understand that some years will be tough, but that motivates them to keep pushing for the year after, when they'll be among the older ones in their group".

This example highlights the belief amongst participants that the birthday-banding approach, mainly perceived to be implemented through competition structures, fosters an environment conducive to growth through appropriate challenges within players' relative biennial birthday-banding structure.

Some participants highlighted that competition structures and their schedules could create unique advantages or disadvantages for a player depending on their birthdate. More specifically, if a players' birthdate closely aligns with key competition events that then allows them to compete in competitions when at their strongest, it would be considered a "good" birthdate. For instance, Participant 4 noted, "The only barrier [to birthday-banding] is the tournament calendar. Some kids might miss out on certain events. If a child has an awkward birthdate, they might not get to perform in some events when they're at their strongest". Participants 12 and 13 added that athletes are quite aware of the unique advantages and disadvantages associated with their birthdates. As an example, Participant 13 added, "They [athletes] often discuss their birthdays and how they relate to tournament schedules. For example, my birthday is on January 4th, and that's considered a disadvantage because I miss out on the British Open, whereas others born on January 10th get to compete in both the nationals and the British Open. They are aware of how their birthdays affect their opportunities in tournaments".

This disadvantage, however, is somewhat counterbalanced by the flexibility birthday-banding provides alongside competitions occurring year-round, thereby minimising the effect of an "optimal" birthdate, or RAEs, allowing players to compete at various times during the year. Participant 6 highlighted "competitions are year-round. A player might miss one opportunity but could excel in another. You can't control everything, but you can manage the training environment to ensure that birthday differences don't become disadvantages". Further, Participant 3 added by suggesting rotating major tournament dates (e.g., British Open Junior) to prevent the same player from consistently benefitting from a fixed cut-off date due to birthdate related advantages. Ultimately, participants agreed that while competition scheduling could be refined, particularly by rotating major tournament cut-off dates, the birthday banding approach helps level the playing field over time. Importantly, participants also emphasised that given the benefits of birthday-banding and the year-round competition structure, performance outcomes should be evaluated across all events rather than focusing solely on major tournaments. This broader perspective helps mitigate birthdate related biases when assessing player development.

Within the birthday-banding approach, high-performing players may be placed in older birthday-banding age categories in competitions, a process commonly referred to as "playing-up". Participants perceived that the flexibility of the birthday-banding approach, allows exceptionally high-performing players to challenge themselves at higher levels in competition structures, ultimately promoting their continued growth. However, participants 8 and 13 both raised concerns about ensuring a balanced competitive environment within each band. Participant 13 noted, if too many top players in a birthday band are playing-up, the remaining competitors in their original birthday band may lack strong opposition, potentially weakening competition within the group. Participant 8 added, "The system seems to be working pretty well. My only concern would be for children who don't participate enough within their banding level. That's dangerous for the overall structure, and I'm not entirely sure how to address that yet". Despite these concerns, most participants highlighted that birthday-banding remains a flexible and effective tool for managing competition structures and performance outcomes in a way that promotes effective player development. By recognising and addressing potential imbalances, stakeholders can refine the system to ensure that all players have access to appropriately challenging competitions and development opportunities.

Building appropriate settings

Participants highlighted the critical role birthday-banding plays in building appropriate settings for players. More specifically,

participants highlighted the capacity to promote flexibility and fluidity in grouping players because of the birthday-banding approach for both training and competition settings. Further, participants expressed the influential role birthday-banding plays on creating environments that encourage long-term player development.

Promoting flexibility and fluidity in groups

Generally, participants believed the birthday-banding approach provided flexibility in grouping players for training and competitions, while also enabling fluid movements for players across birthday-bands (i.e., playing-up or playing down) within the pathway. Participant 1 noted, "I try to avoid restricting players to just one group based on their age. Obviously, there are limits—you wouldn't pit a 17-year-old against a 10-year-old—but overall, I like to mix ability levels, and birthday-banding allows for that flexibility". Alongside the flexibility to mix different levels of abilities and players together in the building appropriate training and competition environments, participants also highlighted the associated fluidity in moving players up and down the pathway. Participant 10 highlighted: "I believe in the importance of getting younger players to train with more experienced athletes. This approach [birthday-banding] promotes development, as long as everyone benefits and is challenged appropriately. It allows for fluidity in moving up and down the pathway, and I think younger players can gain a lot from training with their more experienced peers." In comparison, Participant 9 felt that the traditional year-group system approach would create rigid divisions, where some players dominate while others fall behind, ultimately limiting the opportunities for appropriately building challenging environments to facilitate player development. Indeed, participants agreed with the flexibility and fluidity the birthday-banding approach allows in building training and competition environments to maximise developmental benefits for their players. Players can be moved up or down based on their development at the time, allowing them to face a diverse range of opponents (e.g., faster, stronger, smaller). This exposure challenges them to think strategically, likely enhancing their skill development.

Interestingly, participants also discussed the importance of the birthday-banding approach in building and maintaining competitive environments to ensure players are always appropriately challenged. Relating to the flexibility and fluidity to move players up the pathway, participants often noted how when these younger players moved into older pathways or groups, it created a competitive atmosphere pushing players to compete at a higher level. Further, in the context of competitive high-performance programmes, Participant 12 highlighted, "This flexibility [with birthday-banding] allows coaches to reassess players halfway through a season and bring them into the program if they show promise. It keeps everyone in the group on their toes, knowing that their positions aren't guaranteed and that there are players ready to step in". Overall, participants felt that the birthday-banding approach, and its flexibility and fluidity to move players up and across different pathways, facilitated the building and maintenance of competitive environments to ensure players are always appropriately challenged to maximise player development.

Another advantage of the birthday-banding approach highlighted by participants was the fluidity of transition periods, both within and between groups. Birthday-bands span over a two-year period, whereby players generally remain in their respective band for that duration (e.g., a 12-year-old has two years before moving from an U13 birthday-band to an U15 birthday-band). This process over the 2 years for a player within a birthday-band was perceived by participants to help create a fluid transition into more challenging levels. Participant 15 highlighted, "I think the intention behind birthday-banding is to create a fluid system that facilitates learning and development. The first year serves as a transition year, allowing players to adapt as they move up age groups, where the game becomes faster, and rallies become longer. By grouping players within their brackets, we can ensure they are always competing against similar-aged peers". Participant 15 also added, "Players essentially get two chances: one in their first year and a second opportunity in the next. This reflects the developmental expectations associated with performance". Generally, participants believed that the birthday-banding approach created an environment encouraging fluid progression for players within their groups, while also providing opportunities for players to play across birthday-bands (i.e., playing-up and playing-down) if needed to maintain competitive environments.

Interestingly, participants also noted that many are leveraging the flexibility and fluidity of the birthday-banding approach to group players based on factors beyond age, to build more appropriate environments for player development. Participants 5 added, "In our coaching pathway, banding becomes more fluid and focuses more on skill, ability, and effort rather than age alone". Participant 5 further highlighted how some regional competitions are based purely on ability and not age, stating "Teams are formed based on skill levels rather than age, merging ability-based methods with birthday banding where possible". In fact, many participants referred to the birthday-banding approach as an "ability-based" approach during interviews, thereby underscoring this emphasis beyond age.

Given the fluid and flexible nature in grouping players with the birthday-banding approach, participants highlighted how this simplifies its implementation. Participant 10 highlighted, "Because birthday-banding is very open and fluid, it makes it quite simple to implement. It becomes more difficult if the governing body isn't fully behind it. Since this is a governing body decision, everything else can align and work accordingly". In cases where there may be many players fitting into a certain category, or birthday-band, Participant 10 further suggested that organisations could consider breaking down groups into further ability-based categories within the birthday-band (e.g., elite and development level) to accommodate larger numbers. In an example from their context, Participant 10 noted, "For example, currently, we have two performance sections—development and potential—but also multiple age categories. Adjusting how organisations align their pathways with age categories could improve implementation".

Creating an environment that fosters long-term development

Participants believed that the birthday-banding approach played a significant role in facilitating the creation of training and competition environments that foster long-term player development. Specific features of the training environment that were likely conducive to long-term player development was consistently highlighted by participants. For example, Participant 12 highlighted,

> "I think it [birthday-banding] was to allow a more detailed look at individual players and focus on developing future talent. It provides young players with potential the opportunity to train with older, more successful athletes, which boosts their confidence. The group sizes are relatively small, enabling us to work closely with two or three players instead of cramming four or five into a session. This approach improves the quality of training and allows for specific skill development linked to the higher pathways, including the national junior and adult programs. Overall, it's been a beneficial strategy for individual athletes' development".

Participants generally believed that the environment created, empowered by the birthday-banding approach, allows for a more detailed focus on the individual encouraging long-term player development.

Another advantage highlighted by participants was that the birthday-banding approach encourages a shift away from age-based grouping, and towards building ability-based environments to encourage long-term player development. This connection was reinforced throughout the interviews, as many participants frequently referred to the birthday-banding approach as "ability-based" systems. Participant 10 highlighted,

> "It [birthday-banding] allowed us to work with players operating at a younger age group who might not have made the squad if we were strictly using age categories. It gave us the chance to continue developing those players. We could also mix sessions based on ability rather than limiting them by age. This means a high-quality younger player could train alongside an older player if their abilities matched, removing those barriers".

Participants also added that this approach allows players who may not be excelling now to have more time for development and to reach their potential. Further, by placing them in training environments that match their current ability, participants believed this created an environment which allowed players to still be part of the team and be given meaningful opportunities. This approach aligns with long-term development through building appropriate environments for the individual player.

When discussing the benefits of the birthday-banding approach, participants consistently highlighted the improved player retention rates. Many participants observed that more players remained involved in the sport for longer. Participants attributed the high player retention rates to the environment created, which was influenced by the birthday-banding approach. When discussing the different indicators for successful use of the birthday-banding approach, Participant 14 noted, "Retention and participation are the two main indicators. Once you hook them in, they tend to stay. More kids are showing interest in big tournaments, which leads to bigger draws and better facilities, giving everyone an opportunity to compete". Relatedly, participants particularly continued to highlight the competitive environment available at every level for players as a possible explanation to the higher retention rates of players. Indeed, every player, whether excelling or still developing, has appropriate competition and opportunity to find a suitable challenge due to flexibility and fluidity of the birthday-banding approach. This fosters a sense of continuous challenge and progression pathways, encouraging players to stay in the sport long-term to fulfil and realise their potential. In relation to this, Participant 3 added, "You also see more players making it into the final stages of tournaments. The pyramid at the top is less narrow, and that gives a bigger base of players to choose from. More players can reach national or international levels".

Expanding on player retention and participation rates, participants highlighted the effect of the birthday-banding approach on countering RAEs. Players born across different birth quarters are given equal opportunities because of the competitive environments created, specifically with tournaments spread out throughout the season. Participant 3 added, "It [birthday-banding] definitely seems to be working well in terms of relative age effects. There's a more even spread of participation across different birth quarters, whereas in other sports, you usually see a bias toward players born earlier in the year". As a result, participants consistently highlighted birthday-banding as a fair approach for all players, regardless of RAEs, fostering an environment that supports long-term development.

In further highlighting the "fairness" associated with birthday-banding, participants believed the approach was the most appropriate way to allow players to progress and continue their journey in competitive sports. Participant 4 noted,

> "It's meant to make things fair. You have to play in the age categories—under 11, 13, 15, and 17. You play a certain amount of time in the first season and then a full season in your last year, where you're probably at your strongest. For instance, my daughter just turned 13 in May, so now she's moved up into the next age category. She has two seasons to really improve her squash and achieve her goals".

Participants added that training environments may already expose players to older opponents if appropriate, emphasising the fluid progression and the creation of environments tailored to support the long-term player development of the players. Importantly, Participant 3 highlighted the potential concern about differing systems across other sports that may be raised by parents (e.g., strict cut-off dates in other sports). However, Participant 3 added such concerns can be addressed through communication with key interest-holders of the players (e.g.,

parents) on the long-term benefits of birthday-banding for player development.

Facilitating individual athlete development

Participants perceived the birthday-banding approach as a valuable system to foster individual athlete development, particularly in promoting holistic growth and progression. Participants also emphasised the importance of evaluating players' physical and skill development within the birthday banding approach to ensure continued development.

Encouraging holistic development and progression

Participants highlighted birthday-banding as a particularly important approach in facilitating the holistic development of athletes as they progress through the sporting pathway, including increased motivation, confidence, and resilience. These advantages were attributed to exposure to diverse training and competitive environments underpinned by the birthday-banding approach. Participant 13 highlighted, "Players become comfortable in their zones but also push their limits [with birthday-banding]. I see notable improvements when players mix with different standards. They gain confidence from competing against a range of abilities, which is essential for their growth". Participants added that the birthday-banding approach allows for a more individual focus on players, enabling the monitoring and tracking of development more effectively. Participants 10 and 12 highlighted that the emphasis on results at a young age is not essential. Instead, the birthday-banding approach supports a medium- to long-term focus on individual player development, allowing athletes to progress into competitive pathways at older ages. In contrast, participants felt that the traditional fixed age-grouping system fosters a results-driven mentality within younger ages thereby not maximising holistic development and focusing on short-term results.

Another advantage of the birthday-banding approach noted by participants 6, 10, 12, and 13 is the allocation of more time spent between the coaches and players during their developmental stages. Given birthday-bands span for a 2-year period, coaches are likely to have a greater impact on the athlete. Participant 10 highlighted,

> "It [birthday-banding] has helped us get to know the players better and spend more time with them. Players are part of the pathway more consistently, which allows for greater opportunities for development and impact. We can really help shape their careers and development in a consistent manner, which is a significant benefit".

Participants also added that moving through different birthday bands exposes players to a variety of coaches, creating opportunities to maximise their talent and realise their potential. This diverse coaching experience is likely to help players develop a wide range of skills and abilities, ultimately supporting holistic development.

While most participants highlighted the advantages of holistic development underpinned by the birthday-banding approach, a few noted challenges players may face as they progress into higher birthday-bands and counter increased competition levels. Participants 3 and 9 discussed the challenges players may face when progressing into higher birthday-bands, particularly the mental impact. Indeed, as players enter a new birthday-band, they may no longer be competing at the high level they were accustomed to in their previous age group and must work their way back to the top. Participant 9 highlighted,

> "There's also the confidence issue when players move through the ranks based on their birthdays, not necessarily because they're physically ready to do so. The really good players tend to make that transition more easily than those who aren't as strong. This can be off putting, and we may lose players who find that transition difficult and lose confidence".

However, participants 9 and 3 added if such issues are managed correctly with the individual players, these barriers and issues can be addressed.

Relatedly, the progression of the individual athlete through the pathway is a crucial process that should be carefully evaluated to determine the best approach for their holistic development. Participant 2 highlighted, "It's about where the athlete will benefit the most in terms of their development. Sometimes it's better to challenge them by playing up, but other times staying in their age group makes more sense. It's a balancing act." Ultimately, the birthday-banding approach offers flexibility in considering the aspect of player progression, allowing coaches to assess whether moving up is the in the best interest of the individual player's holistic development, something that the traditional age-grouping approach does not provide.

Evaluating physical and skill development

Participants highlighted that physical and skill development should be consistently evaluated and considered to help support the ongoing development of individual athletes within the birthday-banding approach. Players may dominate the sport early on due to physical advantages (e.g., size or strength), but these short-term benefits may not necessarily guarantee long-term success. As players mature other aspects of their game will likely become more critical (e.g., technique, skill, and mental factors), therefore by not addressing the physical advantages, the individual player's development may not be maximised. Participant 13 highlighted, "Birthday-banding avoids the issue of older, stronger players dominating due to physical maturity. It allows for a mix of players to come into the age group at different times. This diversity means that players are exposed to various standards and coaches, promoting development". Indeed, most participants viewed the birthday-banding approach as highly beneficial in countering physical advantages for individual players.

However, one participant pointed out that significant differences in physical development still exist within the

birthday-banding approach and can negatively impact individual player development. Participant 1 added,

> "For instance, there could be a situation where someone is physically stronger and more developed, just because they were born earlier in the cycle. You might have someone who's very young and facing a two- or three-year difference, which creates a huge gap. This disparity might discourage some juniors from participating or trying to get involved. On the flip side, you might have juniors who are excelling in their age group but are bigger and stronger. As the age groups go up, they might get demoralised because they start losing to someone two or three years younger than them".

This perspective highlights the importance of carefully managing physical development of the individual athletes through competitive and training environments. All participants strongly viewed the birthday-banding approach as highly beneficial in managing and supporting the physical and skill development of individual athletes to ensure continued development. Given the flexibility to move players across the pathway according to their development, or their advantages at the time, birthday-banding is a highly beneficial approach to help manage these disparities.

Importantly, Participant 15 noted, "It's important to look past immediate advantages and consider long-term prospects. We see juniors performing well in competitions at the under-13 level, but sometimes they fade out by the time they reach the under-17 level. For example, a player who is a big hitter might initially excel due to physical and technical advantages, but these weaknesses can become more apparent as they mature. As an organisation, we need to avoid focusing solely on the 'big kid' and instead assess each player's unique attributes". Participants perceived the birthday-banding approach allows coaches and key interest-holders within the individual player development process to consider the individual player and focus on their long-term potential rather than short-term successes (e.g., a player with physical advantages). The flexibility of the birthday-banding approach allows players to be matched together according to their physical and skill development, ensuring appropriately challenging environments to optimise individual athlete development.

Discussion

The current study explored the operational mechanisms of the birthday-banding approach in the England Squash Talent Pathway and potential associations with player development outcomes according to the perceptions of the coaches embedded within. The findings highlighted coaches believed birthday-banding, which has been previously shown to eliminate RAEs in this specific sports setting, has a significant impact on talent identification and development processes. To the authors' knowledge, this is the first study to qualitatively assess coaches' perspectives on this novel approach to address RAEs, and the results provide valuable insights into how birthday-banding may influence environmental, individual, and organisational components of athlete development.

The findings highlighted how birthday-banding influences organisational structures and environmental factors, particularly in terms of competition and selection processes. Participants indicated that the approach not only mitigated biases but also helped to create a more inclusive, flexible, and fluid competition framework. This flexible grouping allows coaches to tailor the athlete experience and selection processes based on a range of factors beyond age to ultimately ensure that players are given appropriate developmental opportunities, and are selected based on attributes the coaches believe are important for long-term development rather than being constrained by current performance metrics. This is particularly important, since previous research has highlighted that the primary challenges and pitfalls of talent identification and athlete development systems are generally centred around the emphasis on short-term, performance-related outcomes (50). By fostering these tailored, adaptive environments, birthday-banding may offer athletes a more equitable experience that promotes their long-term development.

At the individual level, coaches strongly emphasised how birthday-banding facilitates holistic athlete development. This suggests the approach not only enables physical development, but also addresses psychological, technical, and tactical aspects that are important and perhaps become more so at older ages and higher competitive playing levels. Indeed, many studies have emphasised the importance of considering multidimensional factors in talent identification and athlete development settings [e.g., (51)], including preliminary research in squash [e.g., (52)]. By reducing the pressure on relatively younger athletes who may otherwise be overlooked due to their age, coaches suggest birthday-banding creates a more balanced approach to player development that considers a wider spectrum of growth and maturation nuances. As squash players progress through the talent pathway, the holistic development fostered by birthday-banding may help to ensure that athletes have the opportunity to realise their potential, rather than being prematurely pigeonholed based on their early/late birthdate.

While the findings from this study are specific to squash, the implications of birthday-banding may extend to other sports. As demonstrated by the consistent presence of RAEs in youth talent development systems across many sports, including other racket sports (e.g., badminton, table tennis, tennis) (25), birthday-banding could represent an innovative solution to the biases introduced by fixed chronological age cut-off points. The absence of RAEs in squash suggests that sports which currently experience challenges related to RAEs might benefit from adopting a similar model, particularly those whose athletes experience significant developmental pressure at younger ages. Moreover, the flexibility inherent in birthday-banding could also be applied to coaching frameworks, where athletes are not categorised based solely on age but rather on their readiness to perform at various competitive levels (e.g., playing-up and playing-down). By reducing biases related to RAEs, birthday-banding could create more fluid pathways to development, especially in sports where early maturation often provides an advantage. In addition to birthday-banding, it is also important to acknowledge other possible

approaches to group athletes. For example, bio-banding can be used to reduce maturation-based inequalities by grouping athletes according to biological markers or distributing opportunities more equitably across the year (53, 54). Research has shown that stakeholders perceive these models as beneficial for talent development and psychological engagement (55). While the implementation differs from birthday-banding, the underlying rationale is similar, by ensuring fairness and developmentally appropriate environments throughout youth sport pathways (56).

How the coaches viewed birthday-banding, through its operational mechanisms and the associated player development outcomes (i.e., environmental, individual, organisational) aligns with Kelly et al.'s (15, 51) proposal that the Personal Assets Framework (PAF) is a useful model with which to explain the potential mechanisms of RAEs on youth development. According to research in developmental and sport psychology, the PAF identifies three essential "dynamic elements" necessary for sport development to take, including: (a) personal engagement in activities (i.e., the what), (b) appropriate settings and organisational structures (i.e., the where), and (c) quality social dynamics (i.e., the who) (57, 58). The interactions of these elements create an immediate sporting experience that can impact developmental outcomes in the short-term, such as character, confidence, connection, and competence (i.e., the 4Cs), as well as participation, performance, and personal development (the 3Ps) in the long-term. The PAF, therefore, could perhaps be used as a heuristic to help frame discussions regarding the mechanisms of RAEs as well as attempted solutions (e.g., birthday-banding) at mitigating this (un)conscious bias.

Limitations and future directions

Although the current study provides important insights into the potential mechanisms that underpin birthday-banding, it is not without limitations. First, the sample size of 15 coaches, while offering valuable perspectives and a large proportion of coaches in the England Squash Talent Pathway, may not fully represent the diversity of coaching experiences. Future research could expand this sample to include more coaches, female coaches, and other interest-holder such as the athletes themselves to provide a more comprehensive understanding of the approach's impact. Additionally, while the qualitative nature of this study allowed for an in-depth exploration of coaches' perceptions, it would be valuable to investigate the tangible outcomes of birthday-banding in terms of performance metrics, injury rates, and long-term player retention. Quantitative data could offer more empirical evidence to support the efficacy of this approach. Future studies could also compare the outcomes of players within the birthday-banding system against those in traditional age-based groupings to more rigorously evaluate the impact on player development. Importantly, some coaches raised concerns with the ways in which birthday-banding can go wrong. These concerns were compiled as a way to provide a critical evaluation of the approach, and suggestions have been made on ways to minimise their impact on the system, to further improve the birthday-banding approach.

Although our findings suggest birthday-banding could be beneficial for squash in England, its transferability may vary significantly depending on the sport and country. In disciplines with high early-specialisation, dense competition calendars, or where ranking-based selection is predominant (e.g., football, gymnastics, swimming), the effectiveness and feasibility of birthday-banding may be constrained. For instance, Pérez-González et al. (59) have demonstrated varying relative age magnitudes across European women's football leagues, highlighting how institutional structures and competitive density influence relative age dynamics. This suggests that birthday-banding should be applied with caution and adapted to sport-specific environmental and organisational contexts.

Conclusion

Generally, sport policy makers are largely responsible for RAEs, due to the group banding policies that are often implemented within youth sport. As decision-makers, and stakeholders in youth sport, we have the capability and responsibility to look beyond fixed age group structures to try and create more developmentally appropriate settings for every young person to achieve their potential. With this in mind, coaches from England Squash offered a unique insight into their birthday-banding approach, showing the possible environmental, individual, organisational benefits. This study also contributes to the growing body of literature on RAEs and provides novel insights into how birthday-banding can help mitigate these biases in the England Squash Talent Pathway. By shifting away from traditional age-based groupings and focusing more on developmental milestones, birthday-banding appears to foster a more equitable, flexible, and holistic approach to athlete development. The coaches in this sample perceived the birthday-banding approach to be an easy-to-implement way of creating an ability-focused environment that affords more opportunities to athletes to experience challenge and success throughout the developmental pathway. While further research is needed to confirm the long-term effectiveness of this approach, the current findings suggest that birthday-banding may be a valuable solution, not only for squash, but also for other sports seeking to address RAEs and optimise their talent development systems.

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 Health, Education, and Life Sciences Faculty Academic Ethics Committee at Birmingham City University (reference code: #3293). 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

AK: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. AS: Formal analysis, Methodology, Writing – original draft. KJ: Writing – original draft. JB: Writing – review & editing. MF: Data curation, Methodology, Writing – original draft. MJ: Conceptualization, Data curation, Methodology, Writing – review & editing. JT: Conceptualization, Data curation, Methodology, Writing – review & editing. AM: Supervision, Writing – original draft.

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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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Relative age effects and player pathways in international ice hockey: a longitudinal multi-cohort analysis

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Introduction: Past research shows that relative age effects (RAEs) are highly prevalent in ice hockey. Early-born players benefit from more exposure, especially in the early stages of development, and are frequently considered "more talented." Although RAEs are apparent in these early stages, little is known about how it affects pathways leading to the highest levels of competition. This study aims to look more closely at the associations between RAEs and players' career trajectories in 4 hockey nations: Canada, Finland, Czechia, and Slovakia. Specifically, it aims to: (1) evaluate the prevalence of RAEs in each country, (2) identify players' career pathways and examine the impact of RAEs on the players, and (3) compare these effects for each nation.

Methods: Data were drawn from 4,306 players (100% males born between 1992 and 2002), who were invited to national development and selection camps between 2009 and 2019. Trajectory clusters were estimated from the players' participation in 8 career milestones, from U17 to representation of their country at the Olympic Games. Group comparisons were conducted based on birth quartiles and hockey nations.

Results: The results confirmed the presence of RAEs in the four hockey nations. Consistent with past research, early-born players are overrepresented in the early career stage, whereas late-born players begin to emerge during transition to junior level (U20). Some nation-specific differences were observed.

Discussion: This provides further support for the stakeholders of ice hockey association looking to enhance their national team selection processes and discover structuring pathways that offer development opportunities for all groups of players.

KEYWORDS

birth advantage, talent identification, long-term athlete development, competitive sport, high-performance, selection bias

Introduction

Talent identification has been an important topic of interest in sport science for many decades. Professional sports organizations and national governing bodies across sports invest substantial financial and human resources in the search for players who can offer the team a competitive advantage. However, there is still a great degree of uncertainty when it comes to answering questions about the projected potential of any athlete (Baker et al., 2018). Plenty of

examples across different sports point to players who are overlooked as junior athletes, then go on to become break-through success stories (Costello, 2022; Grella, 2023), which suggests that the timing of selections is crucial.

Despite the importance of such selections, many of these processes use pre-determined cut-off dates for player invitations to such events. Selected players can benefit from increased exposure including national/international and showcase-type tournaments. In a longer-term perspective, these athletes are described as more gifted in the earlier stages of development, which offers them opportunities to attain the next echelons of competition (Webdale et al., 2020). Among the factors influencing timing in selection processes are relative age effects (RAEs). RAEs describe the significant and often problematic consequences that arise from the common practice of grouping youth for participation and competition in sport based on chronological age, typically within one-year or two-year bands defined by arbitrary cut-off dates (Webdale et al., 2020). This organizational structure frequently leads to an over-representation of athletes born shortly after the cut-off date (i.e., the relatively older within their cohort) and an under-representation of those born later in the selection year (Webdale et al., 2020). This phenomenon has been documented across a wide array of sports (Bilgiç and Işın, 2023), starting from the seminal studies by Grondin et al. (1984) in ice hockey and volleyball and ice hockey specific conclusions from Barnsley et al. (1985). However, the expression and strength of RAEs are not uniform; they vary considerably across different sporting contexts and are influenced by a multitude of interacting factors including particular sport's popularity, specific physical or cognitive demands of the sport, the competitive level, gender, and the particular age categories in question (Schorer et al., 2020).

Historically, RAEs have often been attributed primarily to the physical advantages, such as greater size and strength, that relatively older children may possess due to, on average, being more biologically mature than their chronologically younger peers within the same age group (Towlson et al., 2022). However, a substantial and growing body of evidence challenges this predominantly maturation-based explanation, suggesting instead that RAEs and biological maturity selection biases, while potentially related, are largely distinct and independent constructs (Towlson et al., 2022; Fitzgerald et al., 2024). Biological maturation selection bias refers to the preferential selection or deselection of individuals based on their advanced or delayed biological development, often irrespective of their birth date (Hill et al., 2020). This bias typically emerges with the onset of puberty, around 11–12 years of age, and its influence can increase as athletes progress through adolescence (Towlson et al., 2022; Fitzgerald et al., 2024; Hill et al., 2020). In contrast, RAEs are observable much earlier in an athlete's development, often in pre-pubertal children as young as 6–8 years old, a period when maturational differences in physical attributes are less pronounced as selection factors (Fitzgerald et al., 2024; Hill et al., 2020). Recent research in sports like soccer and Gaelic football further underscores this distinction, revealing weak or non-significant correlations between an athlete's relative age and their actual biological maturity status within academy settings (Towlson et al., 2022; Fitzgerald et al., 2024). This indicates that relatively older players are not necessarily the more biologically mature individuals in their cohort (Towlson et al., 2022; Hill et al., 2020).

This critical distinction necessitates a broader and more nuanced conceptualization of RAEs, viewing them as phenomena that extend beyond mere physical-maturational advantages (Towlson et al., 2022). In early childhood, for instance, RAEs may be more reflective of age-associated differences in neural development, cognitive skills, motor coordination, and the sheer volume of experience or practice time accumulated (Towlson et al., 2022; Hill et al., 2020). Furthermore, the initial, perhaps small, advantages afforded by relative age can be amplified by a cascade of secondary benefits on their developmental journey (Wattie et al., 2015). Athletes who are relatively older, and thus potentially perceived as more competent or "talented" early on, often receive greater expectancies, more positive feedback, increased attention from coaches, enhanced access to superior training resources, more significant playing opportunities, and higher quality coaching (Schorer et al., 2020; Hill et al., 2020; Lemoyne et al., 2023). This differential investment and experience can create a self-fulfilling prophecy, widening the gap between relatively older and younger athletes over time (Hancock et al., 2013). Conversely, relatively younger or later-maturing athletes, even if possessing high potential, face a greater risk of deselection and dropout, thereby missing crucial developmental opportunities (Towlson et al., 2022). Therefore, it is imperative to consider relative age and biological maturation as independent, though potentially interacting, influences within talent identification and development systems. Each of them likely requires distinct consideration and targeted mitigation strategies, implemented at appropriate developmental stages (Towlson et al., 2022; Fitzgerald et al., 2024).

As cited previously, Grondin et al. (1984) foundational work significantly advanced the understanding of RAEs. Subsequent research has confirmed and expanded on these findings. Lemoyne et al. (2023), for instance, revealed that RAEs are prevalent in most of the senior world's top competitive ice hockey leagues. Furthermore, many authors also reported that RAEs were present in younger cohorts of competitive hockey players (Bruner et al., 2011; Niklasson et al., 2024; Lavoie et al., 2015; Lemoyne et al., 2021; Huard Pelletier and Lemoyne, 2022; Huard Pelletier and Lemoyne, 2024). It was suggested that the selection of players who appear more developed early on (often relatively older) is predicated on the motivation in finding individuals who are cable to perform on rather short-term basis (i.e., performance at the U16 or U17 tournaments) instead of focusing on athletes' long-term projected potential (Niklasson et al., 2024; Sherar et al., 2007; Wattie et al., 2007). As a result, RAEs are likely to have an impact on gatekeeping in elite-level ice hockey like the National Hockey League and/or other levels of competition (Wattie et al., 2007; Fumarco et al., 2017; Deaner et al., 2013; Baker and Logan, 2007), although the accuracy of drafting-process decisions across sports has been questioned (Johnston et al., 2022).

In contrast, relatively younger players face some adversity, requiring them to adapt to the competitive system in which they develop as athletes. In this kind of developmental ecosystem, these players must compensate or *adapt to survive* (Baker and Johnston, 2024; Bruineberg et al., 2024). Two paradigms suggest how they adapt to the context shaped by RAEs. The first explanation, the psychological, stipulates that athletes born in the latter part of the selection year must develop stronger psychological assets (i.e., resilience, adaptability, grit) to overcome the disadvantages sometimes associated with their relative age. This hypothesis is supported in ice hockey by undrafted NHL players (Herbison et al., 2019), who are categorized as "sleepers," whose talent tends to appear in the later stages of their career (Fortin-Guichard et al., 2023). The second explanation, the *biological-athletic*, suggests that to "survive" the selection biases associated

with RAEs, relatively younger athletes may need to exhibit superior athletic skills predisposing them to adapt and excel in highly competitive contexts (McCarthy et al., 2016). Both explanations are plausible, and both may explain RAEs reversal in the later stages of the athlete's pathway.

The reversal effects of RAEs stipulate that players born later in the year tend to equal or surpass those who were born earlier in the year at some point in their career trajectories. Despite the presence of RAEs at the junior level, many studies support the mechanisms underlying their reversal effects at the elite level (Lemoyne et al., 2023; Niklasson et al., 2024; Fumarco et al., 2017; Bezuglov et al., 2020). To date, however, it is not clear at what stage the reversal does begin to be such evident at the senior elite level (Steingröver et al., 2016). Schorer et al. (2020) highlights the need for studies to take a more longitudinal look at RAEs with recent examples from soccer (Brustio et al., 2024), handball (Schorer et al., 2025) and table tennis (Faber et al., 2020).

Hereby, this study takes a deeper look at the multi-cultural junior national team pathways leading to the highest levels of senior competition in ice hockey. The overarching aim of this article is to explore how RAEs relate to pathways leading players to the highest levels of competition in ice hockey. To achieve it, there are three objectives. The first objective is to evaluate the presence of RAEs in the selection processes of national teams in four countries: Canada, Czechia, Finland, and Slovakia. The second objective is to examine how RAEs relates to elite hockey players' pathways to excellence from junior to senior national teams to estimate the phase where RAEs begin to reverse. The third objective of this study is to compare if RAEs and players' pathways differ within and between hockey nations under study.

By examining the national team pathways of athletes in four nations, it refines our understanding of the pathways of athletes selected and/or de-selected across junior national team cohorts by evaluating their career trajectory clusters. Our hypothesis is based on the past and current literature on RAEs. We suggest that RAEs will be stronger in the early stages of career pathways, such as invitations to U17 and U18 national team camps. In line with Lemoyne et al. (2023), we suggest that the presence of RAEs will be similar across nations. Regarding the second objective, we expect to find some support for RAEs reversal at later stages of development (i.e., the professional level). We anticipate, consistent with this hypothesis, some transitional effects of RAEs related to the appearance of late-born players later in the process leading to national team selections.

Methods

Sample and data collection

Data were collected from male junior athletes who attended development or selection camps for junior national teams in four countries (Canada, Czechia, Finland and Slovakia), where ice hockey is a major winter team sport. Despite the popularity of ice hockey in these nations, there are still disparities in terms of registered players over 18 years of age [n_{Canada} = 132,169; $n_{Czechia}$ = 6,622; $n_{Finland}$ = 23,028; $n_{Slovakia}$ = 3,332] (International Ice Hockey Federation, 2025, p. 63–64), which justifies the relevance of analyzing RAEs in such different development systems. The full sample for each nation includes players born between 1992 and 2002 who took part in national team development and selection camps, from invitation/selection of their national team for the World U17 Hockey Challenge (WU17), the World U18 Hockey Challenge (i.e., Hlinka Gretzky Cup), world junior championships (WJC), world hockey championships (WHC) and the Olympic Games (OG). Since playing in the National Hockey League is a key phase in hockey players' careers, the players' NHL draft status was considered a major indicator of their achievement. The professional career was tracked for 3 years following the last year of eligibility to perform at WJC (U20). This period was characterized by the NHL draft and performance in games at the international level (i.e., world championships and Olympic Games). We collected data from the websites of the national governing bodies of each nation and cross verified using open-source data from the *eliteprospects.com* website. When data was missing, we approached the ice hockey association of the respective nation to collect the missing data. The data collection and handling were conducted in strict compliance with general data protection guidelines. We safeguarded the identities of the participants included in this study and provided full confidentiality when reporting results.

Variables

Birth quartile

We calculated birth quartile from the raw data available in each database. All birthdates were coded into birth quartiles (Q1 to Q4) based on the categories commonly used in ice hockey (International Ice Hockey Federation, 2025): (1) Q1: January to March; (2) Q2: April to June, (3); Q3: July to September; and (4) Q4: October to-December. As recommended by Delorme and Champely (2015), we checked to see if birth distributions were different in each country. Because of the prospective nature of our data, birth distributions were verified for each country for the period 1990–2002 by consulting the demographics and population statistics on each nation's website. After verifying birth month distributions during this period, we observed no significant difference relative to birth month (proportions varying from 23 to 26% per quartile for each nation).

Quantifying hockey players' career pathways

We defined the type of trajectory (or career pathway) by identifying players' participation (or not) in eight stages of achievement in terms of national team selections and the NHL draft. As mentioned previously, the information was collected by extracting data from the websites and archives of each of the national governing bodies, with the addition of Open Access Internet Archive.[1,2] First, we divided each stage of the hockey pathway based on player participation at each achievement milestone (*no* = 0; *yes* = 1). Second, we constructed a progressive trajectory starting with an invitation to a U16 national camp for the Europeans and a U17 national evaluation camp for the Canadians. To make all samples comparable, we chose U17 invitation camps as the first stage of players' pathway (1st milestone) since there is no U16 invitation to national camps in Canada (no data available). This was followed by an invitation to U18 national camps (2nd milestone) and selection and participation in the U18 Hlinka Gretzky Cup (3rd milestone). The following stages included invitation to U20 national teams (4th milestone) and

1 https://eliteprosects.com

2 Hockey Canada website.

participation in the World Junior Championships (5th milestone). The three final milestones were recorded as the final stage of players' trajectories. We chose the NHL draft status as 6th milestone because it usually occurs before national teams are invited to World Hockey Championships (7th milestone) and the Olympic Team (8th milestone) in the 3 years following the last year of U20 eligibility. The final database consists of 8 dichotomous variables (e.g., stages of achievement), which characterize the different types of career patterns.

Factor analyses were used to establish cut-off values for quantifying career pathways. Because of the exploratory nature of this study (and the resulting data), we chose Principal Axis Component as the analytical procedure. Given the (high) number of occurrences and potential variability for each career milestone, eigen values were fixed at 1.0 for dimension extraction. We also used varimax rotation to allow for factorial data structure; this is the appropriate procedure when anticipating uncorrelated indicators. Preliminary results were analyzed by evaluating the Kaiser-Meyer-Olkin (KMO) measure of adequacy, which was deemed satisfactory (KMO = 0.755). As a second step of our analysis, we determined the number of factor components by observing eigen values greater than 1.0. We also considered a scree plot to verify support for a three-component factorial structure.

The first factor (EV = 1.355) was defined as *early success* and includes three career milestones: U17 development camp (for all samples), invitation to U18 national camps, and participation in the U18 Hlinka Gretzky Cup. These loading components were strongly associated with their corresponding factor ($\lambda_{U17} = 0.793$; $\lambda_{U18inv} = 0.773$; $\lambda_{U18wc} = 0.638$). The second factor (EV = 2.949) was conceptualized as *junior transition* and includes three indicators considered career milestones: U20 invitation, U20 WJC, and NHL draft. Indicators around this dimension were correlated and displayed significant loadings ($\lambda_{U20inv} = 0.810$; $\lambda_{U20wc} = 0.838$; $\lambda_{NHL} = 0.597$). The third factor (EV = 0.950) was the *senior international pathway* and includes two career milestones: WHC participation and participation in the Olympic Games. Both indicators displayed strong loadings with their corresponding factor ($\lambda_{WC} = 0.638$; $\lambda_{OG} = 0.630$). After establishing this three-dimension factorial structure, factorial scores were calculated based on the regression method (Distefano et al., 2009). We then standardized factorial scores through z-transformation for each pathway. These scores attributed to each player reflect an overview of the dominant component of their career trajectories. They were then used for group comparisons and to verify the effects of RAEs on players' pathways.

Statistical analyses

To meet this study's first objective (presence of RAEs), which consisted of evaluating the presence of RAEs across sub-samples, we conducted crosstabs analyses by calculating the chi-square (χ^2) statistic for the full sample. We also compared RAEs prevalence in each nation to determine if RAEs proportions differ according to the hockey nations where players evolved. We used Cramer's V to interpret the strength of association related to RAEs and interpreted values as weak ($V = 0.10$), moderate ($V = 0.10$–0.30) or large ($V > 0.30$) (Cramér, 1999).

As for the second objective of the study (RAEs and players' pathways), we proceeded in two phases. First, we observed how the proportions of Q4 born players fluctuate at each milestone (e.g., from U17 to NHL). We excluded World Championships and Olympic Games numbers because there were too few observations, which would have potentially inflated the proportions for some countries. To proceed, we first applied Anscombe transformation on proportions and performed Analysis of Proportion using Arsine Transform (ANOPA). ANOPA, similar to classic analysis of variance (ANOVA), is designed for analyzing proportions as continuous variables (Laurencelle and Cousineau, 2023). To analyze the fluctuations of proportions, we tested monotonic variation which allows to see if variation is linearly significant. To base our interpretations, we used the coefficient of monotonicity (from 0 to 1) for the full sample (Laurencelle, 2021) and observed variation for each nation.

For the second phase of analysis (e.g., comparing pathways trajectories), we performed one-way ANOVA by comparing the factor scores. Due to potential violation of normality assumptions, we performed Bootstrapping ($n = 1{,}000$ iterations). We conducted *post hoc* analyses (with Bonferroni correction) in cases where differences were deemed significant. The magnitude of effect sizes was also interpreted according to eta-square values (η^2), as small ($\eta^2 < 0.01$), moderate ($\eta^2 = 0.06$–0.14), and large ($\eta^3 > 0.15$) (Cohen and Cohen, 1983).

Results

As Table 1 shows, an average of 391 players per year represented their team in international events. Canada ($M_{CAN} = 101 \pm 17$) and Finland ($M_{FIN} = 147 \pm 39$) tend to invite more players to national team camps, compared with Czechia and Slovakia who displayed lower numbers ($M_{CZE} = 76 \pm 9$; $M_{SVK} = 6 \pm 7$).

Objective 1: examining presence of RAEs in the international context

Figure 1 shows the proportions of players from each country in terms of birth quartiles. Generally, we observed similar tendencies in each sub-sample where Q1 (39%) and Q2 (29%) players were strongly represented, as compared with Q3 (20%) and Q4 (12%). In fact, RAEs are present across all samples [$\chi^2_{(df)} = 719.16_{(3)}$, $p < 0.001$, Cramer's $V = 0.24$] where Q1 and Q2 born players were predominant (68%). RAEs were observed in all sub-samples, with significant chi-square values and moderate to large effect sizes ($\chi^2_{CAN} = 352.85$, $p < 0.001$, Cramer's $V = 0.97$; $\chi^2_{CZE} = 86.58$, $p < 0.001$, Cramer's $V = 0.55$; $\chi^2_{FIN} = 297.72$, $p < 0.001$, Cramer's $V = 0.74$; $\chi^2_{SVK} = 45.67$, $p < 0.001$, Cramer's $V = 0.43$).

However, some nation comparisons revealed significant differences [$\chi^2_{(df)} = 70.73_{(9)}$, $p < 0.001$]. As Figure 2 illustrates, the Canadian sample displayed a higher proportion of Q1 born players (46%) compared to the European nations (between 32 and 38%). In addition, lower proportions of Q4 players were observed for Canada and Finland (9 and 11%), whereas the proportion of Q4 players was slightly higher across Slovakia and Czech samples (e.g., 14 and 18%). Cramer's V was deemed small ($V = 0.08$, $p < 0.001$), suggesting small differences across countries.

Objective 2: RAEs and players' pathways

The second objective was to determine the impact of RAEs on players' career trajectories. Table 2 provides a descriptive overview of

TABLE 1 Birth cohorts: the full sample (from available data).

Cohort (birth year)	Total (*n*)	Canada	Czechia	Finland	Slovakia
1992	447	104	81	193	69
1993	426	107	69	188	62
1994	469	105	74	214	76
1995	426	91	77	188	70
1996	385	117	78	134	56
1997	324	76	63	121	64
1998	329	83	70	117	59
1999	336	76	72	121	67
2000	397	116	98	119	64
2001	380	120	72	112	76
2002	387	123	82	117	65
Total	4,306	1,118	836	1,624	728

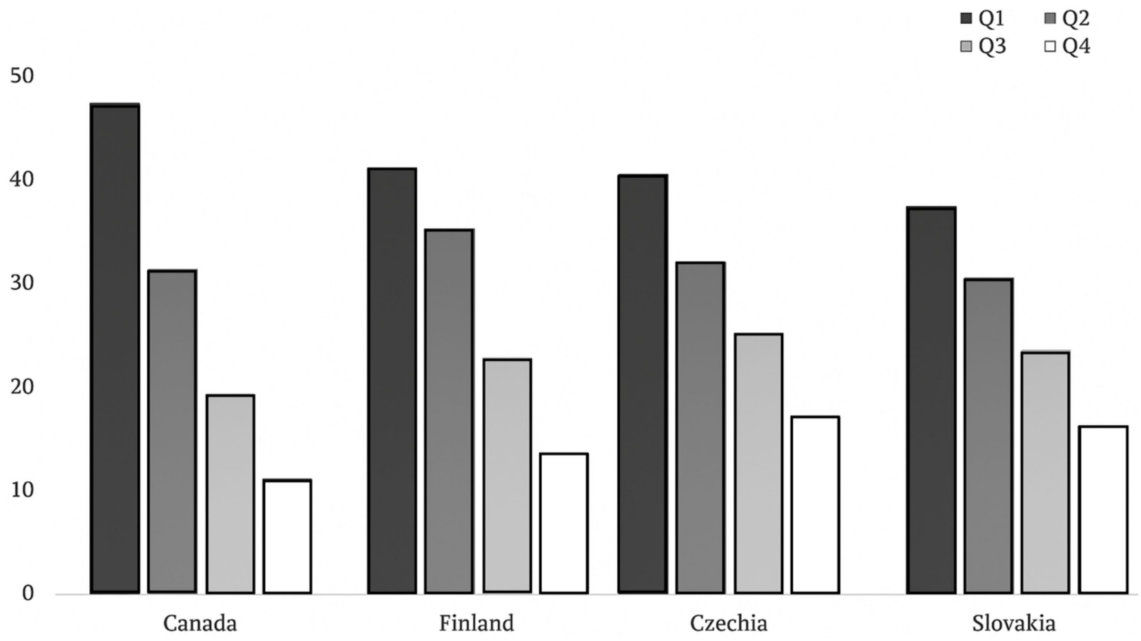


FIGURE 1
Birth quartiles patterns for each nation.

the presence of late-born players (Q4) at each stage of career milestones. Results from monotonic variation test suggest a linear increase (from U17 to the attainment of the NHL): Monotonic variation coefficient = 0.93; $p < 0.01$. When we compared nations separately, Canada and Czech fluctuations were not monotonic (Spearman $r_{CAN} = 0.83$; Spearman $r_{CZE} = 0.54$, $p > 0.10$), whereas those of Finland and Slovakia increases were linearly significant (Spearman $r_{FIN} = 0.95$; Spearman $r_{CZE} = 1.00$, $p < 0.001$).

As Figure 3 depicts the career trajectory patterns, Table 3 shows the associations between RAEs and factorial scores for the full sample (e.g., including all nations). Results reveal a significant RAEs for two factors: Factor 1 (*early success:* $F_{early} = 3.73$, $p < 0.011$). and Factor 2 (*junior transition:* $F_{junior} = 11.21$, $p < 0.001$).

In line with RAEs hypotheses, comparisons regarding Factor 1 (e.g., *early success*) show that early-born players (e.g., Q1) have higher scores than Q3 and Q4 players: $\Delta > 0.04$–0.22, $p < 0.05$. These differences were also interpreted as small ($\eta^2_{early} = 0.003$). For Factor 2, *post hoc* analyses of birth quartiles show that late-born players (Q4) display higher scores (e.g., *junior transition*) than players born in the previous birth quartiles: $\Delta > 0.17$–0.36, $p < 0.001$. Despite its significance, we interpreted the magnitude of this difference as small ($\eta^2_{junior} = 0.008$). We found no significant differences for Factor 3 (e.g., *senior international pathway*): $F_{int} = 1.51$, $p = 0.21$, $\eta^2 = 0.001$.

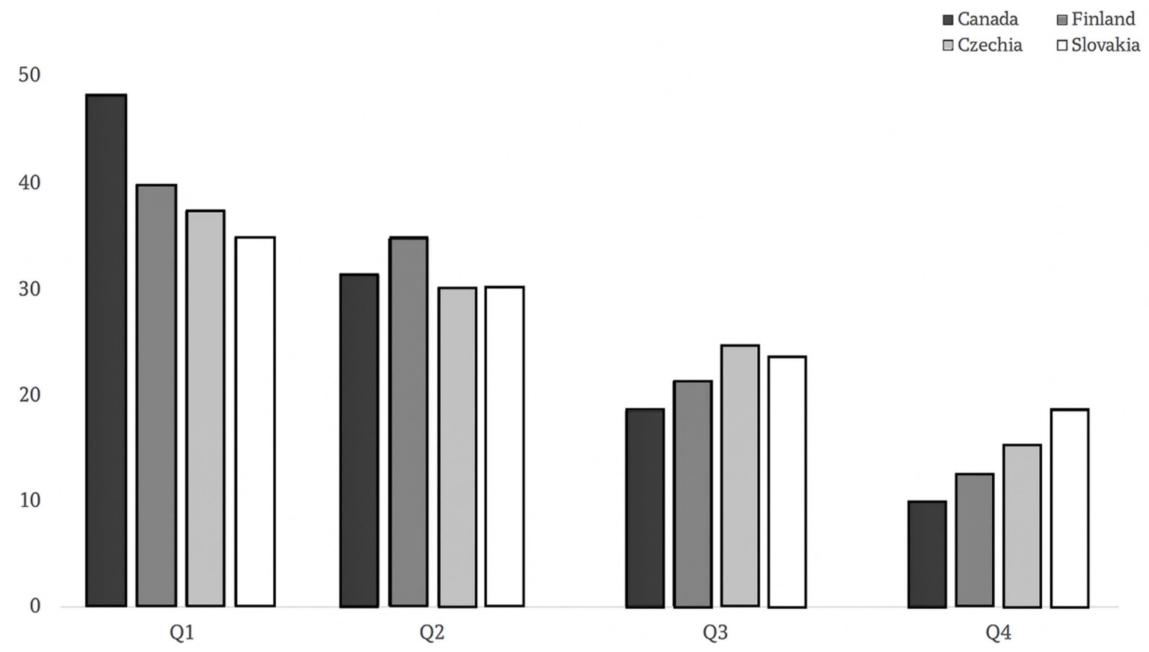


FIGURE 2
Proportions of players from each birth quartile according to nations.

TABLE 2 Proportions of late-born players (Q4) across each career milestone.

	Career milestones							
Nation	U17	$U18_{inv}$	$U18_{HC}$	$U20_{inv}$	WJC	NHL	WC	OG
Canada	69 (7%)	27 (6%)	11 (5%)	37 (15%)	21 (11%)	50 (11%)	18 (17%)	5 (41%)
Czechia	71 (14%)	65 (14%)	29 (17%)	58 (18%)	30 (19%)	10 (14%)	3 (17%)	0 (0%)
Finland	56 (10%)	47 (13%)	21 (13%)	48 (14%)	26 (15%)	21 (15%)	10 (17%)	1 (6%)
Slovakia	61 (14%)	74 (19%)	37 (19%)	61 (21%)	37 (22%)	6 (22%)	11 (34%)	3 (42%)

Values represent proportions of players who achieved each career milestone in numbers (n) and (%). Numbers represent proportions of late-born players who took part in the corresponding milestone in the years following their eligibility to U17 national camps. Milestones descriptions: U17: U17 national camp; $U18_{inv}$: invitation to national U18 camp; $U18_{HC}$: participation in Hlinka Gretzky Cup; $U20_{inv}$: invitation to national junior team camp; WJC: World junior championships; NHL: drafted in National Hockey League; WC: World senior championships; OG: Olympic Games.

Objective 3: nation comparisons: RAEs and career pathways

ANOVA results suggest that some nation-related differences prevail concerning RAEs on players' pathways (see Table 3). Analyses regarding Factor 1 (e.g., *early success*) show support for RAEs in the Canadian sample: $F_{early\text{-}Can} = 9.17$, $p < 0.001$, $\eta^2 = 0.024$. However, no such effects were observed in the European countries: $F_{early\text{-}Cze} = 0.36$; $F_{early\text{-}Fin} = 0.27$; $F_{early\text{-}Svk} = 0.88$, all at $p > 0.45$. This means that despite the greater representation of Q1 players in terms of proportions, there is no RAEs on the *early success* component of European players' pathways. For Factor 2 *(junior transition),* we observed significant effects for three countries: $F_{Can} = 3.35$, $p = 0.018$, $F_{Fin} = 4.19$, $p = 0.006$; $F_{Svk} = 3.90$, $p = 0.009$. *Post hoc* analyses showed that Q4 players tend to surpass Q1 players at this specific stage of development. However, there were no RAEs in Czechia's sample: $F_{Cze} = 1.17$, $p = 0.17$. For Factor 3 (senior international pathways, we found no significant differences in regard with birth quartiles: $F = 0.1.51$, $p = 0.21$; $\eta^2 = 0.001$. When we compared each nation separately, Q4 players displayed higher scores than the three other birth quartiles: $F = 8.51$, $p < 0.001$, $\eta^2 = 0.022$ (Table 4).

Discussion

This study first aimed to evaluate whether RAEs are present among a cohort of junior players in Canadian, Finnish, Slovakian and Czech national teams. Our second objective was to examine how RAEs relate to elite hockey players' pathways to excellence from junior to senior national teams and estimate the phase where RAEs begin to reverse.

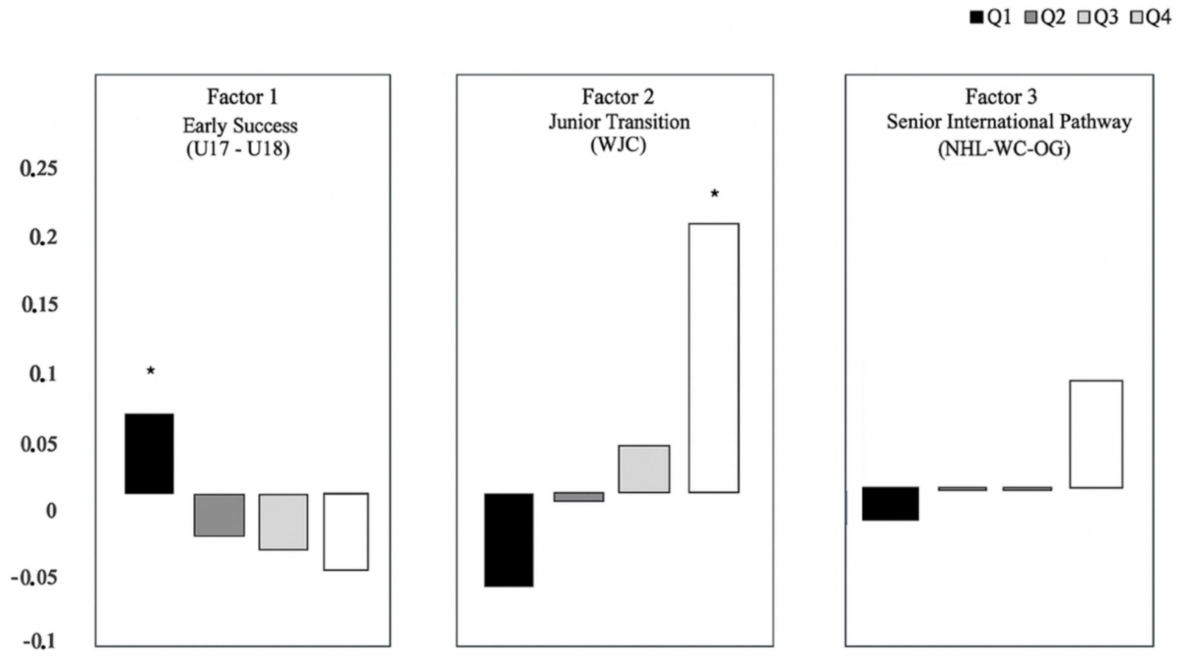


FIGURE 3
Birth quartile and early career trajectories (normalized factor scores according to birth quartile).

TABLE 3 RAEs and career achievement in elite hockey (standardized scores).

Career trajectories	Q1	Q2	Q3	Q4	Effects
F1	0.063 ± 0.98	−0.033 ± 1.01	−0.042 ± 1.01	−0.060 ± 1.02	Q1 > Q4*
F2	−0.075 ± 0.96	−0.005 ± 0.96	0.032 ± 1.04	0.210 ± 1.11	Q4 > Q1*
F3	−0.022 ± 0.86	−0.002 ± 0.91	0.003 ± 1.13	0.084 ± 1.39	No differences^{ns}

F1: early success; F2: junior transition; F3: senior international pathway. *$p < 0.001$: significant differences between quartiles.

TABLE 4 RAEs and career achievement in elite hockey by country.

Country		Q1	Q2	Q3	Q4	Effects
Canada (n = 1,118)	F1	0.324 ± 0.04	0.175 ± 0.05	0.100 ± 0.06	−0.144 ± 0.09	Q1 > Q3*, Q4**
Canada (n = 1,118)	F2	−0.027 ± 0.06	0.083 ± 0.07	0.222 ± 0.09	0.328 ± 0.127	Q4 > Q1*
	F3	0.183 ± 0.05	0.298 ± 0.06	0.167 ± 0.08	0.791 ± 0.11	Q4 > Q1, Q2, Q3**
Czechia (n = 836)	F1	0.312 ± 0.06	0.228 ± 0.06	0.292 ± 0.07	0.244 ± 0.09	No effects^{ns}
Czechia (n = 836)	F2	−0.011 ± 0.06	0.049 ± 0.06	0.019 ± 0.07	0.221 ± 0.07	No effects^{ns}
	F3	−0.193 ± 0.03	−0.200 ± 0.03	−0.149 ± 0.04	−0.247 ± 0.05	No effects^{ns}
Finland (n = 1,624)	F1	−0.385 ± 0.04	−0.400 ± 0.04	−0.441 ± 0.05	−0.397 ± 0.07	No effects^{ns}
Finland (n = 1,624)	F2	−0.153 ± 0.32	−0.132 ± 0.35	−0.076 ± 0.45	0.082 ± 0.06	Q4 > Q1**
	F3	−0.079 ± 0.04	−0.017 ± 0.05	0.035 ± 0.06	−0.040 ± 0.08	No effects^{ns}
Slovakian (n = 723)	F1	0.328 ± 0.07	0.304 ± 0.07	0.205 ± 0.09	0.172 ± 0.09	No effects^{ns}
Slovakia (n = 723)	F2	−0.066 ± 0.06	0.116 ± 0.07	0.038 ± 0.08	0.284 ± 0.09	Q4 > Q1**
	F3	−0.102 ± 0.07	−0.210 ± 0.08	−0.119 ± 0.09	−0.023 ± 0.09	No effects^{ns}

*$p < 0.05$; **$p < 0.01$. F1: early success; F2: junior transition; F3: senior international pathway.

The third objective of this study is to compare if RAEs and players' pathways differ within and between hockey nations under study. To this end, we quantified players' career trajectories by taking a deeper look at the different stages leading to professional and international careers and which involve three specific milestones: early success, transition to junior level and senior international pathway. By considering multiple career milestones at once, this analytical approach allowed us to verify the impacts of birth month on career achievement during early career stages, resulting in three specific observations that help shed light on talent selection (and development) in team sports. They include: the persistence of RAEs on the international stage, the impact of RAEs on career trajectories, and the presence of country-specific differences.

Observation 1: RAEs are (still) present on the international stage

As initially anticipated, results indicated that RAEs are present in all four hockey countries in our investigation, and are congruent with those of past research, suggesting that RAEs are highly prevalent in (popular) team sports like soccer and ice hockey (Lemoyne et al., 2023; Brustio et al., 2024). This prevalence is observed for the full sample, which confirms that early-born players (e.g., Q1 and Q2), representing nearly 70% of this sample, are predominant. Given that the data derive from an 8-year follow-up period of 11 birth year cohorts (2002–1992), this suggests that RAEs persist through time, a recognized fact for the last 40 years (Grondin et al., 1984; Barnsley et al., 1985). A few explanations support our results. First, we must consider the context in which the samples were selected. Considering the high number of players invited to U17 development camps (and U16 in European countries), we believe early born advantages may be inflated because of the need to perform (or stand out) early. Considering evidence from previous research in ice hockey (Lemoyne et al., 2023; Lemoyne et al., 2021), larger numbers of these types of players were expected. In fact, the byproducts of RAEs such as the complexity of interaction between physical, neural, psychological and cognitive development, play a major role in sports like hockey, and those with these developmental assets at an early stage of development is likely to possess a significant advantage over others (Lemoyne et al., 2021). Since the RAEs appear to be an enduring phenomenon in ice hockey, we consider these dynamics natural to some extent. The results of this investigation show that coaching staff and association's stakeholders tend, understandably, to prioritize assembling the strongest possible teams for international competitions, especially during the early stages of international tournaments (U17 and Hlinka Gretzky Cup). These actions then reinforce the presence of RAEs in international ice hockey despite many publications warning about this bias in player selection across sports (Cohen and Cohen, 1983) and particularly ice hockey. Hence, it could be argued that national ice hockey associations need to consider re-orienting the paradigm of player selection and development (Güllich and Barth, 2024).

Observation 2: RAEs impact career trajectories

The three trajectories identified in our analysis were affected by RAEs at different levels. The first factor (*early success*) included milestones regarding selection to U17 development camp (for all samples), invitation to U18 national camps, and playing in the U18 Hlinka Gretzky Cup. The second factor (*junior transition)* included three indicators we view as career milestones: U20 invitation, U20 WJC, and NHL draft. The third factor (*senior international pathway*) included two career milestones: WHC participation and participation in the Olympic Games. Our results are consistent with the hypothesis of RAEs reversal at later stages of development. This is supported by two key stages of players' pathways to the highest levels of competition. Accordingly, this study shows that successful transition to junior level may be the first stage when RAEs reversal (or fading) occurs. Late-born (Q4) players displayed higher scores in this crucial phase of development (U20 and NHL draft), so it appears they survived the RAEs. This RAEs reversal may be explained in part by late-born players' ability to adapt to and survive in a highly competitive environment (Fumarco et al., 2017; Steingröver et al., 2016). Inversely, a substantial proportion of early-born players (Q1, Q2) tend to lose these physical advantages, making it difficult for them to adapt to the next level. Results indicate that Q4 born players begin to emerge during the successful transition to junior level, which coincides with a time when the physical advantage may be less obvious, and other qualities such as skilled engagement with the puck, dexterity (movement problem solving; Bernstein, 1996), and psychological or perceptual-cognitive factors may come to the fore. Results for Factor 3 show no differences and offer additional support for RAEs reversal at the international stage (McCarthy et al., 2016). Indeed, no significant differences were observed for the birth quartiles. This means that even at early career stages (8-year timeline - from U17 to early participation in world class events), no advantages derive from birthdate. This suggests a reversal has already occurred earlier in the international career, which is likely the introduction to international junior hockey. Finally, our results support the presence of a clear advantage for early-borns (Q1) in terms of RAEs in the early stages of elite players' pathways (U17, U18), where Q1 players are over-represented. Labelled *early success*, the findings align with past research revealing that players born in Q1 have numerous advantages (neurological, cognitive, biological and psychological) over those born later in the year and may be the national team's preferred choice in the short term due to their physical maturity.

Observation of RAEs reversal during the years of junior transition leads to a call to action. First, we maintain that, rather than structure international pathways around the quest to win, decisionmakers should emphasize the creation/implementation of comprehensive player development programs (Wattie et al., 2015; Till and Baker, 2020). As it is crucial to acknowledge that winning alone is not necessarily a sign of success and knowing that reversal seems to occur during the key stage of junior transition, we should continue to think about finding ways to discover "latent" talent (Fortin-Guichard et al., 2023). In fact, involving larger number of players annually and increasing players' turnover by exposing them to high-level competitive environments may be a practice worth promoting. Based on our results, federation-led initiatives should be extended and reinforced at U17, U19, and even U21 level events. For example, international game breaks present an excellent opportunity to organize "shadow tournaments" or showcases for players not currently representing their country. In other contexts, special camps for these kinds of players (e.g., late-maturing, late-born) could be organized to allow them to overcome previous disadvantages. These approaches

would offer both players and governing bodies the opportunity to discover emerging talents, making the development pathway deeper and potentially more efficient.

Observation 3: international differences in RAEs patterns

Considering the unique constraints of each country in this study, it's important to consider the impact they have on the factors discussed here (Røsten et al., 2024). The predominance of Q1 players in the early stages of national team camps (in terms of proportion) was similar for each nation. Despite these similarities, we observed some different patterns regarding the effects of birth month on players' pathways. As for the *junior transition* factor, we note that late-borns displayed higher scores, which seems to correspond to the stage when they could overcome their previous disadvantage. Results indicate that this effect was stronger among the Finnish and Slovakian cohorts, whereas it was a tendency for Canadian players. A possible explanation is that the player pool, throughout the career pathway, provides more players invited to national events during the later stages of the junior national team pathway. A look at the Finnish sample size shows that despite the smaller total size of registered players, Finns tend to invite more players (relative to their number of available players) at this specific stage of development. No effects of RAEs were seen in the Czech sample, which could be due to a smaller pool of available elite players. Inversely, the RAEs on players' pathways was deemed significant at all stages in the Canadian sample. The strong RAEs on early success came as no surprise, considering the number of highly competitive players across the country. Additionally, the sociodemographic aspects of the organization of ice hockey in Canada are also to be considered explanations. Since Canada is a vast territory, it has multiple provincial branches that work in different contexts. Nevertheless, it was interesting to note the gradual disappearance of RAEs during the elite junior years, which is similar to international junior hockey and the NHL draft. These results must be taken into account in future to persuade stakeholders in highly competitive hockey that this is a crucial stage for the potential emergence of late born-players (Niklasson et al., 2024; Wattie et al., 2007).

Future perspectives

This study's findings underscore that the predominant trend in international junior ice hockey involves selecting early-born players at first national team selection events at the age of 15 or 16 (depending on the nation). Following the COVID-19 pandemic, the Finnish Ice Hockey Association decided to delay the time of first selection to the first national team (U16) by 7 months. The long-term impact of the decision has yet to be studied. For practical reasons, we believe an initiative of this kind should be encouraged as the foundational problem in the talent pathways is the practice of early selection itself. This premature filtering of athletes creates a systemic vulnerability to bias, where factors like RAEs and differences in biological maturation become primary determinants of success. These factors should not be viewed as the cause of the problem, but rather as prominent symptoms of a system fundamentally flawed by its focus on selection. When performance at a single moment is the primary criterion, the system inevitably favors athletes who are temporarily advantaged, leading to significant survivorship bias. Consequently, interventions such to mitigate these biases, while promising, are inherently limited; they attempt to manage the symptoms without confronting the underlying issue, which is the philosophical commitment to identifying talent through early selection.

Some nations have recently begun to integrate a U19 Challenger team to enlarge the pool of invited players to U20 training camps. Hence, a similar strategy could be adopted at earlier stages of development (U16, U17, U18), allowing young athletes to improve the different skills related to sport development. Every nation has its own constraints in terms of organizational constraints, yet more players in the national team pipeline would allow ice hockey governing bodies to expose greater number of athletes to better-quality coaching and training opportunities as well as a greater number of competitive games at the international level (Till and Baker, 2020).

Limitations and research recommendations

This study only covers the 3 years since the last year of eligibility to play in U20 international tournaments. Hence, future studies need to consider a more longitudinal trajectory and study athlete's pathways from the beginning to end of their playing career to obtain a more complete picture. We recognize, furthermore, that player development occurs mainly at the club level, but we only considered athletes' national team pathway. In the future, studies should take into consideration club or team level. It would allow us to acquire a more nuanced understanding of athletes' development years. This suggestion may apply more to the European cohorts owing to the structure of the club and competitions. Future research should also take into consideration players' performance and integrate relevant metrics to capture the potential gap between international and club level performance. Finally, while we looked at the outcomes of the selection decisions of junior national team coaches and scouts, we did not consider socio-cultural aspects such as the playing style preferences of each country and/or the national values that might impact decisions about the players (Røsten et al., 2024).

Conclusion

Although ice hockey shows overwhelming evidence of RAEs at the junior level and its reversal effects at the elite level (Lemoyne et al., 2023), the policy of sports governing bodies to "fight" this bias has changed minimally, despite some attempts to delay selection time. Therefore, we propose that a fundamental philosophical shift is required, moving away from a focus on early talent identification and toward a holistic, development-centered model. Adopting a different approach that recognizes individual and non-linear developmental pathways. The primary purpose of junior sport should be redefined as maximizing long-term development for all participants, not selecting the best performers early. By postponing high-stakes selection until athletes are older would diminish the impact of selection biases associated with RAEs and maturation. This paradigm shift necessitates a complete re-evaluation of youth sporting structures, from coaching pedagogy to the nature of competition, to create an environment that

prioritizes learning and growth over immediate results, ultimately ensuring a more equitable and effective pathway for talent development. Thus, we hope this work will help associations and professional sports organizations reflect on the possible competitive advantage to be gained from delaying the selection of athletes and broadening the pool of players to provide opportunities for the athletes born later in the year to flourish instead of dismissing them early on the pathway.

Data availability statement

The original contributions presented in the study are publicly available. This data can be found here: https://osf.io/u6xqr/?view_only=23e0e27faee74598833a5faba325b0cc.

Ethics statement

Ethical approval was not required for the studies involving humans because the data is from public databases (websites, access to data from different sport organizations). This is justified in the methods section. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements because the data is from public databases (websites, access to data from different sport organizations). This is justified in the methods section.

Author contributions

JL: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing. VB: Conceptualization, Data curation, Formal analysis, Resources, Validation, Writing – original draft, Writing – review & editing, Visualization. MS: Conceptualization, Data curation, Formal analysis, Resources, Supervision, Writing – review & editing, Investigation, Methodology, Validation.

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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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Age effects in NHL draftees: a data-driven review of a multi-dimensional concept

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Introduction: Relative age effects (RAEs) have been extensively documented in youth sports, where artificial age cut-offs create advantages for relatively older athletes throughout development. Despite four decades of research, these effects persist in many sports, particularly in ice hockey, where misaligned cut-off dates between developmental systems and professional selection create unique challenges. This study examines varying age cut-off dates, athletes' development trajectories and career outcomes in elite ice hockey.
Methods: Using one of the most comprehensive longitudinal datasets to date, the present paper also explores whether an "underdog effect" (i.e., where relatively younger athletes who survive selection barriers may achieve greater success) is present within the current sample of athletes. We analyzed the complete population of 10,485 NHL-drafted players spanning 44 years (1980-2024), examining birth quarter distributions, time to league entry, and career permanence (defined as playing ≥5 seasons and ≥268 games). Using Cox proportional hazards models and multinomial regression analyses, we investigated how birth quartile influenced player career trajectories while controlling for draft position, nationality, anthropometrics, and playing position.
Results: Results revealed that while relatively younger players were significantly underrepresented in the draft, those who were drafted demonstrated superior career trajectories. In standard analyses, Q4 players showed a faster time to enter the NHL after getting drafted (HR = 1.32, 95% CI = 1.15-1.52), and Q3 players showed significantly higher likelihood of achieving permanence (HR = 1.39, 95% CI = 1.10-1.75). When accounting for the September 15 draft cut-off (2005-2024), a "dual disadvantage" was identified within the sample, with Q3 athletes showing the strongest effects, with 61% higher likelihood of achieving permanence (HR = 1.61, 95% CI = 1.27-2.05).
Discussion: These findings support the "underdog hypothesis," suggesting that relatively younger athletes who overcome systemic disadvantages develop compensatory skills that enhance long-term performance. Future athlete development systems should consider implementing strategies such as bio-banding or "future teams" to better support relatively younger athletes, potentially increasing talent retention across the entire player pool.

KEYWORDS

relative age effect (RAE), ice hockey, national hockey league (NHL), athlete development, player selection

1 Introduction

The process of athlete development is complicated and complex; complicated in the sense that it involves many variables, across multiple domains (e.g., physical, psychological, cognitive, social, and environmental variables), and complex in the sense that these variables interact in a continuous, generally progressive way that advances over time. While researchers are only beginning to understand the web of interactions among these influences, those responsible for the delivery of sport to young athletes are tasked with developing strategies and policies to provide environments that are balanced and equitable for the greatest proportion of athletes. One of the ways in which sport systems have tried to do this is through the use of age-based standards for competition, training, and evaluation. In nearly all sports, it is the norm for athletes to compete against similarly aged peers throughout their development. On the face of it, this approach is reasonable and clearly intended to minimize differences between athletes as they age, mature, and learn. Moreover, it recognizes that the needs of athletes change as they develop (e.g., the requirements to keep a 7-year-old flourishing in a sport are different from those of a 17-year-old). To group athletes based on age, sports typically establish "cut-off" dates or "league ages" (i.e., setting a cut-off date of January 1 for an Under-13 [U13] team, means all athletes must be younger than 13 years as of Jan 1).

In the context of ice hockey, these age-based systems vary considerably depending on the country, and region within the country. In North America, and specifically in ice-hockey, athletes regularly participate in youth organizations until they reach high school, where diverging pathways begin (1). As an athlete progresses through the system, the available pathways become greatly impacted by location. For example, ice hockey players in Ontario, Canada will play at the under 16 AAA level in their age-16 season, leading up to the Ontario Hockey League draft. In contrast, an athlete born in Minnesota, USA, may primarily participate in Minnesota high school hockey at that same age. In both of these systems, there is an age cut-off which determines the minimum and maximum age for athletes to participate in. In Canada, the current standard for youth representative (i.e., rep league) hockey (which includes the highest levels a youth hockey player can participate in) includes athletes born between January 1st and December 31st of the same calendar year eligible to play on the same team.

Despite their prevalence, past research has emphasized several limitations associated with arbitrary cut-off dates as the standard for grouping individuals into cohorts for instruction and learning (2). Maturity-related biases, for example, reflect the tendency for differences in biological maturation between players in the same cohort/team to affect how players perform, and how they are evaluated (3, 4). These biases focus on how differences in rates of biological maturation between individuals affect performance on relevant tasks (e.g., early vs. later maturing players in assessments of speed, power, or endurance) (5).

Relative age biases, on the other hand, focus on how the cut-off dates used to group young athletes into age groups create artificial, but meaningful, divisions between the relatively oldest (those born nearest the date used for grouping) and the relatively youngest (born furthest from this date). The earliest relative age effects were identified in ice hockey by Grondin et al. (6) and Barnsley et al. (7), who found that relatively older players were more likely to be successful compared to relatively younger players. Since these initial studies, similar effects have been noted in many countries and several sports [see (2) for a review]. These effects have been impressively consistent over the past four decades [see (8, 9) for historical examinations of ice hockey and soccer, respectively] and difficult to eliminate (10). Moreover, what appears, on the surface, to be a relatively direct effect of an arbitrary date used for administrative purposes, is actually a multi-faceted series of effects [e.g., (11)] affecting different sports in nuanced ways [see (12, 13)].

Despite over 40 years of research in this area, most work has been rather straight-forward, providing breakdowns of birth rates in elite or highly skilled samples over 6-month (half years) or 3-month (quartiles) categories, compared to estimates of an expected distribution (normally an equal distribution of births across the year). Typical relative age effects show a decrease in the proportion of birthdates as the year progresses, highlighting the advantage of being relatively older in the group. However, maturity-related biases and traditional (i.e., within year) relative age effects are not the only age-related concerns in athlete development. For instance, constituent year effects examine differences between year cohorts in sports where youth are grouped into two-year age bands [e.g., ice hockey; (14)]. Other age-related factors have the potential to influence opportunities for success at different points across the athlete development pathway. For instance, when cut-off dates are not aligned across different systems or levels of competition, or when different policies use different cut-off dates (e.g., when the date used by one country differs from that used by another), age effects can be affected.

Despite these real and perceived advantages for athletes who are relatively older, relatively younger athletes who "survive" the system may also experience success. The phenomena, where athletes with a late birthday not only get selected to the system but survive and thrive, is known as the "underdog effect" (15–17). This effect reflects potential compensatory skills that relatively younger athletes must develop in order to compete and succeed against their relatively older peers, though the relationship between relative age and biological maturation is complex and not always aligned (16, 18, 19). In ice-hockey for example, Gibbs and colleagues (17) demonstrated support for the underdog effect, when examining National Hockey League (NHL) rosters of Canadian-born players from 2000–2009. Specifically, the authors found that a relative age effect was moderate for the average Canadian NHL player but reversed when examining the "most elite" professional players [i.e., All-Star and Olympic Team rosters; (17)]. Similarly, Kelly et al. (20) noted that later-maturing players in professional football academies were four times more likely to achieve senior professional status compared to their earlier-born counterparts.

In addition to categorizing the late maturing individuals as "underdogs," Hill et al. (16) discussed "the released." The

released are those who struggle with overstimulation, may face injury or burnout, and do not "survive" the system (21, 22). Both of these phenomena may be especially relevant in North American ice hockey, where athletes may be "dually disadvantaged." This term, adapted from Rubajczyk et al. (23), originally described athletes disadvantaged by multiple factors such as birth date and physical development. In the present context, we use it to describe athletes who face compounded disadvantages from misaligned cut-off dates: they are relatively young throughout youth development (with January 1 cut-offs) and then become the youngest eligible players in their NHL draft selection cohort (with September 15 cut-offs). For example, a player born in early September faces nearly a full year disadvantage in youth hockey and remains among the youngest when eligible for NHL selection.

One way to examine these influences, is to divide the year into four quarters (also called quartiles, i.e., four three-month blocks). This allows for the examination of differences between early, middle, and late quarters relative to a cut-off date. For example, with a cut-off date of January 1, quartile 1 (Q1) would span from January 1 – March 31, Q2 from April 1 – June 30, Q3 from July 1 – September 30, Q4 from October 1 – December 31. Athletes born in the third quartile of the year (between June and September) are younger relative to their age cohort throughout development but are also the youngest within their selection cohort for NHL, where athlete selection cohort cut-offs are currently between September 15 and September 14 of the next year. For example, an ice hockey player born on September 14 would be considered relatively young throughout their youth hockey development, and then further impacted by being the youngest player eligible for selection. At a population level, interestingly, between 2000–2019, the top three months for births in Canada (for those who responded to the survey) were each in Q3, with July being the month with the most births, followed by August, and September (24). While most sport systems recognize the importance of maturation, a deeper understanding of this bias could lead to more balanced long-term player development.

Given these unique challenges faced by relatively younger players in hockey, the present research seeks to explore whether *relatively younger NHL draftees show superior career trajectories despite systematic disadvantages compared to their relatively older peers*. By analyzing over four decades of NHL draft and career data, we examine whether relatively younger players who overcome selection barriers demonstrate different career trajectories, specifically, whether they enter the league faster and achieve greater career longevity than their relatively older counterparts. Additionally, we investigate how the misalignment between youth hockey and NHL draft eligibility cut-offs affects these patterns, providing a unique lens to understand the multidimensional nature of age effects in athlete development. Finally, we explore the concept of "dually disadvantaged" athletes, examining how those born in Q3 (July-early September) face compounded disadvantages: they remain relatively young throughout youth development with January 1 cutoffs, then continue as the youngest eligible players under the September 15 NHL draft cutoff, creating a unique natural experiment for understanding the "underdog effect" in athlete development.

Collectively, we aim to examine relative age effects in ice hockey from multiple angles, ranging from the consideration of unique developmental circumstances (e.g., do relatively older players enter the league quicker after selection than younger?) to the impact of incongruent cut-offs between developmental and professional systems on career outcomes (e.g., do Q3 athletes who face dual disadvantages achieve different permanence rates than other birth quartiles?)

2 Methods

2.1 Sample description

All athletes drafted to the NHL (n = 10,570 unique male athletes) between the 1980 NHL entry draft, and the 2023/24 NHL entry draft were retrieved from Elite Prospects (25), a third-party hockey data aggregator, and an NHL draft archive website (26). A total of 10,485 unique drafted players from the 1980/81 to 2023/24 NHL seasons were included in the analysis. The sample was comprised of forwards (n = 56.74%), defensemen (n = 33.27%), and goalies (n = 9.99%), with players predominantly from Canada (47.19%), the United States (22.99%), Sweden (7.70%) and Russia (7.12%).

2.2 Data collection and processing

Athlete information retrieval from these two data sources (i.e., the NHL website and Elite Prospects) was done using Python, primarily utilizing the `request` modules for data extraction and processing (27). From the Elite Prospects website, athlete draft selection information (i.e., overall draft pick, draft round) and season statistics (i.e., the seasons where an athlete played at least one game in, and total games played) were retrieved. From the NHL draft website, each athlete's anthropometric information (i.e., height and weight) at the time of the draft selection was collected. Body mass index (BMI) was calculated using the athlete's height and weight information. Using an athlete's selection year and selection number, data from both websites was merged to build the full dataset for our analyses.

In situations where players were selected more than once (n = 85 unique athletes), selection information from the athlete's second time being drafted was used. The second draft was used under the assumption that the player had decided to re-enter the draft, making their second selection period more reflective of a team's evaluation of them relative to their professional performance. Given that less than 0.01% of all players were selected more than once, we did not control for secondary selection in any of the analyses performed. Additionally, two players selected in the 1980s were removed due to missing

information that could not be retrieved, resulting in a total of 87 selections being removed from the original dataset.

2.3 Variables

2.3.1 Predictor of interest

Birth quartiles: To determine the relative age of each athlete, birth dates were separated into quartiles based on calendar year: January–March (Q1), April–June (Q2), July–September (Q3), October–December (Q4).

Adjusted quartiles: To account for the misalignment between youth hockey cut-off dates (January 1) and NHL draft eligibility cut-offs (September 15), we conducted a secondary analysis using adjusted quartiles. Q3 was redefined as July 1 to September 14, and Q4 as September 15 to December 31. This adjustment was particularly relevant for players drafted from 2005 onward (n = 4,080), following the 2005 NHL collective bargaining agreement.

2.3.2 Outcome measures

Two primary career trajectory outcomes were defined: **Time to NHL Entry:** Number of seasons elapsed between draft and first NHL game appearance. Players who never entered were right-censored at the 2023/24 season, and **Time to NHL Permanence:** Number of seasons elapsed between draft and achieving "permanence," defined as competing in ≥5 NHL seasons across ≥268 regular-season games. The five-season threshold was selected to align with peak performance windows in professional hockey, as prior research indicates NHL players typically reach peak performance between ages 24–26 (28). Given that the median time to NHL entry in our sample was 2 years post-draft, a five-year career would position players squarely within this peak performance window. The 268-game threshold represents the mean number of regular season games played by all NHL players in our dataset. Given the right-skewed distribution of games played, using the mean provides a more conservative threshold than the median, ensuring that "permanent" players have sustained regular participation rather than sporadic appearances across multiple seasons. This created three career outcome groups: "drafted but not entered," "entered but not permanent," and "permanent."

2.3.3 Control variables

Several covariates were included to isolate the effects of birth timing from confounding factors. Anthropometric variables (e.g., height, weight, BMI) were included to control for physical size differences at the time of draft, recognizing that body size may correlate with but does not directly measure biological maturation (19, 29). While these measures cannot capture the timing or tempo of biological development, controlling for physical size helps isolate birth quartile effects from size-related selection advantages. Player position was included given positional differences in developmental trajectories and selection criteria, with positions such as goaltending potentially less susceptible to the physical advantages (30). Nationality was included to help control for heterogeneity in development systems, as international variations in league structures, coaching philosophies, and age cut-offs create different selection environments that may moderate relative age effects (2).

2.3.4 Statistical analysis

All statistical analyses were conducted in R using the `survival` and `nnet` packages (31–33). Statistical significance was set at $p < 0.05$, and 95% confidence intervals (CIs) were reported for all estimated parameters.

3 Results

3.1 Whole sample analysis

Distributions of NHL selections by birth quartile and NHL draft round, and birth quartile, NHL selection round, and NHL entrance status are reported in Figures 1–3 respectively. The average BMI at selection was 25.40 (SD = 1.75).

3.1.1 Permanence status

Among all drafted players, 4,574 players (43.63%) successfully played at least one NHL game. However, only 1,757 players (16.76%) achieved permanence status. The median time to NHL entry was 2 years (IQR 1-4), while the median time to permanence from draft was 8 years (IQR 6-11).

3.1.2 Time to NHL entry

Cox proportional hazards modeling demonstrated significant effects of birth quartile and draft pick on time to NHL entry (Figure 4). Later-born players exhibited faster entry times, with Q4 players reaching the NHL significantly earlier than Q1 players (HR = 1.32, 95% CI = 1.15–1.52, $p < 0.001$). However, when controlling for draft rank, the advantage diminished, with significant interaction effects between Q2 and Q3 players and draft rank ($p = 0.015$, $p = 0.002$, respectively). This suggests that while later-born players had greater likelihood of playing in the NHL, draft rank remains the strongest determinant of NHL entry timing.

3.1.3 Time to NHL permanence

The model assessing time to NHL permanence revealed that later-born players, particularly those in Q3 and Q4, were more likely to reach permanence status than athletes born in Q1 (Figure 5). Specifically, athletes in Q3 demonstrated a hazard ratio of 1.39 (95% CI = 1.10–1.75, $p < 0.01$), and athletes in Q4 demonstrated a hazard ratio of 1.25 (95% CI = 1.02–1.54, $p < 0.03$). Similar to time to entry, when draft position is accounted for, the strength of these relationships diminished with the hazard ratio for Q3 lowering to 1.00 (95% CI = 0.9976–1.0021, $p = 0.90$), and the hazard ratio for Q4 reduced to 1.001 (95% CI = 0.9984–1.0032, $p = 0.50$). A multinomial logistic regression was used as a sensitivity analysis, further supporting these findings. Players with lower draft ranks (higher pick numbers) were disproportionately affected by birth quartile: Q1 and Q2 players were significantly less likely to achieve permanence at

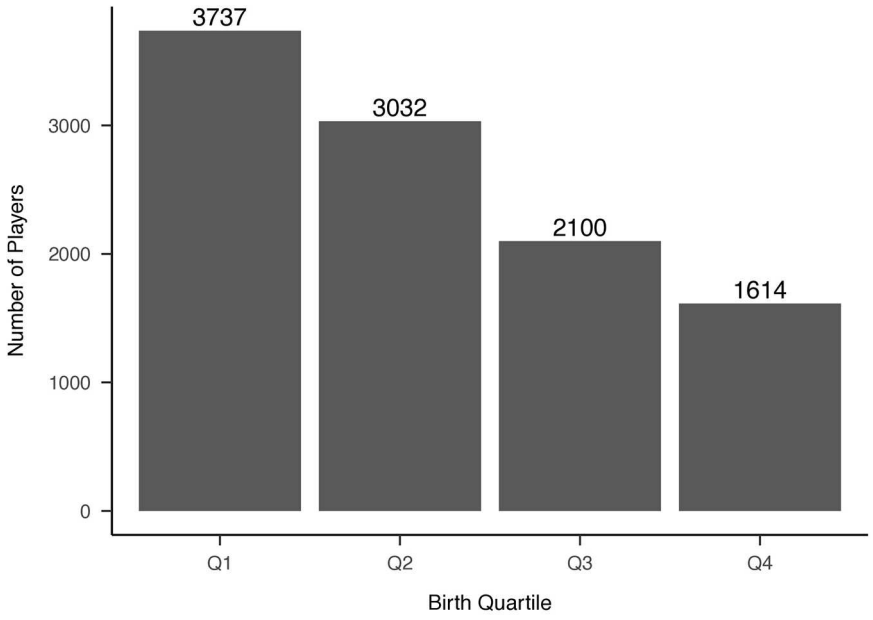


FIGURE 1
Distribution of players' birth quartiles (unadjusted). Distribution of players' birth quartiles, showing an overrepresentation of Q1 births, consistent with the relative age effect in ice hockey.

lower draft ranks ($p < 0.05$), whereas Q4 players maintained a higher likelihood of permanence across all draft ranks.

3.2 Adjusted quartile analysis

The distributions of birth quartiles using the adjusted quartile method can be found in Figure 6. By adjusting quartiles, Q3 athletes represented 14.65% of all selections compared with 20.03% previously, while Q4 athletes represented 20.78% compared with 15.40%, respectively. When using modified quartiles and examining athletes selected in 2005 and beyond (n = 4080), Q3 athletes represented 16.25% of all selections, while Q4 athletes represented 19.92% (Figure 7).

When examining time to entry and time to permanence using the post 2005 draft cohort with adjusted quartiles, Cox proportional hazards modeling found statistically significant effects of birth quartiles in both analyses (see Table 1 for comparison with standard quartile results). Evaluating time to entry showed that athletes selected from Q3 had a HR of 1.24 (95% CI = 1.08–1.42) relative to Q1, while Q4 exhibited nearly identical findings with a HR of 1.24 (95% CI = 1.08–1.40). When evaluating time to permanence using this cohort, Q3 athletes now demonstrated a HR of 1.61 (95% = 1.27–2.05) compared to Q1 athletes, while Q4 athletes demonstrated a HR of 1.24 (95% CI = 0.99–1.56).

4 Discussion

Relative age effects have been examined in ice hockey for over forty years, and despite significant research in this area, these effects persist. What seems clear is that an individual's relative age is an influential factor in their long-term development, with similar findings seen in ice hockey using wide ranges of outcomes, including advanced analytics (12). Given that previous research has demonstrated that later born ice hockey athletes are equally, or more likely to be, successful at the NHL level (12, 34), and that disproportionate numbers of younger ice hockey players exist on junior hockey rosters (17, 35), RAEs most likely impact athletes prior to playing the highest levels of amateur hockey.

When examining the two different outcomes with respect to RAE: time to entry and time to permanence, in both contexts, results revealed that relatively younger players were more likely to enter earlier than their relatively older peers, and that younger players were more likely to achieve permanence than older athletes in their selection cohort. These effects become even more pronounced in the adjusted quartiles for selections after 2005, where interestingly, Q3 athletes demonstrated the greatest probability of achieving permanence, even when controlling for draft selection. This finding is particularly notable given that these Q3 athletes face a "dual disadvantage" in North American hockey systems. Throughout their youth development, they compete as relatively younger players within the January 1 cut-off system, potentially facing age-related physical and competitive disadvantages. Then, when becoming eligible for NHL selection, they remain among the youngest in their draft cohort due to the September 15 cut-off. For instance, a player born in early September consistently competes as one of the younger athletes throughout youth hockey and continues to be among the youngest when draft-eligible. The notion that these dually disadvantaged athletes not only survive selection,

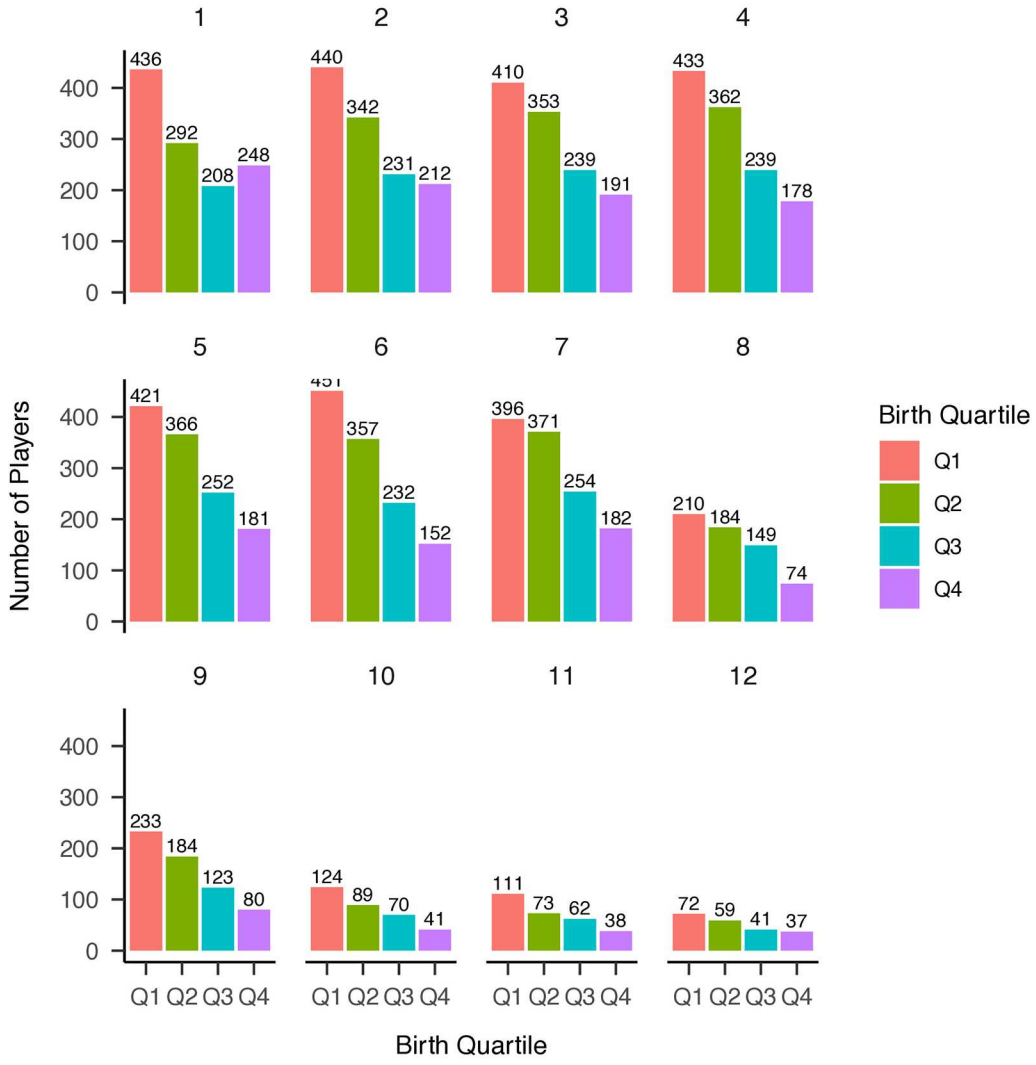


FIGURE 2
Distribution of players' birth quartiles by draft round (unadjusted). Distribution of players' birth quartiles by draft round, showing a persistent relative age effect across selection rounds.

but demonstrate superior career trajectories suggests remarkable resilience and skill development. Despite these findings, the number of adjusted Q3 athletes represent only 16.2% of selections, despite the time period representing just under 21% of the days in the calendar year. Similarly, using adjusted quartiles in the post 2005 cohort, Q4 athletes accounted for 19.9% of selections, while the time period accounted for 29.6% of the calendar year. As previously reported [see (17)], relatively younger athletes playing in leagues scouted by NHL teams may simply be more skilled than their relatively older peers in order to overcome some of the impacts of age. As illustrated in Figure 8, these Q3 athletes who overcome the dual disadvantage of misaligned cut-off dates demonstrate superior career trajectories, supporting the underdog hypothesis.

The exceptional performance of Q3 athletes in our study aligns with previous research suggesting these players possess compensatory skills. Despite being underrepresented in elite junior leagues that comprise the Canadian Major Junior Hockey League, including only 18.6%, 20.1%, and 16.7% of rosters in the Western Hockey League (WHL), Ontario Hockey League (OHL), and Quebec Maritimes Junior Hockey League (QMJHL) respectively, Q3 players who reach these levels demonstrate superior scoring ability compared to their relatively older peers (30). This pattern suggests that to overcome systematic age-related disadvantages throughout development, Q3 athletes must possess exceptional skill levels that ultimately translate into the faster NHL entry times and higher permanence rates observed in our data. Such findings provide strong empirical support for the underdog hypothesis, wherein the selection pressures faced by relatively younger players create a cohort of exceptionally talented survivors.

Time to permanence is likely impacted by a number of factors related to the athlete themselves, their playing pathway, and the team selecting the athlete. For example, an athlete selected at

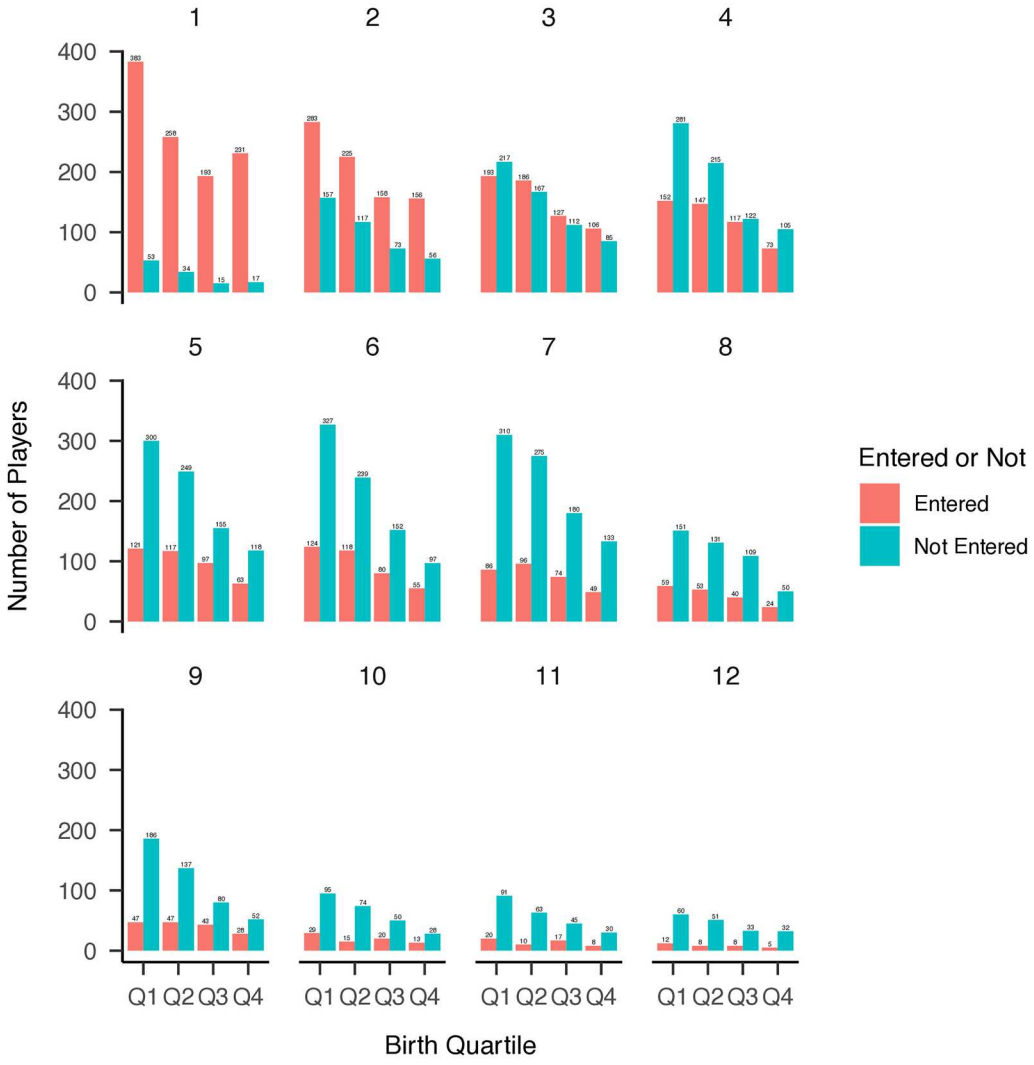


FIGURE 3
Distribution of birth quartiles by draft round and NHL entry status (unadjusted). Distribution of players' birth quartiles by draft round, comparing those who entered the NHL versus those who did not. The relative age effect remains evident across both groups.

age 18 who has decided to play collegiate hockey in the National Collegiate Athletic Association (NCAA) may have a longer pathway to both enter the NHL and achieve permanence, given that they may choose to play collegiate hockey for four years. This pathway is notably different from an athlete playing in the Canadian Hockey League, who could only remain in amateur hockey until age 21, and until recently, could not play collegiate hockey in the NCAA. Despite these differing pathways, it is likely that athletes with the greatest ability would both enter and achieve permanence in the NHL quicker. This can be seen in both models presented in this paper, as the impact of relative age effects decreases when accounting for draft position (36).

This type of investigation offers a unique lens to examining the effects of age and player progression in the system. Given that relatively younger athletes appear to be equally or more successful then their relatively older peers, scouts and other stakeholders involved in selection may wish to adjust their approach to assessment, evaluation, and selection. It is possible that younger players who have successfully reached elite levels possess some type of compensatory factor (e.g., resilience, superior technical or tactical skill) that has allowed them to overcome the disadvantages of their birth timing. That said, more information would be valuable to learn about these relatively younger athletes in the sample, for instance, what systems they were in after they were drafted (e.g., how, where, and for how long athletes are called up, or sent down into the "farm" systems, etc.) as these can help shape the trajectory of the athlete's career.

Importantly, there are several implications of this work. Perhaps most notably, this study focused on different elements of selection at the NHL level, but it is clear that the largest area in which RAE research should be considered is at the grassroots level. With Q3 and Q4 ice hockey athletes remaining a relatively small sample compared with their older

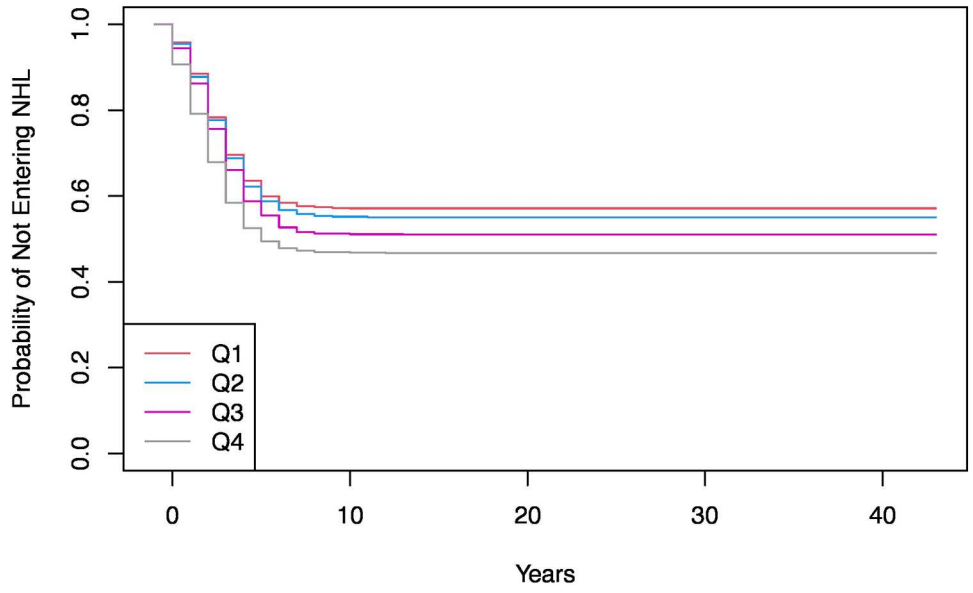


FIGURE 4
Kaplan-Meier curve for probability of not entering the NHL by birth quartile (unadjusted). Kaplan-Meier survival curves for NHL entry by birth quartile, showing the probability of not entering the league over time. Players born in Q1 exhibit a higher likelihood of entry compared to later quartiles.

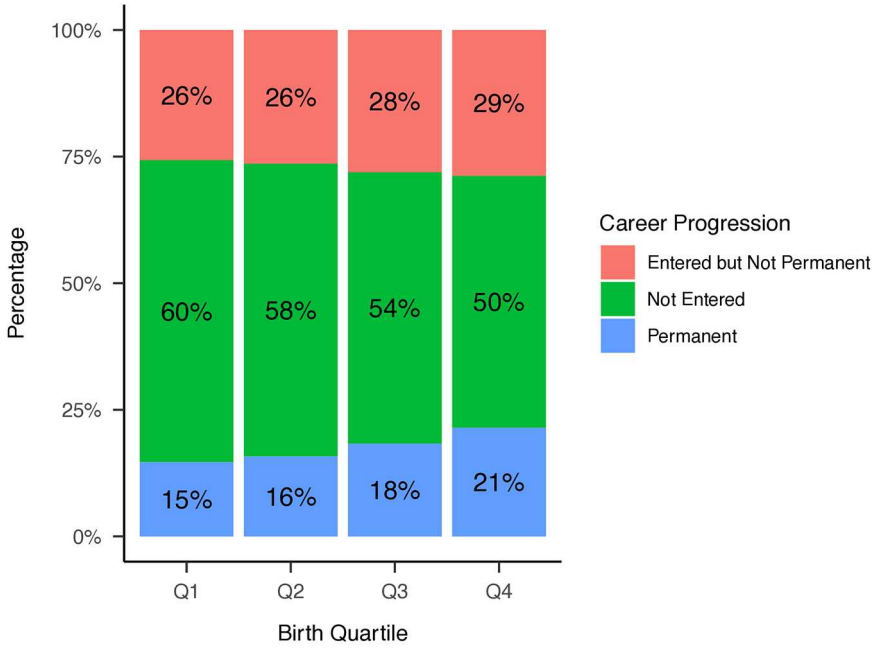


FIGURE 5
Career progression by birth quartile (unadjusted). Career progression percentages by birth quartile, illustrating differences in NHL entry and permanence. Q4 players have the highest rates of permanent NHL careers, consistent with underdog hypothesis.

peers at the level of NHL selection, efforts to better support younger athletes could have a range of benefits. Some of these solutions are not resource intensive, and include concepts such as bio-banding, which focuses on classifying athletes based on biological maturity rather than age alone (37, 38). Another method of accounting for better inclusion of relatively younger athletes (and thus more likely to be late maturing) is the use of "future teams" (39). Future teams are national level teams which select late maturing youth athletes (e.g., an U16 team that features athletes with physical profiles

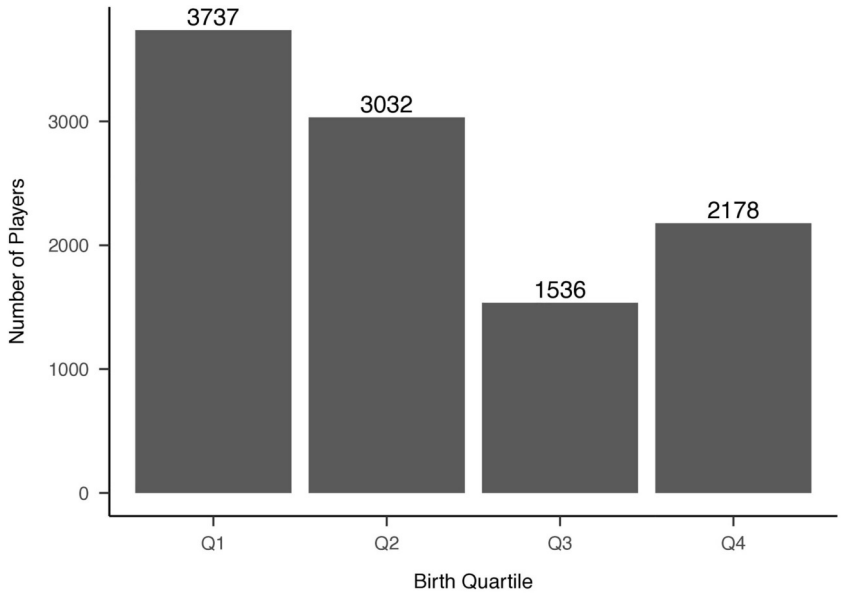


FIGURE 6
NHL selections from 1980–2024 using adjusted quartiles. Distribution of players' birth quartiles using adjusted cut-offs (Q3: July 1 – September 14, Q4: September 15 – December 31) for NHL selections from 1980–2024. The relative age effect remains evident, though quartile distributions shift under the adjusted framework.

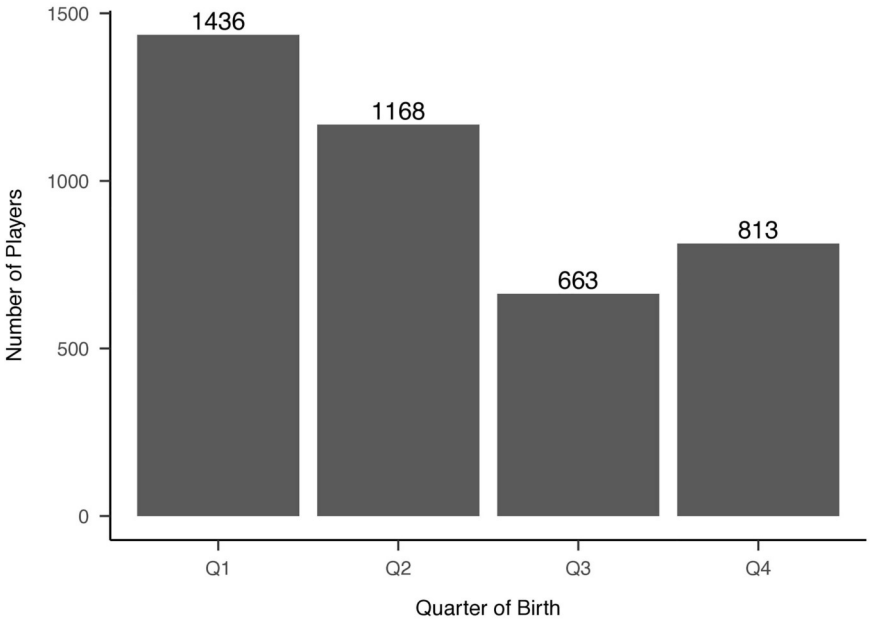


FIGURE 7
Distribution of players' dates of birth quartiles (2005 onwards) by adjusted quartiles. Distribution of players' birth quartiles (2005 onwards) using adjusted cut-offs, showing continued evidence of the relative age effect in recent NHL selections.

more similar to that of a U15 group), with the goal of retaining these athletes at the national level and providing them with access to better training, competition, and coaching (39). Future teams offer one form of athlete retention which may benefit athletes at the national level; however, this may be difficult to apply in some contexts (e.g., North American settings) where amateur teams are organized and administrated outside the control of a central national sport governing body.

TABLE 1 Summary of hazard ratios between standard and adjusted quartile analyses.

Birth quartile	Standard quartiles (1980–2024)		Adjusted quartiles (2005–2024)	
	Time to entry	Time to permanence	Time to entry	Time to permanence
Q1 (January–March)	Reference	Reference	Reference	Reference
Q2 (April–June)	0.94 (0.82–1.08)	1.03 (0.84–1.25)	1.04 (0.92–1.17)	1.23 (0.99–1.53)
Q3 (Jul–September)[a]	1.05 (0.89–1.25)	1.39 (1.10–1.75)**	1.24 (1.08–1.42)**	1.61 (1.27–2.05)***
Q4 (October–December)[b]	1.32 (1.15–1.52)***	1.25 (1.03–1.51)*	1.24 (1.08–1.40)**	1.24 (0.99–1.56)

Values show HR (95% CI). *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
[a]Q3 in adjusted model = July 1–September 14.
[b]Q4 in adjusted model = September 15–December 31.
All models controlled for draft position, player position, BMI, nationality, and handedness.

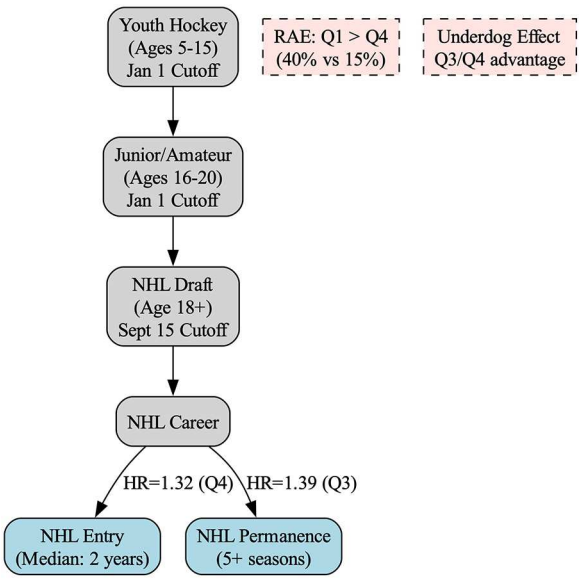


FIGURE 8
Conceptual framework of relative age effects across NHL development stages. This framework illustrates how relative age effects operate across developmental stages in ice hockey. The misalignment between youth hockey cut-off dates (January 1) and NHL draft eligibility (September 15) creates a dual disadvantage for Q3 athletes. Despite underrepresentation at draft, relatively younger players (Q3/Q4) who survive selection barriers demonstrate faster NHL entry and higher likelihood of achieving career permanence, supporting the underdog hypothesis.

4.1 Limitations

Despite what this investigation has to offer the sport and research community, it has limitations worth noting. First, our dataset only includes athletes who were actually drafted to the NHL, creating a selection bias that does not capture the full extent of relative age effects among all youth hockey players, particularly those who may have dropped out of competitive hockey before reaching draft eligibility. Second, while we controlled for anthropometric measures (height, weight, BMI) at draft, these variables represent physical size rather than biological maturation status. Without direct measures of maturation such as peak height velocity or skeletal age (5), we cannot make definitive claims about maturational differences between birth quartiles. Indeed, research in other sports has shown that some relatively younger athletes may be early maturing, potentially compensating for chronological age disadvantages (19, 29). Future research incorporating actual maturation assessments would provide more complete understanding of how biological development interacts with relative age effects.

A third limitation is that our analysis does not account for variations in the development systems and league structures across different countries, which may influence how relative age effects manifest and impact player development trajectories before reaching the NHL draft. Finally, while we examined time to entry and permanence, we did not analyze specific performance metrics or playing styles that might differ between relatively older and younger players, which could provide further insights into how these athletes adapt and succeed despite age-related disadvantages.

Additionally, we acknowledge that this analysis provides an incomplete picture of athlete performance and development. Performance-based outcomes such as scoring statistics, time on ice, and advanced metrics (e.g., Corsi numbers, expected goals) could provide valuable insights into how relative age affects on-ice performance at multiple career stages. As noted by Baker, Johnston, and Wattie (40), this means we capture only those who "survived" the development system, missing the potentially larger population of relatively younger athletes who were released from competitive hockey earlier. Finally, this dataset contained only men's hockey players, limiting our ability to generalize findings across genders and missing the opportunity to compare relative age effects between men's and women's professional hockey development pathways.

4.2 Future directions

Future work could benefit from incorporating longitudinal tracking of players from youth hockey through to professional leagues, analyzing not just career outcomes but also the developmental pathways, playing styles, and specific skills that relatively younger players develop to overcome systemic disadvantages in the selection process.

To address the selection bias inherent in examining only drafted players, future studies can implement population-based cohort designs that capture complete age cohorts from youth

hockey entry through draft eligibility, documenting attrition patterns and exit points for relatively younger athletes. This would require partnerships with national hockey federations to access comprehensive registration data across developmental stages.

International comparative research examining how structural variations in development systems moderate relative age effects could provide crucial insights. Different countries employ varying age cut-off dates, league structures, and player development models'systematic comparison of these approaches would identify which organizational features best support relatively younger athletes' development and retention.

The integration of performance analytics represents another critical avenue. Future research should incorporate advanced metrics (e.g., expected goals, Corsi, zone entries, passing efficiency) and player tracking data to examine whether successful relatively younger players exhibit distinct performance profiles or compensatory advantages. Time-series analyses of these metrics could reveal how playing styles evolve across career stages and whether early disadvantages translate into later advantages in specific performance domains.

Finally, extending this analytical framework to women's professional hockey would address current gender limitations and test the generalizability of findings. Given potential differences in maturation rates, competitive structures, and career opportunities between men's and women's hockey, comparative analyses could yield important theoretical and practical insights for developing more equitable talent development systems across all levels of the sport.

5 Conclusion

Relative age effects in ice hockey have been extensively studied, and while new research continues to extend these effects, the overall pattern of results has been highly consistent over 40 years. Until systemic level change is adequately implemented at the grassroots level, relatively younger athletes will remain underrepresented. Athletes who are relatively younger (whether true Q4, or adjusted quartile Q3/Q4 as we discuss) will likely succeed due to having already survived the systemic barriers they encountered. Overall, using new outcomes and modified cut-offs, we identified findings that further support the extensive research on this topic indicating that relatively younger athletes are underrepresented, but are equally or more successful than their relatively older peers. Future research should prioritize how grassroot and amateur ice hockey systems can allow for better developmental opportunities for relatively younger and less biologically mature athletes.

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/s.

Author contributions

YW: Visualization, Data curation, Formal analysis, Methodology, Writing – review & editing, Writing – original draft, Software. BC: Validation, Methodology, Data curation, Writing – original draft, Conceptualization, Writing – review & editing. KJ: Writing – review & editing, Conceptualization, Supervision, Methodology, Project administration, Writing – original draft. JB: Writing – original draft, Supervision, Writing – review & editing, Funding acquisition, Investigation, Project administration, Resources, Conceptualization, Validation.

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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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