Improving talent identification through analysis and consideration of biological and relative age

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Abstract

Modern talent identification (TID) and talent development (TD) models should include biological development. This requires practicable methods for the consideration of biological age (BA) and relative age (RA). Until 2008, most Swiss sports federations selected young athletes on the basis of current competition results rather than development potential. This meant that many of these talent selection processes failed to integrate important indicators when assessing young talent. Because of these shortcomings, a new standardised national talent selection instrument for all Swiss sports federations was developed. In addition to having six major assessment criteria, the instrument includes biological development, which is subdivided into BA, RA, and relative age effects (RAEs).

However, in the current sports system, the participants are categorised into annual age groups to reduce the developmental differences during childhood and adolescence. In this regard, an unfortunate problem remains because of the potential for RA and BA differences among individuals within an annual age cohort. This means that in many TID processes, the athletes do not have equal opportunities, the resources are used inefficiently, and potential talent is lost.

This thesis summarizes the last eight years of research in RA and BA. Questions arose about the prevalence and evolution of RAEs at the various development stages and selection levels. Furthermore, gaps exist in the research on RAEs in female athletes. The number of extant studies was limited, and the data were inconsistent. Therefore, this cumulative habilitation aims to show: (1) the prevalence of RAEs by sport type, competition level, and gender; (2) the underlying mechanisms in RAEs; and (3) the possible approaches for considering BA and RA in the selection process.

Studies on RA and BA have shown that even a small age difference of a few months could exert a significant effect on talent selection and TD. The current sports system, which uses chronological age

categories, results in the selection of a disproportionate number of biologically and/or chronologically older athletes. This phenomenon has been observed throughout the Swiss TD program, particularly with regard to male athletes. RAEs also influence the selection of female athletes; therefore, these effects must be taken into account. Comparisons of sports have shown that high physical demands and high performance density (many selection levels) strengthen RAEs.

Differences in BA are the principal cause of RAEs. This can lead to performance differences, which, along with parental influence, can trigger selection and self-selection processes. The most important environmental factors are the popularity (i.e. number of participants and economic factors), requirement profiles, and selection levels of the sports. The athletes who are selected benefit from greater support, better training, access to higher competition levels, higher involvement, and positive feedback, which have a positive influence on performance. This leads to an upward spiral for athletes at higher BAs and RAs and a negative spiral for those at lower BAs and RAs (the "vicious circle"). ”False” talent is encouraged, and ”true” talent is lost. Thus, many athletes with the potential for success in adulthood are overlooked. The suggested solutions to counteract the differences in RA and BA are: (1) the implementation of corrective adjustments to reduce RAEs and (2) low-dose hand–wrist imaging or coaches' subjective evaluations to account for BA. TID programmes must seek to reduce the risk of RAEs by raising awareness, monitoring the athletes' BAs, and avoiding early selection or deselection. If selection is necessary because of a lack of resources, RA and BA considerations should be integrated into a long-term multidisciplinary approach. With the implementation of these measures, TID can be more equitable, and the available resources can be used more efficiently.

Overview of the cumulative habilitation achievements

Peer reviewed publication (sorted by author and year)	**Full text page**
Cobley, S., Abbott, S., Dogramaci, S., Kable, A., Salter, J., Hintermann, M., & **Romann, M.** (2018). Transient Relative Age Effects across annual age groups in National level Australian Swimming. Journal of Science and Medicine in Sport, 21(8), 839-845.	35
Cobley, S., Abbott, S., Eisenhuth, J., Salter, J., McGregor, D., & **Romann, M**. (2019). Removing relative age effects from youth swimming: The development and testing of corrective adjustment procedures. Journal of Science and Medicine in Sport.	42
Franchi, M. V., Ellenberger, L., Javet, M., Bruhin, B., **Romann, M**., Frey, W. O., & Spörri, J. (2019). Maximal eccentric hamstrings strength in competitive alpine skiers: cross-sectional observations from youth to elite level. Frontiers in Physiology, 10, 88.	48
Romann, M., & Cobley, S. (2015). Relative age effects in athletic sprinting and corrective adjustments as a solution for their removal. PLoS One, 20(3).	56
Romann, M., & Fuchslocher, J. (2011). Influence of the selection level, age and playing position on relative age effects in Swiss women's soccer. Talent Development & Excellence, 3(2), 239-247.	68
Romann, M., & Fuchslocher, J. (2013a). Relative age effects in Swiss junior soccer and their relationship with playing position. European Journal of Sport Science, 13(4), 356-363.	78
Romann, M., & Fuchslocher, J. (2013b). Influences of player nationality, playing position, and height on relative age effects at women's under-17 FIFA World Cup. Journal of Sports Sciences, 31(1), 32-40.	86
Romann, M., & Fuchslocher, J. (2014a). The need to consider relative age effects in women's talent development process. Perceptual and Motor Skills, 118(3), 1-12.	95
Romann, M., & Fuchslocher, J. (2014b). Survival and success of the relatively oldest in Swiss youth skiing competition. International Journal of Sports Science and Coaching, 9(2), 347-356.	107
Romann, M., & Fuchslocher, J. (2015). Validation of digit-length ratio (2D: 4D) assessments on the basis of DXA-derived hand scans. BMC Medical Imaging, 15(1), 1.	117
Romann, M., & Fuchslocher, J. (2016). Assessment of Skeletal Age on the basis of DXA-Derived Hand Scans in Elite Youth Soccer. Research in Sports Medicine, 24(3), 200-211.	129
Romann, M., Javet, M., & Fuchslocher, J. (2017). Coache's eye as a valid method to assess biological maturation in youth elite soccer. Talent Development & Excellence, 9, 3-13.	141
Romann, M., Rössler, R., Javet, M., & Faude, O. (2018). Relative age effects in Swiss talent development–a nationwide analysis of all sports. Journal of Sports Sciences, 1-7.	152
Smith, K. L., Weir, P. L., Till, K., **Romann, M.**, & Cobley, S. (2018). Relative Age Effects Across and Within Female Sport Contexts: A Systematic Review and Meta-Analysis. Sports Medicine. 48(6),1451-1478.	159

Table 1: Cumulative habilitation achievements.

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General background

Several international scientific studies have discussed the advantages of a national framework for sports development. The objective is to optimise the synergies of the individual stakeholders who contribute to sports promotion (Abbott & Collins, 2004; Bergeron et al., 2015; Gulbin, Croser, Morley, & Weissensteiner, 2013). In Switzerland, the Rahmenkonzept zur Sport- und Athletenentwicklung (FTEM) was developed to systematise sports promotion and to optimise limited resources (Fuchslocher, Romann, & Gulbin, 2013; Grandjean, Gulbin, & Bürgi, 2015). The concept provides a framework for the development, planning, and implementation of strategies and programmes that benefit all athletes. It helps the federations to determine the types of support and inputs that are needed by athletes. In addition, the FTEM should help the associations to review their structures to systematise athlete development, to define the athletes' strengths and weaknesses, and to develop suitable measures. In principle, the objective is to optimise the processes in all the federations and sports through a uniform comprehensive system within a framework. The three principal objectives are to improve the coordination and systemisation of sports promotion, to keep people in sports throughout their lives, and to raise the level of competitive sports.

An examination of competitive sports has found that the early and sustained demand for young athletes exerts a positive influence on performance at the elite level. This is determinative for international competitiveness in top-level sports. For this reason, the Federal Office of Sport (FOSPO) and the Swiss Olympic have been investing approximately 11 million Swiss francs annually in the performance-oriented promotion of young talent as part of the Youth and Sport Promotion of Young Talent program. Competitive youth sports have been receiving additional support directly from the sports federations, cantons, municipalities, and private partners. The limited financial resources and the competition systems in youth sports inevitably lead to selection processes. Talent selection in Switzerland was based almost exclusively on competition results (Fuchslocher & Romann, 2013a; Fuchslocher et al., 2016). Important criteria, such as young athletes' biological and psychological development and their potential, were not sufficiently considered (Fuchslocher, Romann, Rüdisüli, Birrer, & Hollenstein, 2011).

Since 2008, the Prognostic Integrative Systematic Trainer Evaluation (PISTE) has been used for talent selection. In accordance with the recommendations in the extant literature, the PISTE facilitates the repeated systematic multidisciplinary assessment of performance potential over longer periods of time (Abbott & Collins, 2004; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). In addition to competition results, the following performance tests are taken into account: sport-specific motor and other performance tests; performance development (Baker, Cobley, & Schorer, 2011); psychological components, such as performance motivation and management of performance pressure (Abbott & Collins, 2004; Jean Côté & Abernethy, 2012; Jean Côté, Strachan, & Fraser-Thomas, 2008); resilience (Fröhner & Wagner, 2011; Franchi et al., 2019); biological and psycho-social development (Malina, Rogol, Cumming, Coelho e Silva, & Figueiredo, 2015); and young athletes' relative ages ([RAs]; Romann & Fuchslocher, 2014a; Romann, Rössler, Javet, & Faude, 2018). Each federation has adapted the PISTE criteria to suit its specific sports while consulting with the Swiss Olympic and the Swiss Federal Institute of Sport Magglingen (SFISM). Relevant performance-determining factors are to be integrated on the basis of developmental stage to enable an overall assessment of a young athlete's performance potential (Fuchslocher et al., 2013). The present habilitation thesis is intended to increase the understanding of the research on biological age (BA) and RA as talent selection indicators.

Scientific Background and Objective

Definition

Children and adolescents are usually placed into annual age groups to reduce age and developmental differences. Although this is done in good faith to establish fair competition and equitable selection, chronological age (CA) differences, i.e., RA differences, among the athletes remain. The differences between two individuals in a one-year category can be as much as 12 months. Relative age effects (RAEs) have been defined as the over-representation of chronologically older participants within an age category (Barnsley, Thompson, & Barnsley, 1985). BA, as distinct from CA, defines the skeletal, dental, and sexual maturation in childhood and adolescence (Malina et al., 2004).

Prevalence

The RAE phenomenon in youth sports is well known, and it has been well documented (Cobley, Baker, Wattie, & McKenna, 2009; Musch & Grondin, 2001). It can lead to biased views of children's potential in particular sports. Athletes born early in the selection year have more advanced physical and cognitive abilities than those born later in the year; therefore, they have a higher likelihood of being identified as being more talented (Cobley et al., 2009; Gil et al., 2014; Raschner, Müller, & Hildebrandt, 2012). RAEs are most prevalent in youth team sports (Cobley et al., 2009; Romann & Fuchslocher, 2014a). They have been extensively analysed in international male soccer (Cobley, Schorer, & Baker, 2008; W. F. Helsen et al., 2012; Takacs & Romann, 2016), rugby (Till, Cobley, O'Hara, Cooke, & Chapman, 2013), handball (Schorer, Cobley, Busch, Brautigam, & Baker, 2009), and baseball (Thompson, Barnsley, & Stebelsky, 1991). Only 2% of the existing RAE research includes female athletes. More recent studies have found that females and males in individual sports are also affected. Sports such as track and field (Romann & Cobley, 2015), Alpine skiing (Müller, Hildebrandt, & Raschner, 2015; Müller, Müller, Hildebrandt, & Raschner, 2016; Romann & Fuchslocher, 2014b), swimming (Cobley et al., 2018, 2019; Costa, Marques, Louro, Ferreira, & Marinho, 2013), and tennis (Edgar & O'Donoghue, 2005), as well as a variety of other strength, endurance, and technique-based events, were identified in a study of Youth Winter Olympics participants and the entire Swiss TD system (Raschner et al., 2012; Romann et al., 2018). Conversely, in sports, such as golf, that emphasise skills more than physical ability, RAEs have not been reported (Côté, Macdonald, Baker, & Abernethy, 2006).

Origin and mechanisms

Children of higher RAs and/or BAs have a greater chance of being selected for representative teams or talent centres; thus, they tend to receive a greater amount and level of support. The reason for this temporary performance advantage in relatively older children is their higher average BAs (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004). A higher BA is associated with better physical ability, e.g., aerobic and muscle strength, speed, and endurance (Viru et al., 1999), and this is in turn associated with a physical performance advantage in most sports tasks (Malina et al., 2004). Relatively older people are more likely to have entered puberty earlier, thereby gaining physiological and psycho-social advantages (Beunen & Malina, 1988). Thus, in the short term, coaches are more likely to classify relatively older and more advanced athletes as being talented and to place them in higher selections (Helsen, van Winckel, & Williams, 2005; Romann & Fuchslocher, 2010, 2013a). Unfortunately, relatively younger and late-maturing athletes are more likely to be overlooked or excluded in selection processes (Malina et al., 2004).

As was previously mentioned, BA is also central to talent selection (Armstrong & McManus, 2011). Therefore, it is not surprising that higher junior squad levels are composed almost exclusively of "average" and "early developed" athletes (Beunen & Malina, 1996; Philippaerts et al., 2006). During puberty, athletes of the same CA may have BA differences of up to 5 years (Malina et al., 2004). Thus, it is necessary to assess young athletes' BAs to classify their performance potential correctly. Some young athletes might not be selected because of their later biological development and current lower performance levels. In addition, young athletes who develop early and have few long-term prospects might be promoted (Romann & Fuchslocher, 2011, 2013a). This means that in many selection processes, talent selection is inequitable, resources are used inefficiently, and potential talent is lost.

The reasons for RAEs are complex. The sports that are particularly affected are those that are characterised by physical characteristics and those that enjoy high popularity. For example, 18,000 basketball players are licensed in Switzerland; however, there are 268,000 players (Romann et al., 2018). Therefore, RAEs in soccer, the most popular sport in Switzerland, are more likely (odds ratio [OR]: 4.6) than in basketball (OR: 2.5). Furthermore, the requirement profile for each sport is determinative. On the one hand, physical sports are more susceptible to RAEs. On the other hand, disciplines in which small agile athletes have an advantage (e.g., gymnastics, figure skating, and dancing) often have minor, sometimes even inverse, RAEs.

Studies have shown that the RAEs for left-handed tennis players are weaker than those for right-handed players. One possible explanation could be that left-handers face less competitive pressure because of their smaller population (Loffing, Schorer, & Cobley, 2010). Good data are available on the RAEs for male athletes at high performance levels (Cobley et al., 2009). Most of the studies focused on team sports, especially soccer and ice hockey (Cobley et al., 2009; Musch & Grondin, 2001).

The interactions among BA, RA, and RAEs in female athletes are not well understood. The data are inconsistent, and the number of available extant studies is limited. Gaps exist in the research on the evolution of RAEs at different development stages and selection levels. Furthermore, each sport's influence on the potency of RAEs remains largely unclear. Currently, the development of measures to prevent the systematic disadvantaging of biologically and/or relatively younger athletes is a priority. Therefore, this cumulative habilitation aims to show: (1) the prevalence of RAEs by sport type, competition level, and gender; (2) the underlying mechanisms in RAEs; and (3) the possible approaches for including RA and BA in the selection process.

Methodological Approach

Study populations

A study of the entire Swiss talent-development system included 5,353 female athletes and 13,506 male athletes in 70 sports (Romann, Rössler, Javet, & Faude, 2018). Two previous studies of Swiss youth soccer analysed the prevalence of RAEs among female players (n = 6,229) and male players (n = 50,581; Romann & Fuchslocher, 2011, 2013). Within the scope of this study, the development of RAEs from popular sports to junior national teams in soccer could be presented. In addition, differences in RAEs at various match positions could be analysed. Because of the gap in the international research on female athletes, an analysis of the women's FIFA U-17 World Cup was conducted and extended to specific Swiss individual (non-team) sports (e.g., Alpine skiing, track and field, and tennis; Romann & Fuchslocher, 2013a, 2013b).

In a third step, possible solutions were developed and tested to better evaluate BA and to correct RAEs (Romann & Fuchslocher, 2015, 2016; Romann, Javet, & Fuchslocher, 2017). These studies analysed the potential Swiss U-15 national team players (N = 144).

Procedure

In Switzerland, all sports use a reference date of 1 January for age group classification. Therefore, this informed the placement of the athletes into one of four relative quartile categories: Q1 = born January–March, Q2 = April–June, Q3 = July–September, and Q4 = October–December. The RA distributions across all athletes and age groups were then calculated and compared to the actual corresponding birth distributions within the Swiss population.

BA was determined by the gold standard: X-rays of the bones in the left hand (Malina et al., 2004). Dual X-ray absorptiometry (DXA) was then used for the comparison and validation of BA (Romann & Fuchslocher, 2016). In addition, the experienced coaches provided subjective visual assessments of each athlete's biological maturity. These were then validated with the gold standard (Romann, Javet, & Fuchslocher, 2017) and compared to the existing non-invasive method (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002).

Context and results

The results of the mentioned Studies were divided into sub-areas: prevalence of RAEs; origins and mechanisms of RAEs; methods for determining biological age; and possible solutions for integrating relative and biological age into selections.

Prevalence

The prevalence of RAEs is evident for female and male athletes in popular sports on regional, national and international selection levels (Cobley et al., 2019; Cobley et al., 2018; Romann & Cobley, 2015; Romann & Fuchslocher, 2013a; Romann & Fuchslocher, 2013b; Romann & Fuchslocher, 2014a; Romann & Fuchslocher, 2014b)

In one study the entire Swiss talent development system in 70 sports was analysed among female and male athletes (Romann, Rössler, Javet, & Faude, 2018). It could be shown that within the basic population of Swiss youth promotion lies a 'small' RAE for all athletes. Small RAEs also were evident for females (OR 1.35 [95%-CI 1.24, 1.47]) and males (OR 1.84 [95%-CI 1.74, 1.95]). At the highest selection level (national), a 'small' RAE (OR 1.30 [95%-CI 1.08, 1.57]) was found in female athletes and a 'large' RAE (OR 2.40 [95%-CI 1.42, 1.97]) in male athletes. Generally, it could be shown that RAEs are stronger among men than women, and that when the sport is highly popular (e.g., Olympic sports), RAEs increase. Higher selection level included higher RAEs only for males.

In a study 6,229 female soccer players from the entire Swiss women's soccer population were evaluated to determine the prevalence of RAEs (Romann & Fuchslocher, 2013b). Significant RAEs were found in self-selected extracurricular (n = 2,987) soccer teams and in the subgroup 'talent-promotion teams' (n = 450) in the 10- to 14-year-old age range. No significant RAEs were found for players ages 15 and up (n = 3,242) and in the subgroup 'all national teams' (n = 239). An analysis of player positions showed significantly stronger RAEs for defenders and goalkeepers than for midfielders.

Although no RAEs were found for players 15 years old and up (n = 3,242) and in the subgroup 'all national teams' (n = 239), significant RAEs were found in self-selected extracurricular (n = 2,987) soccer teams and in talent development (n = 450) within the 10- to 14-year-old age category. In addition, defenders born at the beginning of the year were over-represented significantly compared with goalkeepers, midfielders and strikers.

Another study was conducted at the international level on the U-17 Women's FIFA World Cup and the connection with player positions (Romann & Fuchslocher, 2013b). In the entire cohort of 672 players, we found significant RAEs in the Europe, North and Central America geographic zones; no RAEs in the Asia, Oceania and South America zones; and significant, inverse RAEs in the Africa zone.

In popular sports, the most popular Alpine skiing race for children ages 7 to 14 in Europe with 17,992 in 2010, 2011 and 2012 was analysed. Chi-square analyses showed no RAEs for the entire group of finishers in the qualifying race for girls in the U-8 to U-13 categories (n = 7,010) and all boys (n = 10,410). However, significant RAEs were found for the entire group of both female (OR = 1.49) and male (OR = 2.18) skiers who qualified for the final race. RAEs additionally were apparent in all age categories of female and male finalists. Results showed that RAEs already bias selections in popular sports in childhood (e.g., U-8), which may lead to unequal participation in competitive skiing.

To sum up, it could be shown that RAEs also influence selections of female athletes and, therefore, must be taken into account (Romann & Fuchslocher, 2014a; Smith, Weir, Till, Romann, & Cobley, 2018). In addition, it was shown that RAEs are stronger in male athletes than in female athletes. A comparison of various sports shows that high physical component, high performance density (many selection levels) and high popularity strengthen RAEs.

Origin and mechanisms

Children grow at different speeds and intervals, leading to different biological maturation states. In many sport systems, almost exclusively 'normal' and 'early developed' athletes are chosen in selections (Beunen & Malina, 1996; Philippaerts et al., 2006). This is not surprising, as children of exactly the same chronological age (CA) in puberty may show differences of up to five years in BA

(Malina et al., 2004). Therefore, the most widely supported hypothesis on the origin of RAEs is the maturation-selection hypothesis (Cobley et al., 2009), which states that a higher chronological age is equated with a higher probability of increased anthropometric features from normative growth and development. These developmental differences, induced by BA and RA, lead to short-term performance advantages for relatively older and/or earlier maturing athletes (Lovell et al., 2015). They are more likely to be regarded as better athletes and selected by coaches for higher cadres. Unfortunately, relatively younger and later-maturing athletes in various stages of development are rather overlooked and excluded until the end of puberty (Romann & Cobley, 2015).

In summary, the assertions illustrate how relatively older and/or earlier maturations are overrepresented, and relatively and biologically younger can be overlooked or excluded in sports-related selections (Romann & Cobley, 2015).

Further explanations for superior performance in relatively older children include psychological development, practical experience and mechanisms associated with selection procedures (Musch & Grondin, 2001). After selection, relatively older children also experience better coaching, more positive feedback, deeper engagement and more intense competition, all of which improve performance (Sherar et al., 2007). On the other hand, children with a relative age disadvantage play at a lower level competitively, with less support and training. As a result, these children are less likely to reach the highest levels of competitive sports (Helsen, Starkes, & Van Winckel, 1998) and more likely to drop out of a particular sport (Delorme, Boiche´ & Raspaud, 2010a). In line with this assumption, Delorme et al., (2010) reported an overrepresentation of male soccer from age categories U-9 to U-18 born late in the selection year. Musch and Grondin (2001) described factors related to the sports environment that can increase RAEs in men's sports, such as the sport’s popularity, competition level, early specialisation and the expectations of coaches involved in the selection process. Generally, soccer’s importance and popularity, for example, has increased over the past decade, leading to a larger number of players wishing to play (Cobley et al., 2008). Increasing participation and infrastructure are intensifying competition for elite teams. In addition, greater emphasis is being placed on clubs tracking down young players who are likely to become world-class athletes (Wattie, Cobley, & Baker, 2008).

Suggested solutions

Analogous to the maturation-selection hypothesis, a classification into categories according to biological age would be a possible option to prevent RAEs. For this reason, studies have been conducted to simplify the determination of BA in practice (Studies 2 and 3). Similarly, correction factors to reduce RAEs were developed and tested (Studies 4, 10 and 11).

Since the DXA technique uses 10 times less radiation than the gold-standard X-ray technique for determining BA, it was used to investigate whether imaging bones in the left hand with DXA allows for a valid determination of BA. Comparing X-ray and DXA images of 63 Swiss U-15 national players' left hands indicated excellent intrarater and interrater reliability. Bland-Altman plots showed that SA scores between X-rays and DXA did not differ significantly: by -0.2 years, with 95% of contract limits at ±0.6 years.

Another study compared BA, prediction of the age of peak height velocity (APHV) and coaches' visual estimates of 121 soccer players' biological maturation levels (Romann, Javet & Fuchslocher, 2017). The BA of soccer players was 13.9 ± 1.1 years and did not differ significantly from CA. The correspondence between BA-CA and APHV was 65.5%. The Spearman rank-order correlation (rs) between the maturities was moderate, and the kappa (k) was 0.25. The subjective classifications of coaches corresponded with the gold standard in 73.9% of the cases. The rs between maturity classifications was strong, with a k of 0.48, which was better than the widespread APHV rating.

In a study with 7,761 male athlete's aged 8-15 years, RAEs were analysed in athletic sprinting. When all athletes were included, typical RAEs occurred. RAE effect sizes grew with increasing performance levels (i.e., all athletes were in the top 10%) regardless of age group. In the second part, all athletes born in each quartile and within each annual age group were recorded linearly. Regression analyses showed that a relative age difference of almost one year resulted in average expected performance differences of 10.1% at age 8, 8.4% at age 9, 6.8% at age 10, 6.4% at age 11, 6.0% at age 12, 6.3% at age 13, 6.7% at age 14, and 5.3% at age 15. Correction adjustments then were calculated by day, month, quarter and year, and were used to show that RAEs can be removed effectively from all performance levels.

The same basic idea was applied to a population of Australian swimmers (Cobley et al., 2019). Based on raw swim times, RAEs were found at all performance levels and increased at each selection level. By correcting swimming times according to exact chronological age, RAEs also could be eliminated in swimming.

To sum up, it could be shown that DXA scans, which use significantly less radiation, still produce valid results in determining biological age. Furthermore, it could be shown that experienced trainers' subjective assessments of athletes' biological development indicates broad agreement with the gold standard and is superior to the currently used Mirwald method (Mirwald et al., 2002). Regarding RAEs, correction factors have been developed and tested in track and field (sprinting) and swimming, which eliminated RAEs.

Discussion

The prevalence of RAEs in the Swiss sports system and specific international sports has been shown. In addition, the causes and mechanisms have been described. BA has been considered to be the principal cause of RAEs; therefore, methods for its determination have been developed, validated, and implemented. In the current Swiss system, athletes who are favoured because of their RAs or BAs have benefitted from preferential selection, increased support, higher competition levels, additional training, longer playing times, more positive feedback, and improved coaching (Sherar et al., 2007). In Switzerland, biological development, specifically RA and BA, should be considered more systematically in talent identification (TID). In addition, before puberty, the focus should be less on current competition results and more on technical and tactical skills and the athletes' long-term potential (Vaeyens et al., 2008).

Prevalence

Generally, RAEs were found to play a role in athletes' trajectories at all selection levels, i.e., from participation in popular youth sports to junior competitive sports at the national level. For male athletes, RAEs increased at each selection level. Despite the presence of a systematic nationwide multi-level TID system, the RAEs in Switzerland were comparable to those of the other nations described in the extant literature (Cobley et al., 2009). However, knowledge of the prevalence of RAEs and the related activities in trainer education has not seemed to have exerted adequate influence. The challenge for the Swiss sports system is to retain the athletes who are physically or psychologically disadvantaged because of RAEs or BA. This applies particularly until the end of puberty.

Average RAEs were found in all 70 male sports in the Swiss TD programme. The effects were significantly greater at the national selection level. This finding was supported by the extant literature, which has shown an increasing risk for RAEs at a higher competitive level (Unnithan et al., 2012). Several factors can increase the risk of RAEs in a particular sport (see causes). In contrast to men's sports, all 63 women's sports registered few RAEs, with no relevant differences between the regional and national selection levels. Previous data have also shown differences in RAEs for girls and boys.

Cobley et al. (2009) summarised the results of 38 studies published between 1984 and 2007. They found a larger OR (Q1 vs. Q4) of 1.65 (95% CI [1.54, 1.77]) for male athletes than for female athletes {OR 1.21 [95% CI (1.10, 1.33)]}. Raschner et al. (2012) also observed a difference between men (OR 3.32) and women (OR 1.89) in a study of the more than 1,000 athletes who participated in the 2012 Youth Olympic Games. In a recent study of more than 10,000 participants in the London Youth Games, fewer RAEs were found in the girls' sports than in the boys' sports, in general (Reed, Parry, & Sandercock, 2017). A possible additional explanation could be that the number of male athletes in the Swiss TD was 2.5 times that of the female athletes. Approximately 11% of the national athletes were boys, and approximately 18% were girls. This reflects a larger selection pool and greater selection pressure for male athletes, and it could explain the difference in the RAEs for boys and girls. As suggested by Vincent and Glamser, additional factors might determine the RAEs in women's sports (Vincent & Glamser, 2006). In some sports, young women born in Q1 and Q2 are more likely to participate than their younger counterparts. Those born in Q3 and Q4 exhibit a kind of self-selection before even trying an activity possibly because of their less-suited physical characteristics (Romann et al., 2018).

However, in a different sport, the popular women's skiing sport, significant inverse RAEs occurred in the qualifying races. Thus, more girls born in Q4 than in Q1 participated. One possible explanation could be that female anaerobic and aerobic capacities, speed, and physical fitness plateau shortly after the onset of menstruation (Thomas, Nelson, & Church, 1991). Therefore, some of the physiological benefits of a high RA in a competition year could disappear in the U-14 and U-15 age categories. Accordingly, later-developed women often catch up to peers who matured early, and they can even become outstanding athletes (Malina et al., 2004). This can influence participation in ski races. During and after puberty, the physical characteristics required for athletic performance are sometimes in conflict with the stereotypical thin dainty ideal female body in Western countries (Choi, 2000). Accordingly, social pressure could also prevent women from performing at their best in competitive sports, and this could lead elite female skiers to abandon sports such as Alpine skiing (Romann &

Fuchslocher, 2011). In short, during and after puberty, female skiers in the first quarter may be more likely to drop out of ski racing than those in the fourth quarter.

Origin and mechanisms

The principal cause of RAEs is the differences in BA. This could result in performance differences that, together with parental influence, could trigger self-selection processes that determine a child's participation in organised sports. The next step entails the trainers' athlete assessments and selections, which enhance RAEs. The most important environmental factors are the sport's popularity (number of participants and economic factors), requirement profile, and selection level. Selection results in greater support, better training and higher competition levels, increased involvement, and more positive feedback, which positively influence performance. This results in a positive spiral for athletes at high RAs and a negative spiral for those at low RAs (the "vicious circle"), i.e., "false" talent is encouraged and "true" talent is lost. In this context, sociology and psychology play an important role. The Matthew effect (positive feedback: success always produces new success), the Pygmalion effect (individual performance matches external expectations), and the "self-fulfilling prophecy" (positive expectations lead to positive behaviour) are well-known mechanisms that influence current performance and promotion (Figure 1).

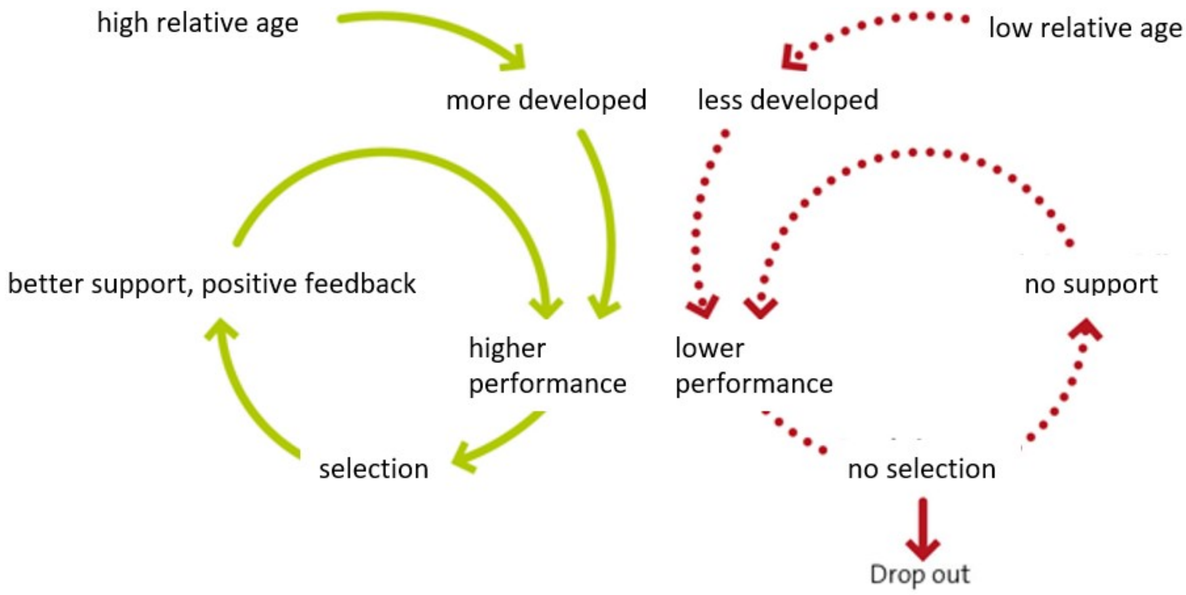

Figure 1. Vicious circle of RAEs in sports (Romann & Fuchslocher, 2010).

In the negative spiral, athletes are not selected because of their lower BAs and/or RAs and their lower performance levels. This leads to less support and training, lower competition levels, less involvement, and little positive feedback, which negatively influence performance. In addition, non-selected players might tend to have lower self-esteem and higher drop-out rates (Helsen et al., 1998). Delorme et al. (2010) offered two explanations for drop-out. First, it is common for children born late in the selection year to join a sport later or less often. Second, those who participate in sports have fewer chances of being selected or positively assessed; therefore, they have a higher drop-out rate.

Coaches or clubs are not the only entities that make selections. Because of a sport's popularity, stereotypes, and the associated social pressure, young athletes already might be performing self-selection upon entry (Romann & Fuchslocher, 2011, 2013a). A study of all Swiss sports showed that non-Olympic sports registered a lower risk of RAEs than Olympic sports. This could be attributed to the higher attractiveness of Olympic sports because of their greater media presence and funding. Non-Olympic sports are less popular and attract fewer young people (Fuchslocher et al., 2013). Higher attractiveness could lead to larger athlete pools for Olympic sports, and this increases the selection pressure (Musch & Grondin, 2001). This view is reinforced by the fact that only approximately 10% of the sample were involved in non-Olympic sports. The remaining athletes were active in Olympic sports. Interestingly, 12.4% of the Olympic athletes and 21.6% of the non-Olympic athletes were admitted to the national level, thereby confirming the higher selection pressure in Olympic sports. Moreover, the higher professionalism and the talent selection tools could be another reason for an increased risk for RAEs in Olympic sports (Armstrong & McManus, 2011). On the basis of the available evidence (Albuquerque et al., 2012, 2013), no relevant RAEs were found in the promotion of men's weight-class sports to young people. Similar observations have been made for martial arts (Delorme, 2014). This phenomenon could be explained as a "strategic adjustment," i.e., the voluntary transfer of children to another sport in which their physical abilities are less critical to their performance.

Parents also exert significant influence on the timing of their children's joining a club and the types of sports that they play. These mechanisms can be found in the data for Swiss youth soccer (Lüdin, Javet, Hintermann, & Romann, 2018; Romann & Fuchslocher, 2011, 2013a). Figure 2 illustrates these influential factors and interrelationships in RAEs.

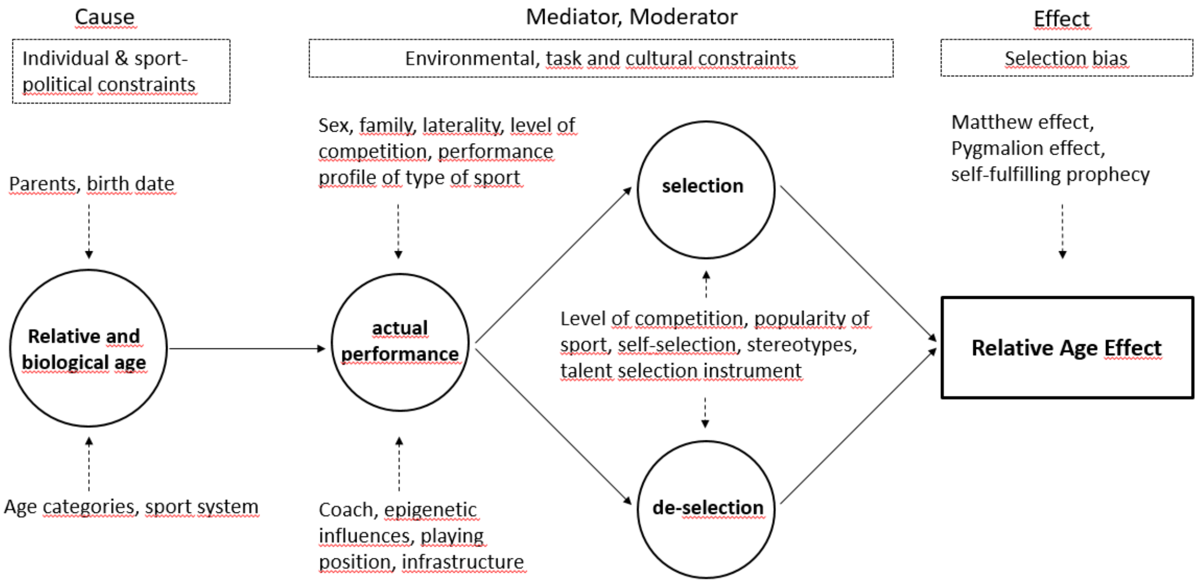

Figure 2: Mechanism of relative age effects

In the early childhood years, RA exerts the greatest influence within a one-year category in relation to CA. This influence decreases continuously as the CA increases (Figure 3). This means that by the end of puberty, athletes born in Q4 can catch up to or overtake those born in Q1. With the decreasing advantage of RA for Q1 birth and the decreasing talent pools (decreasing squad sizes), Q1 athletes in the older selection teams are less often. RA and BA explain the differences in the development of young athletes within an annual category. The fact that the greatest deviations in biological development occur during puberty means that some young athletes' physical and psychological advantages up to age 8 can be attributed mainly to differences in RA. From age 8, the influence of BA increases steadily. Simultaneously, the influence of RA decreases continuously. Therefore, it is estimated that from age 11 (young men), BA differences comprise the greater share of differing conditions. This larger proportion remains until the end of the growth spurt. It is clear then that the age category at which the selection is made is determinative. Before the eighth year of life, minor BA differences exist. Thus, it makes sense to pay attention to RA. Selections at a young age should generally be avoided because of the low prognostic validity (Höner & Feichtinger, 2016; Pearson, Naughton, & Torode, 2006). As athletes reach the age of 11, their BAs should be the focus.

A recent study by Müller et al. (2017) showed that selected young soccer players and Alpine skiers from the fourth quarter were classified disproportionately, relatively speaking, as physically early developed. Conversely, physically later-developed juniors were represented in only the first two quarters. In other words, the disadvantages caused by RA and BA seem to be “too much of a bad thing” for a junior athlete to overcome in selection. Either the disadvantages of RA can be compensated by advanced BA, or, conversely, these advantages can mask a low BA.

Suggested solutions

Modern TID and development models require that biological development be included in the selection processes (Unnithan et al., 2012), which require practical methods for determining and considering BA and RA. Therefore, assessments of BA through DXA and sports coaches’ subjectivity were developed and validated. In addition, it could be shown that RAEs can be adjusted by the implementation of correction factors.

An association’s or club’s goal is to identify and to develop promising young players who can subsequently be promoted to elite teams. Thus, it is crucial that talent models be able to distinguish between the players’ current and potential performance levels (Vaeyens et al., 2008). However, athletes’ BAs strongly influence their performance levels. Therefore, for TID, it is necessary to classify young people according to their development levels so that the appropriate training and competition programmes can be designed.

Many sports clubs and associations already select their athletes on the basis of scouts’ and coaches’ subjective assessments. However, these assessments are often aimed at selecting players with early biological maturity because of the strong correlation between biological maturity and the development of physical characteristics, motor skills, and specific soccer skills. Invasive methods, such as X-rays of the hand bones to measure age, and the Tanner scale, are often ethically and financially unacceptable in junior sports. Because the non-invasive Mirwald et al. (2002) method is not applicable at young ages (under age 12), a new method for determining BA is needed (Malina & Koziel, 2014).

The study with Swiss elite coaches showed that the coaches' visual assessments of the athletes were a valid method for determining biological maturation in selecting the U-15 junior national team. Such assessments were even more reliable than the widely used APHV method. A comparison with the gold-standard X-ray method indicated that the trainer's eye has the advantage of much faster information retrieval, lower costs, and the absence of radiation exposure. Therefore, the classification and integration of biological maturity on the basis of the coach's eye could be the first step toward the more equitable and efficient identification and development of young athletes. In sports, the systematic and comprehensive implementation of maturity classifications could exert a significant influence on assessment, selection, training, and performance evaluation during athlete development (Romann et al., 2017).

Corrective adjustments calculated by day, month, quarter, and year showed that the influence of RA and, thus, normative growth and development can be taken into account, with the RAEs removed from sprint performance. Corrective adjustments could also be considered for other track and field disciplines (e.g., 100 m sprints, long jump, and throwing sports); however, evaluations will be needed. It is important that the results provide a possible solution for removing RAEs, increasing children and youth sports participation, and improving athlete assessment and selection. Corrective action can exert a significant influence on children and youths in team and individual sports measured in cm, grams or seconds (CGS) (Cobley et al., 2019; Romann & Cobley, 2014b, 2015). The elimination or lack of consideration of the influence of RA results in consistent and, sometimes, large RAE sizes. In Switzerland, corrective action can help to prevent potential sprinters from being ignored or missed because of RA or late maturity. For team sports, such as soccer and rugby, in which the players are often assessed through standard multi-anthropometric and physiology or fitness tests (e.g., sprint times, vertical jump), corrective action could inform and improve the validity of player assessment and selection procedures. Therefore, the implementation of testing and corrective action in specific junior

CGS sports or sports in which physical performance components are measured are important directions for the future. However, whether sports instructors, federations, managers and athlete development systems would benefit from the implementation of such procedures remains to be seen. The greatest challenge might be to obtain a comprehensive reference dataset to generate accurate regressions and subsequent corrections. The possible measures for counteracting RAEs are summarised in Table 2.

Measure	Method	Note on the method; effort	Reference
Bio-Banding (biological indicators) Advantages: • Large reduction of BA differences • Large reduction of RAEs • Adjusted intensities	Age at peak height velocity (Mirwald)	Exact standardisation necessary; middle	(Mirwald, Baxter-Jones, Bailey, & Beunen, 2002)
	Subjective evaluation	High experience needed Control of interrater variability needed; small	(M. Romann, M. Javet, & Fuchslocher, 2017)
	Bone age (Hand-wrist X-Ray)	Minimal radiation exposure Gold standard; large	(Malina, Coelho, Figueiredo, Carling, & Beunen, 2012)
	Percent of adult height	Body height is just one indicator of biological age; small	(Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017)
	Actual height	Ethically problematic (heavy children at disadvantage); small	(Malina, Ribeiro, Aroso, & Cumming, 2007; Moore et al., 2015)
	Actual weight	Body height is just one indicator of biological age; small	(Reilly, Williams, Nevill, & Franks, 2000)
Corrective adjustments Advantages: • reduction of BA differences • Large reduction in RAEs	Bonus points for low relative/biological age	Only for selections; middle	(Fuchslocher et al., 2013)
	Corrective adjustment of relative age	Additional research is needed; middle	(Romann & Cobley, 2015)
	Shirt numbering, which indicates relative/biological age	Only for selections; middle	(Gil et al., 2014; Sherar et al., 2007)
	Quotas	High selection pressure for Q1/early maturing athletes; small	(Musch & Grondin, 2001)
Structural adjustments Advantages: • reduction of BA differences and RAEs	Rotating cut-of dates	Shift of RAEs; middle	(Barnsley et al., 1985)
	Change of category takes place on the birthday of the athlete	Constant change of individual athletes; small	(Cumming et al., 2017)
	Smaller age bands (e.g. 6 month)	Implementation complex more teams; large	(Boucher & Halliwell, 1991)
	Change grouping by sensitizing coaches to BA or RA issues	Effectivity low; middle	(W. F. Helsen et al., 2012)
	Q4/late mature selection days	Subsequent correction; middle	(Cumming et al., 2017)

Table 2: Measures to counteract RAEs.

Conclusive Summary

In sum, RAEs are present in many sports, and they expose the biases in many TID systems. Because of the incentives for short-term success in junior competitive sports, coaches select athletes who demonstrate highly competitive performance levels in the short term. This means that they select athletes with advanced physical and psychological development. In the current sports selection system, which is based on CA categories, this leads to the selection of a disproportionate number of biologically and/or chronologically older athletes.

The differences in BA are the principal cause of RAEs. This leads to differences in performance, which, together with parental influence, trigger the self-selection processes that determine a child's participation in organised sports. The next step is for coaches to make assessments and selections that enhance RAEs. The most important environmental factors are the sport's popularity (number of participants and economic factors), requirement profile, and selection level. Selection affords an athlete increased support, more training, participation at higher competition levels, greater involvement, and constructive feedback, which positively influence performance. This leads to a positive spiral for athletes with higher RAs and a negative spiral for those with lower RAs (the "vicious circle"). This means that "false" talent is encouraged and "true" talent is lost. Thus, many athletes with the potential for success in adulthood are overlooked. In particular, women's sports can benefit from knowledge about BA and RAEs.

TID programmes must seek to reduce the risk of RAEs by raising awareness, monitoring athletes' maturity, and avoiding early selection or deselection. If selection is necessary because of a lack of resources, BA and RA considerations should be integrated into a long-term multidisciplinary approach. The implementation of these measures can result in equity in talent selection and the more efficient use of available resources.

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Annex I

Declaration of habilitation procedures that were started earlier or failed

I declare that I have written the present work independently, without outside assistance and without the use of aids other than those specified. Additionally I declare that I have not yet started any other habilitation or that one has failed.

Magglingen, 02 December 2020

…………………..
Michael Romann

Annex II

Full texts of publications

Peer reviewed publication (sorted by author and year)	**Full text page**
Cobley, S., Abbott, S., Dogramaci, S., Kable, A., Salter, J., Hintermann, M., & **Romann, M.** (2018). Transient Relative Age Effects across annual age groups in National level Australian Swimming. Journal of Science and Medicine in Sport, 21(8), 839-845.	35
Cobley, S., Abbott, S., Eisenhuth, J., Salter, J., McGregor, D., & **Romann, M**. (2019). Removing relative age effects from youth swimming: The development and testing of corrective adjustment procedures. Journal of Science and Medicine in Sport.	42
Franchi, M. V., Ellenberger, L., Javet, M., Bruhin, B., **Romann, M**., Frey, W. O., & Spörri, J. (2019). Maximal eccentric hamstrings strength in competitive alpine skiers: cross-sectional observations from youth to elite level. Frontiers in Physiology, 10, 88.	48
Romann, M., & Cobley, S. (2015). Relative age effects in athletic sprinting and corrective adjustments as a solution for their removal. PLoS One, 20(3).	56
Romann, M., & Fuchslocher, J. (2011). Influence of the selection level, age and playing position on relative age effects in Swiss women's soccer. Talent Development & Excellence, 3(2), 239-247.	68
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Romann, M., & Fuchslocher, J. (2014a). The need to consider relative age effects in women's talent development process. Perceptual and Motor Skills, 118(3), 1-12.	95
Romann, M., & Fuchslocher, J. (2014b). Survival and success of the relatively oldest in Swiss youth skiing competition. International Journal of Sports Science and Coaching, 9(2), 347-356.	107
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Romann, M., Rössler, R., Javet, M., & Faude, O. (2018). Relative age effects in Swiss talent development–a nationwide analysis of all sports. Journal of Sports Sciences, 1-7.	152
Smith, K. L., Weir, P. L., Till, K., **Romann, M.**, & Cobley, S. (2018). Relative Age Effects Across and Within Female Sport Contexts: A Systematic Review and Meta-Analysis. Sports Medicine. 48(6),1451-1478.	159

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Original research

Transient Relative Age Effects across annual age groups in National level Australian Swimming

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ABSTRACT

Objectives: To determine the prevalence, magnitude and transient patterning of Relative Age Effects (RAEs) according to sex and stroke event across all age-groups at the Australian National age swimming Championships.
Design: Repeated years of cross-sectional participation data were examined.
Methods: Participants were 6014 unique male (3185) and female (2829) swimmers (aged 12–18 years) who participated in Freestyle (50, 400 m) and/or Breaststroke (100, 200 m) at the National age swimming Championships between 2000–2014 (inclusive). RAE prevalence, magnitude and transience were determined using Chi-square tests and Cramer's *V* estimates for effect size. Odds Ratios (OR) and 95% Confidence Intervals (CI) examined relative age quartile discrepancies. These steps were applied across age-groups and according to sex and each stroke event.
Results: Consistent RAEs with large-medium effect sizes were evident for males at 12–15 years of age respectively, and with large-medium effects for females at 12–14 respectively across all four swimming strokes. RAE magnitude then consistently reduced with age across strokes (e.g., Q1 vs. Q4 OR range 16 year old males = 0.94–1.20; females = 0.68–1.41). With few exceptions, by 15–16 years RAEs had typically dissipated; and by 17–18 years, descriptive and significant inverse RAEs emerged, reflecting overrepresentation of relatively younger swimmers.
Conclusions: Performance advantages associated with relative age (and thereby likely growth and maturation) are transient. Greater consideration of transient performance and participation in athlete development systems is necessary. This may include revising the emphasis of sport programmes according to developmental stages and delaying forms of athlete selection to improve validity.

1. Introduction

Across many youth sports contexts, the procedure of (bi-)annual age-grouping is implemented for logical organisation purposes and to reduce developmental differences between competitors on the basis of safety and equity.[1,2] However in athlete development terms, annual age-grouping still permits the potential for up to 12 months of chronological age difference and potentially greater biological age difference during years associated with maturation.[3] As a consequence, Relative Age Effects (RAEs[4]) can emerge; reflecting outcomes from an interaction between participants' birth dates and the dates used for chronological age grouping.[5] Being relatively older within an age grouping is associated with consistent attainment and selection advantages across junior and representative stages of sport, including an increased likelihood of selection to access further resources within athlete development systems, such as coaching expertise; skill development programmes; and, physical conditioning support.[1,3,6]

RAEs are most prevalent and with the highest effect sizes in male team sports contexts. By comparison, sport and age-matched female contexts have shown either lower RAE effect sizes or have been less prevalent; though fewer samples have been examined.[1,7] At various male junior and youth tiers (i.e., school, local community, representative and international) of soccer,[8,9] baseball,[10]

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handball,[11] rugby[6] and Australian rules football,[12] participation ratios between the relatively oldest and youngest quartiles have varied from small (e.g., 1.51), moderate (3.51) and in some cases large (≥51). Higher magnitude RAEs are associated with selective representative contexts at ages associated with puberty and maturation.[13] More recently, studies have identified that individual but still physically demanding sports are also associated with RAEs, notably including athletic sprinting,[5] tennis,[14] ski-jumping, cross-country and alpine skiing.[15,16] By comparison, sports with less dependence on physical characteristics and which have a technical skill emphasis have not been associated with RAEs (e.g., golf & shooting).[17]

Several hypotheses have been proposed to account for RAEs,[3,18] though most supported by evidence is the 'maturation-selection hypothesis'.[1,19,20] The hypothesis states that greater chronological age is equated with an increased likelihood of enhanced anthropometric characteristics from normative growth. Greater height and lean body mass (to a degree) are predictive of better physical capacities such as aerobic power, muscular strength, endurance and speed.[21] In turn, these provide physical performance advantages in specific tasks.[22] Also, during puberty, the timing and tempo of physical development generate further anthropometric and physical variation between individuals until its cessation.[23] Unfortunately for the relatively younger or later maturing, these processes lead to shorter-term disadvantages where they are more likely to be overlooked and excluded[24] at various stages of junior and youth sport, at least until the end of growth and maturation.

In the longer-term, recent studies suggest RAE and maturation inequalities may be transient on athlete development. Based on examining Candian ice-hockey players entering the professional NHL draft (aged 18–20), Deaner et al.,[25] initially identified a typical RAE with 36% and 14.5% being relatively older and younger respectively. However, the relatively younger actually went on to play in 20% of all NHL games played by the sample and were twice as likely to attain career benchmarks (i.e., 400–600+ games played). The relatively older were less likely to play a single NHL game and underperformed given their draft overrepresentation. Similarly, in UK Rugby League, the likelihood of attaining a professional contract at 18+ years old was associated with being relatively younger and later maturing. In their longitudinally data, it was identified that by 15–16+ years old later maturing players 'caught-up' with their early maturing counterparts on performance measures[26–28] illustrating transient patterns. That said, evidence of these transient patterns is still limited and explanatory mechanisms remain speculative. Thus, identifying RAE transiency is significant with important implications for sport systems, their practitioners and athletes.

As an individual sport context with high physiological demands, competitive swimming has received limited RAE examination,[29,30] yet RAE prevalence can be hypothesised. Relative age and maturation relate to physical (e.g., VO_2max; upper and lower body strength) and anthropometric (e.g., height, lean mass) development and these characteristics predict performance.[23,31] The influence of relative age and maturation on performance can also be isolated as other extraneous or confounding inter-athlete factors are not present (e.g., coach selection, team interaction).[12,25] Further at many swimming events, there are often sex-specific age-groups spanning junior and youth ages (e.g. 12–18 years old), divided according to stroke (e.g., freestyle; breaststroke) and distances (50 m & 400 m). Therefore, whilst recognising performance requirements in these events, an examination of transient RAE participation patterns is feasible.

In Australia, swimming is culturally iconic and one of the most popular individual sporting and leisure activities. Twenty-eight–thirty percent of all children and 14–16% of all adults are estimated to participate at some level.[32] Swimming Australia (the National sporting organisation) contains nearly 1000 swimming clubs and 90,000 registered members[33] reflecting participation from grassroots community to the elite National team. Connecting participation to competition, Swimming Australia has a junior and youth competition structure spanning states and territories reflecting regional or state level competition. The culmination and pinnacle of junior competition are the National age Championships. It is in this latter context that the current study resides. Based on a substantial data-set tracking 14 years of participation at the National age Championships, the purpose of this study was to determine the prevalence, magnitude and transient patterning of RAEs according to sex and four stroke events (i.e., Freestyle — 50 m & 400 m; Breaststroke — 100 m & 200 m) within and across Australian Swimming age-group competition. If RAE patterns were identified, we rationalised findings held potentially significant and wide-ranging implications for Swimming Australia and their athlete development system.

2. Methods

Following institutional ethical approval, participants were N = 6014 unique male (n = 3185) and female (n = 2829) male and female swimmers (aged 12–18 years). These swimmers had competed in either specific or multiple swimming stroke events at the Australian National age Championships between 2000–2014 (inclusive). Multiple years of cross-sectional data were examined to increase participant numbers in the sampling frame and to capture an accurate representative account of participation trends over time. To participate at the championships, swimmers have to be 12–18 years old, and whether competing in 'heats' only or 'finals' for a given stroke and distance, participation reflected the fastest qualification times in Australia for a given year. Respective age-groups were determined by the swimmer's age on the first day of the annual championship event, with cut-off dates marginally changing each year (often early April). For example, in the year 2000 the cut-off date was 10th April while in 2014 it was 14th April.

In this study, data pertaining to Freestyle (50 m & 400 m) and Breaststroke (100 m & 200 m) were examined to reflect a sampling frame acknowledging between stroke and within stroke factors. Freestyle was sampled as it is considered to be the fastest of the four strokes, while Breaststroke is regarded as the slowest.[34,35] Due to mechanical and drag differences associated with these strokes,[36] they are also associated with different energetic requirements[37] and which interact with distance. Thus, two different distances for each stroke were examined. However, as we wanted to examine RAE trends across males and female and across multiple years of annual Championships, constraints related to stroke distances sampled were apparent. As the National Age Championships mimics the Olympic event schedule, the 50 m and 400 m Freestyle reflected the shortest and longest distances where both sexes participated and permitted an assessment as to whether physiological factors attenuated RAE trends. However, equivalent distances in Breaststroke were not available, and the 100 m and 200 m were the only events available. That said, these sampled stroke events did reflect the most competitive (i.e., higher participation numbers) in the Championship schedule and were considered informative for athlete evaluation and selection purposes.

In collaboration with Swimming Australia, participation data associated with the National age Championships was retrieved from two secure databases (i.e., 'Team Manager' and 'Event Manager') by two employees. Data was then systematically screened for data entry errors, with multiple identified and corrected. Data entry accuracy was also randomly checked with coaches and former participating athletes. Screening checked that only one participant entry was permitted for a given stroke and distance per year. In other words, multiple registering for heats and a final in one stroke and distance were removed. If a participant competed in another stroke, distance or year of the Championship the entry remained as strokes were examined independently. An anonymised dataset containing only swimmer date of birth, sex, year of Championship event, date applied for annual age group cut-offs, age-group, swimming stroke and distance, date of performance and performance time was then transferred for further analysis.

To confirm RAEs were not associated with broader population birth patterns, the number and distribution of births in the Australian population were examined. Monthly live birth data was accessed from the Australian Bureau of Statistics.[38] Mean monthly birth rates in Australia from 1981–2001, coinciding with the month and birth years of swimmers, were extracted. Considering the specific and marginally altering annual dates used for age-group cut-offs at the age Championships (i.e., early April), wider population birth distributions were grouped from April 1st into quartiles. Across the sampling period, 5,253,444 live births occurred and were evenly distributed (i.e., Q1: April–Jun = 24.89%; Q2: July–Sept = 25.02%; Q3: Oct–Dec = 25.56%; Q4: Jan–Mar = 24.53%, $w = 0.01$). For data analysis purposes, the finding suggests that a theoretically equal distribution of participants could be expected. Secondly, if RAEs were identified, they were unlikely to be associated with broader population trends and more likely associated with processes within the swimming system.

For both male and females in age-groups (i.e., 12–18 years) and according to each of the four identified strokes examined, Chi-square tests were initially deployed across relative age quartiles (i.e., Q1–Q4) to determine differences between observed and normatively expected distributions. Post hoc tests, using Cramer's V, identified the magnitude of effect size between Q1 and Q4 frequency counts. Magnitude estimates ranging between $0.06 < V \leq 0.17$ were used to indicate a small effect size, $0.17 < V < 0.29$ a medium effect, and, $V \geq 0.29$ a large effect size.[39] In addition, Odds Ratios (OR) and matching 95% Confidence Intervals (CI) between quartiles (i.e., Q1 vs. Q4; Q2 vs. Q4; Q3 vs. Q4) provided a common risk indicator of effect size. OR estimates and accompanying CI's >1 identified an odds increase in favour of Q1, while OR's and CI's below 0 indicated a risk reduction with Q4's more likely to be participating. Q4 swimmers were used as the referent group in all quartile comparisons.

3. Results

Table 1 summarises relative age (quartile) distributions, Chi-square, effect size estimation and categorization, as well as Odds Ratio analyses for male participants according to stroke, distance and age-group. Results identified that regardless of event examined, RAEs were particularly prevalent in the 12–14 years old age groups with large-medium effect sizes respectively. Across strokes, Q1 vs. Q4 OR's identified that at 12 years old, the relatively older were between 8.00–23.50 times more likely to participate than the relatively younger. Thereafter, while RAEs remained, they reduced in effect size with age across strokes and distances (i.e., 13 years old — Q1 vs. Q4 OR range = 2.05–2.92; 14 years = 1.77–2.29). By 15 (200 m Breaststroke) or 16 years (400 m Freestyle & 100 m Freestyle) and often around the peak of participant numbers at the Championships, RAE related inequalities dissipated (except for 50 m Freestyle where typical RAEs remained). Of particular note however, by 17–18 years of age descriptive inverse RAE patterns had emerged (e.g., see 400 m Freestyle — Q4 > Q1). Supplementary material 1a & b and 2a & b provides a visual summary of RAEs transiency across age-groups in male Freestyle (50 m and 400 m) and Breaststroke (100 m & 200 m) respectively.

Table 2 summarises data related to female participants according to stroke, distance and age-group. Results identified that typical RAEs were prevalent in the 12–13 years old age groups with large-medium effect sizes respectively. In 50 m Freestyle, significant RAE discrepancies remained until 15 years of age. Specific OR comparisons were also in alignment, identifying regardless of stroke OR's between 4.00–9.00 in Q1 vs. Q4 comparisons at 12 years old, reducing linearly to approximately 1.10–1.39 by 14 years of age. By 15 years of age typical RAEs either had small effect sizes (50 m Freestyle), had dissipated (e.g., 100 m & 200 m Breaststroke) or descriptive inverse RAE patterns had emerged (400 m Freestyle). At 16 and 17 stroke specific trends emerged, though distributions all progressively moved toward favouring the relatively younger (e.g., 200 m Breaststroke). By 17 and 18 in the 400 m Freestyle, significant inverse RAE patterns were evident with small-medium effect sizes. Q1 vs. Q4 comparisons identified the relatively older as potentially being 68% less likely to compete in the 18-year-old 400 m Freestyle (95% CI 0.11–0.92). Transiency toward overrepresentation in relatively younger swimmers was also supported by significant trends in Breaststroke (100 m and 200m) at 18 years of age. Fig. 1a & b provides visual summary of transient RAEs across age-groups in female Freestyle (50 m and 400 m), while Supplementary material 3a & b graphically summarises data related to Breaststroke (100 m & 200 m).

4. Discussion

The purpose of the present study was to determine the prevalence, magnitude and transient patterning of RAEs across Australian National level age-group competition according to sex and stroke (distance). Findings identified that regardless of swimming stroke examined, consistent RAEs with large-medium effect sizes were apparent for males at 12–15 years of age, and with large-medium effects for females at 12–14. Again irrespective of stroke and distance, RAE magnitude then consistently and progressively reduced with age-group (Q1 vs. Q4 OR range — 14-year-old male = 1.77–2.29; female = 1.10–1.39) so that by 15–16 years (with a few notable exceptions) RAEs were typically absent or minimal. However, by 17–18 years, descriptive and significant inverse RAEs had emerged, reflecting over representations of relatively younger swimmers in National level swimming and at a time point close to senior (adult) competition transition.

Efficacy for present findings is reinforced by the examination of 14 years of annual competition participation data at all age-groups of the National age Championships. From within the dataset, Freestyle (50 m & 400 m) and Breaststroke (100 m & 200 m) events were sampled, and a standard analytical approach applied to aid comprehensive analysis. Present findings add to existing literature in several ways. They highlight (i) how RAE effect sizes in earlier age groups are transient, reducing and potentially reversing at later age stages; (ii) examine RAE prevalence in an under-examined individual sport context; and (iii) identify similar RAE prevalence and magnitudes in female swimming events, adding to limited data available related to female sport contexts.[1]

Present findings also indirectly support the 'maturation-selection hypothesis'[1,19,20] of RAEs. Historically speaking, swimming has been synonymous with 'earlier age' athlete development programmes, 'early specialisation' practices (e.g., high intensive training loads) and tiers of selection and representation during ages associated with growth and maturation (males 12–15; females 11–14).[13] On this basis, it perhaps less surprising that the relatively older and/or 'early maturing' have benefitted from anthropometric and physical advantages underpinning performance, accounting for their over-representation in corresponding age-groups. Support is also gained from the consistency in transient patterns between

Table 1
Distribution, Chi-square and Odds Ratio analysis of male participants at the National Swimming Championships (2000–2014 inclusive) according to stroke, stroke distance, annual age-group and quartile.

Stroke	Age-group	Total *N*	Q1%	Q2%	Q3%	Q4%	X^2	*P*	*V*	*ES cat.*	OR Q1 vs. Q4	(95%CI)	OR Q2 vs. Q4	(95%CI)	OR Q3 vs. Q4	(95%CI)
50 m Freestyle	12 years old	81	0.59	0.22	0.11	0.07	54.56	0.000*	0.47	Large	8.00*	2.80–22.83	3.00*	1.01–9.11	1.50	0.45–4.99
	13 years old	621	0.43	0.26	0.17	0.15	123.39	0.000*	0.26	Medium	2.92*	2.11–4.05	1.77*	1.26–2.49	1.13	0.79–1.62
	14 years old	787	0.39	0.26	0.18	0.17	93.70	0.000*	0.20	Medium	2.29*	1.72–3.04	1.55*	1.15–2.08	1.08	0.80–1.47
	15 years old	715	0.35	0.25	0.20	0.20	43.98	0.000*	0.14	Small	1.73*	1.29–2.32	1.23	0.91–1.67	0.97	0.71–1.32
	16 years old	708	0.31	0.24	0.19	0.26	19.18	0.000*	0.10	Small	1.20	0.90–1.60	0.96	0.71–1.28	0.75	0.55–1.02
	17 years old	279	0.29	0.24	0.17	0.29	11.19	0.011*	0.12	Small	1.00	0.64–1.57	0.82	0.51–1.30	0.59	0.36–0.95
	18 years old	268	0.27	0.22	0.22	0.29	4.12	0.249	0.07	Small	0.92	0.58–1.47	0.77	0.48–1.24	0.74	0.46–1.20
400 m Freestyle	12 years old	40	0.60	0.28	0.08	0.05	31.00	0.000*	0.51	large	12.00*	2.22–64.90	5.50	0.96–31.43	1.50	0.20–11.00
	13 years old	269	0.37	0.32	0.16	0.15	40.90	0.000*	0.23	Medium	2.44*	1.48–4.01	2.10*	1.27–3.47	1.02	0.59–1.77
	14 years old	339	0.37	0.32	0.15	0.17	49.50	0.000*	0.22	Medium	2.23*	1.44–3.45	1.93*	1.24–3.00	0.89	0.55–1.45
	15 years old	345	0.32	0.26	0.21	0.21	9.86	0.020*	0.10	Small	1.47	0.97–2.24	1.20	0.78–1.85	0.99	0.64–1.53
	16 years old	325	0.29	0.26	0.19	0.25	6.61	0.086	0.08	Small	1.16	0.76–1.77	1.04	0.67–1.60	0.77	0.49–1.20
	17 years old	124	0.24	0.30	0.16	0.30	6.26	0.100	0.13	Small	0.81	0.41–1.62	1.00	0.51–1.96	0.54	0.26–1.13
	18 years old	113	0.23	0.22	0.19	0.36	8.17	0.043*,a	0.16	Small	0.63	0.31–1.30	0.61	0.30–1.25	0.51	0.24–1.07
100 m Breaststroke	12 years old	70	0.67	0.23	0.07	0.03	72.51	0.000*	0.59	large	23.50*	4.93–112.12	8.00*	1.60–40.12	2.50	0.43–14.66
	13 years old	460	0.38	0.28	0.18	0.16	53.97	0.000*	0.20	Medium	2.35*	1.62–3.42	1.72*	1.17–2.52	1.15	0.77–1.72
	14 years old	531	0.34	0.28	0.17	0.17	47.52	0.000*	0.17	Medium	2.00*	1.41–2.83	1.64*	1.15–2.33	1.00	0.69–1.46
	15 years old	546	0.30	0.26	0.21	0.22	11.93	0.008*	0.09	Small	1.37	0.98–1.91	1.19	0.85–1.67	0.95	0.67–1.35
	16 years old	514	0.27	0.23	0.22	0.28	6.39	0.094	0.06	Small	0.97	0.69–1.35	0.81	0.58–1.15	0.77	0.54–1.08
	17 years old	227	0.29	0.25	0.20	0.26	3.43	0.330	0.07	Small	1.08	0.65–1.80	0.93	0.56–1.57	0.77	0.45–1.31
	18 years old	175	0.23	0.21	0.23	0.33	5.73	0.125	0.10	Small	0.72	0.40–1.29	0.63	0.35–1.14	0.72	0.40–1.29
200 m Breaststroke	12 years old	45	0.71	0.18	0.07	0.04	52.87	0.000*	0.63	large	16.00*	3.07–83.34	4.00	0.69–23.16	1.50	0.21–10.77
	13 years old	375	0.35	0.29	0.18	0.17	33.95	0.000*	0.17	Medium	2.05*	1.35–3.09	1.66*	1.09–2.53	1.06	0.68–1.65
	14 years old	419	0.32	0.31	0.20	0.18	26.62	0.000*	0.15	Small	1.77*	1.20–2.62	1.72*	1.16–2.55	1.09	0.72–1.65
	15 years old	438	0.29	0.27	0.21	0.23	7.28	0.064	0.07	Small	1.29	0.89–1.88	1.19	0.82–1.74	0.94	0.64–1.38
	16 years old	407	0.27	0.25	0.21	0.28	5.24	0.155	0.07	Small	0.94	0.64–1.37	0.87	0.59–1.28	0.73	0.49–1.08
	17 years old	186	0.30	0.22	0.24	0.25	2.60	0.457	0.07	Small	1.17	0.67–2.05	0.85	0.47–1.53	0.94	0.53–1.67
	18 years old	129	0.26	0.23	0.20	0.31	3.25	0.355	0.09	Small	0.83	0.42–1.61	0.75	0.38–1.48	0.65	0.32–1.30

Notes: Q1–Q4 = Quartile 1–4; Q1–Q4% = Quartile percentage of total number; χ^2 = Chi-square value; *P* = probability value; *V* = Cramer's *V* effect size. *ES cat.* = effect size category; OR = Odds Ratio; 95%CI = 95% Confidence Intervals.
[*] Significance $p < 0.05$.
[a] Inverse RAEs (Q4 > Q1).

Table 2
Distribution, Chi-square and Odds Ratio analysis of female participants at the National Swimming Championships (2000–2014 inclusive) according to stroke, stroke distance, annual age-group and quartile.

Stroke	Age-group	Total *N*	Q1%	Q2%	Q3%	Q4%	X^2	*P*	*V*	*ES cat.*	OR Q1 vs. Q4	(95%CI)	OR Q2 vs. Q4	(95%CI)	OR Q3 vs. Q4	(95%CI)
50 m Freestyle	12 years old	163	0.43	0.29	0.18	0.10	39.18	0.000[*]	0.28	Medium	4.12	2.08–8.17[*]	2.76	1.37–5.59[*]	1.71	0.81–3.57
	13 years old	628	0.37	0.29	0.16	0.18	72.14	0.000[*]	0.20	Medium	2.02	1.47–2.77[*]	1.62	1.18–2.24[*]	0.87	0.61–1.23
	14 years old	802	0.30	0.30	0.19	0.21	28.55	0.000[*]	0.11	Small	1.39	1.06–1.84[*]	1.41	1.07–1.86[*]	0.92	0.68–1.23
	15 years old	723	0.27	0.28	0.20	0.25	12.12	0.007[*]	0.07	Small	1.07	0.80–1.43	1.10	0.83–1.47	0.78	0.57–1.05
	16 years old	639	0.24	0.26	0.23	0.27	2.52	0.471	0.04	no	0.89	0.66–1.22	0.98	0.72–1.33	0.86	0.63–1.17
	17 years old	332	0.22	0.27	0.23	0.28	3.54	0.315	0.06	no	0.79	0.51–1.22	0.99	0.65–1.51	0.83	0.54–1.27
	18 years old	177	0.21	0.24	0.24	0.31	3.72	0.293	0.08	Small	0.69	0.38–1.24	0.76	0.43–1.36	0.76	0.43–1.36
400 m Freestyle	12 years old	40	0.45	0.30	0.18	0.08	12.60	0.006[*]	0.32	large	6.00	1.33–27.00[*]	4.00	0.86–18.64	2.33	0.47–11.69
	13 years old	260	0.35	0.31	0.15	0.19	27.42	0.000[*]	0.19	Medium	1.86	1.14–3.03[*]	1.63	1.00–2.68[*]	0.82	0.48–1.40
	14 years old	294	0.27	0.29	0.21	0.24	3.99	0.263	0.07	Small	1.10	0.70–1.73	1.18	0.75–1.86	0.86	0.54–1.38
	15 years old	348	0.22	0.27	0.20	0.32	12.62	0.006[*,a]	0.11	Small	0.68	0.45–1.04	0.86	0.58–1.29	0.62	0.40–0.94[a]
	16 years old	287	0.20	0.29	0.22	0.29	8.54	0.036[*,a]	0.10	Small	0.68	0.42–1.08	1.00	0.64–1.56	0.74	0.46–1.17
	17 years old	136	0.20	0.29	0.16	0.35	11.71	0.008[*,a]	0.17	Small	0.57	0.29–1.12	0.85	0.45–1.61	0.47	0.23–0.94[a]
	18 years old	64	0.13	0.25	0.23	0.39	9.13	0.028[*,a]	0.22	Medium	0.32	0.11–0.92[a]	0.64	0.25–1.63	0.60	0.23–1.54
100 m Breaststroke	12 years old	132	0.47	0.30	0.16	0.08	46.97	0.000[*]	0.34	large	6.20	2.72–14.13[*]	3.90	1.67–9.09[*]	2.10	0.86–5.14
	13 years old	405	0.34	0.32	0.19	0.16	39.69	0.000[*]	0.18	Medium	2.14	1.43–3.21[*]	2.00	1.33–3.01[*]	1.19	0.77–1.83
	14 years old	541	0.30	0.28	0.19	0.23	15.86	0.001[*]	0.10	Small	1.30	0.93–1.81	1.23	0.88–1.73	0.83	0.58–1.18
	15 years old	535	0.25	0.26	0.23	0.26	1.44	0.696	0.03	no	0.97	0.69–1.36	0.98	0.70–1.37	0.87	0.62–1.23
	16 years old	559	0.35	0.21	0.19	0.25	35.98	0.000[*]	0.15	Small	1.41	1.01–1.97[*]	0.84	0.59–1.20	0.74	0.53–1.05
	17 years old	239	0.24	0.23	0.24	0.29	1.92	0.589	0.05	no	0.83	0.50–1.36	0.81	0.49–1.34	0.83	0.50–1.36
	18 years old	87	0.22	0.28	0.14	0.37	9.78	0.021[*,a]	0.19	Medium	0.59	0.26–1.35	0.75	0.34–1.66	0.38	0.15–0.91[a]
200 m Breaststroke	12 years old	95	0.47	0.36	0.12	0.05	45.08	0.000[*]	0.40	large	9.00	3.04–26.63[*]	6.80	2.27–20.38[*]	2.20	0.66–7.31
	13 years old	313	0.37	0.31	0.18	0.14	45.58	0.000[*]	0.22	Medium	2.66	1.67–4.24[*]	2.20	1.37–3.54[*]	1.25	0.75–2.07
	14 years old	420	0.30	0.28	0.21	0.21	9.54	0.023[*]	0.09	Small	1.39	0.95–2.04	1.29	0.88–1.90	0.99	0.66–1.47
	15 years old	429	0.24	0.24	0.24	0.27	1.24	0.744	0.03	no	0.90	0.62–1.31	0.90	0.62–1.31	0.87	0.60–1.27
	16 years old	374	0.23	0.26	0.21	0.30	6.86	0.077	0.08	Small	0.75	0.50–1.12	0.85	0.57–1.26	0.71	0.47–1.06
	17 years old	187	0.20	0.27	0.22	0.31	5.45	0.142	0.10	Small	0.64	0.36–1.14	0.86	0.50–1.50	0.72	0.41–1.28
	18 years old	67	0.30	0.24	0.12	0.34	7.57	0.05[*,a]	0.19	Medium	0.87	0.35–2.15	0.70	0.27–1.76	0.35	0.12–1.01

Notes: Q1–Q4 = Quartile 1–4; Q1–Q4% = Quartile percentage of total number; χ^2 = Chi-square value; *P* = probability value; *V* = Cramer's *V* effect size. *ES cat.* = effect size category; OR = Odds Ratio; 95%CI = 95% Confidence Intervals.
[*] Significance $p < 0.05$.
[a] Inverse RAEs (Q4 > Q1).

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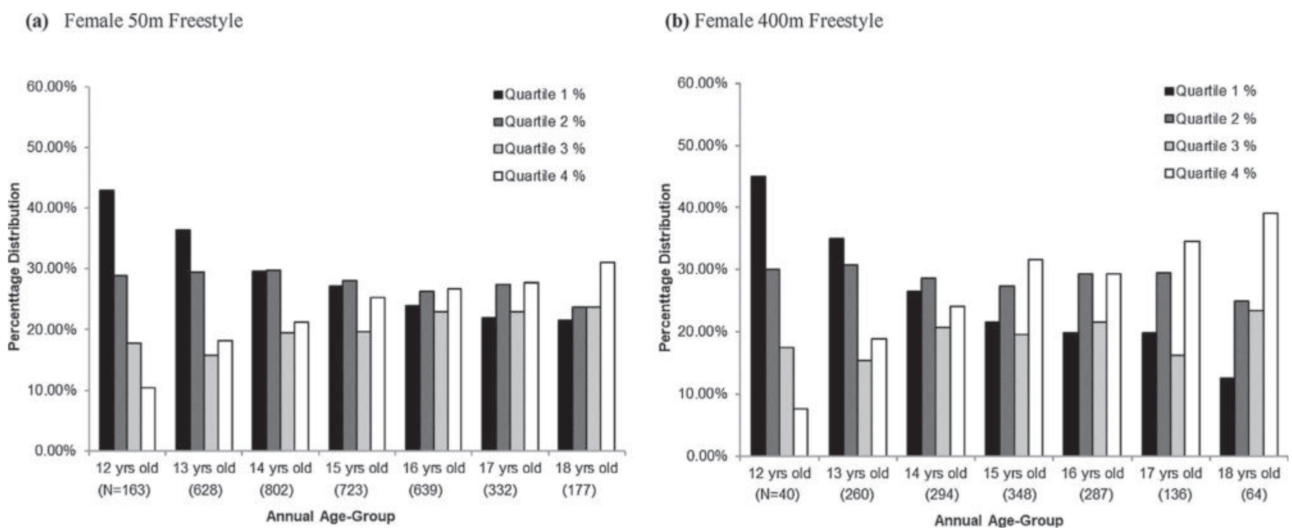

Fig. 1. (a & b) A graphical summary of female participants competing in the 50 m (a) & 400 m (b) Freestyle at the National Swimming Championships (2000–2014 inclusive) according to annual age group and quartile.

males and females. As maturation occurs chronologically earlier in females, transient RAEs did appear to initiate and reverse earlier than males (i.e., 1 year); and inverse RAEs observed in females appear more sustained and advanced at 17–18 years. The exception relates to 50 m Freestyle where physical strength and power demands may still associate with relative age and/or earlier maturing advantages.

Present findings support recent studies highlighting how relatively younger and later maturing athletes actually may be more likely to go onto to attain senior adult success. The dissipation of RAEs and emergence of over representations of the relatively younger toward the latter years of junior age Championships (i.e., 17–18 years of age) coheres with studies examining who attained professional contracts beyond 18 years of age[27,28] and who experienced relatively more career success beyond draft selections.[25] While the exact processes and mechanisms accounting for these changes remain speculative, we suspect that multiple interacting factors are involved. Adhering to the maturation-selection hypothesis, the equalising of RAEs at 15–16 years aligns with attainment (or passing) of peak height velocity in maturation as well as increased anthropometric and physical development in the later maturing. Anthropometric and physical disadvantages in the relatively younger, possibly offset by high technical competency, may be nullified (or overtaken) leading to performance advantages at later time points. In parallel, psychological perceptions and beliefs may change. Growing competence and confidence may occur with biological transiency; while similar constructs may be undermined in the relatively older and/or early maturing, due to comparatively lesser performance development over a similar time period. Whatever the processes involved, (ir)rational biases in coaching selection were not responsible[25] in this context, as participation at the Championships was determined by individual performance qualification times.

Finally, in addition to transient RAEs patterns, transient participation patterns were also apparent at the Championships. Whilst acknowledging that small performance variations (and many other factors; e.g., injury) can account for (non-)participation at the national age-championships, our data highlighted that regardless of sex in a given stroke event, the composition of relative age groups (Q1 & Q4) also changed with age-group. Put another way and to exemplify, of the relatively older or younger swimmers present at a Championship at 13 years old, only 50–60% participated at the same event the following year. These figures then linearly diminished each year to 5–8% four years later. Correspondingly, of those participating at 18 years of age, 60–70% participated the previous year, reducing to 12–26% four years earlier. From a sport system and athlete development perspective, these observations further question the significance of earlier age-groups particularly when confounded by growth and maturation, and their potential relationship with detrimental outcomes (e.g., dropout and sport withdrawal). Findings point toward greater relevance of later age-groups with closer proximity to senior adult transition. Considered together, transient RAEs and transient participation in National level junior swimmers highlight several implications for sport systems, athlete development programmes and their practitioners.

5. Conclusion

As highlighted by RAEs across and within junior age swimming, performance advantages from relative age and thereby growth and potentially maturation are transient. Regardless of sex or stroke (and distance) examined, typical RAEs were highly prevalent with large-medium effects sizes in earlier age-groups (e.g., 12–14 years old). RAE magnitude reduced with age group, and predominantly were diminished by 16 years of age. By 17–18 years of age descriptive and significant inverse RAEs were apparent. Greater consideration of RAEs as well as growth and maturation is necessary to minimise their impact on participation and athlete development systems.

Practical implications

- The influence of relative age in representative swimming is transient. While relatively older are more likely to achieve National swimming qualification standards and participate in National Championships in junior developmental years, the relatively younger are equally or more likely to attain similar outcomes after 16 years of age.
- Athlete development systems, youth competition structures and models of coaching in swimming (and other sport contexts) need to consider and account for the relatively younger and later development trajectories of youth athletes.
- To help remove RAEs and prevent growth and development from influencing local-National level participation sports organizations are encouraged to revise the purpose and emphasis of their programmes according to developmental stages; consid-

ering strategies to delay athlete selection and differentiation to improve validity.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2017.12.008.

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Original research

Removing relative age effects from youth swimming: The development and testing of corrective adjustment procedures

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ABSTRACT

Objectives: (1) Generate accurate estimates of the relationship between decimal age (i.e., chronological and relative) with swimming performance based on longitudinal data. (2) Determine whether corrective adjustment procedures can remove Relative Age Effects (RAEs) from junior/youth swimming.
Design: Longitudinal and repeated years of cross-sectional performance data were examined.
Methods: (1) Participants were 553 male 100 m Freestyle swimmers (10–18 years) who participated in ≥five annual events between 1999–2017. Growth curve modelling quantified the relationship between age and swimming performance, permitting corrective adjustment calculations. (2) Participants were N = 2141 male 100 m Freestyle swimmers (13–16 years) who swam at state/national events in 2015–2017. Relative age distributions for 'All', 'Top 50%', '25%' and '10%' of swimming times were examined based on raw and correctively adjusted swim times. Chi-square, Cramer's *V* and Odds Ratios (OR) determined whether relative age (quartile) inequalities existed according to age-groups, selection level and correctively adjusted swim times.
Results: Based on raw swim times, for 'All' swimmers RAEs was evident at 13 and 14 years-old and dissipated thereafter. But, RAE effect sizes substantially increased with selection level, with large-medium effects between 13–15 years-old (e.g., 15 years — Top 50% Q1 v Q4 OR = 2.28; Top 10% = 6.02). However, when correctively adjusted swim times were examined, RAEs were predominantly absent across age-group and selection levels.
Conclusions: With accurate longitudinal reference data, corrective adjustment procedures effectively removed RAEs from 100 m Freestyle swimming performance, suggesting the potential to improve swimming participation experience and performance evaluation.

1. Introduction

Whether considered from a public health or athlete development perspective, addressing factors that undermine health behaviours, such as sport participation in children and adolescence, are of interest to policy-makers, sporting organisations and practitioners alike. Relative Age Effects (RAEs) represent one important, influential factor leading to differential outcomes across sport and education settings. RAEs reflect an interaction between an individuals' birth-date and the dates used for chronological age grouping in developmental ages and stages.[1] In sporting contexts being relatively older within an age group – compared to being relatively younger – is associated with consistent attainment and selection advantages. These include the likelihood of longer-term participation[2,3] across male[4] and female[5] sporting contexts.

Across junior and youth school-representative-international tiers of soccer,[6] baseball,[7] handball[8] and rugby[9] for instance, participation ratios between the relatively oldest and youngest quartiles have varied from small (e.g., 1.5–1), moderate (3–5–1) and in some cases large (≥5–1). That said, RAE's in females are typically lower and occur at earlier chronological ages.[5] The highest RAEs are commonly associated with selective representative contexts at ages and time points associated with puberty and maturation.[10,11] Recently, studies have identified that individual but still physically

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demanding sports are also associated with RAEs, notably athletic sprinting,[12] tennis,[13] swimming,[14] ski-jumping, cross-country and alpine skiing.[15,16] By comparison, sports with less dependence on physical characteristics and which have a higher technical skill emphasis are less likely to be associated with RAEs.[17]

Several hypotheses have been proposed to explain RAEs,[18,19] but most empirically supported is the 'maturation-selection hypothesis'.[4,20] The hypothesis states that greater chronological age is equated with an increased likelihood of enhanced normative anthropometric growth. Greater height and lean body mass are predictive of better physical capacities such as aerobic power, muscular strength, endurance and speed.[21] In turn, these characteristics provide physical performance advantages in specific tasks.[22] Also during maturation, the timing and tempo of further anthropometric and physical development generate further inter-individual variation, until cessation.[11,23] Unfortunately for the relatively younger (and later maturing), these processes lead to short-term performance disadvantages as shown by their lower likelihood of selection for representative tiers of sport. In the longer-term, recent studies suggest that RAE-related and maturation inequalities may be temporary and transient,[24,25] yet the consequences upon psychological factors (e.g., motivation, enthusiasm and satisfaction) may account for their lower sporting involvement in the junior and adolescent years.

To address relative age and developmental inequalities within junior and developmental sport, a range of feasible organisational and practitioner strategies have been proposed.[26] In individual sport contexts, corrective performance adjustments have been identified as a strategy to remove relative age-related (and potential growth and maturation) differences.[12] In such contexts, objective outcome measurements (i.e., centimetres, grammes & seconds)[27] determine performance relative to similar aged (or age-grouped) others and are less influenced by other (team)-interaction dependencies; and, the influence of relative age on performance can more accurately be quantified. Romann and Cobley[12] developed corrective adjustments when examining a large cross-sectional sample (N = 7761) of 9–15 year-old Swiss sprinters. Expected performance differences from being one day to one year older in each annual age group were calculated. Given the chronological age-group being examined, individual performance times were then adjusted to a standard reference point and a corrected sprint time created. Relative age distributions of corrected sprint performance times were then re-examined. Findings identified that for almost all annual age-groups, relative age attainment discrepancies were removed – if not at least reduced – as RAEs became absent in the 'Top 10%' of sprint times. Corrective adjustments in youth sport contexts could, therefore, help ensure more equitable participation and attainment by removing performance dis-advantages for the relatively younger in age-based competition.

The purpose of the present study was first to generate accurate estimates of the relationship between decimal age (i.e., chronological and relative age) and swimming performance based on longitudinal competition data (Part 1). The second purpose was to determine whether a corrective adjustment procedure could effectively remove RAEs; potentially permitting a more equitable procedure for swimming performance evaluation (Part 2).

2. Methods

2.1. Part 1: Relationship between decimal age and swim performance based on longitudinal data

Participants. Participants were N = 553 male swimmers, aged 10–18, who participated in official long-course 100 m (m) Freestyle events (N = 202), at age-group and/or open-level Australian domestic competitions between 1999-2017 (inclusive). Participants were included if they registered a time within one second of the state level qualification time; who registered multiple years (≥5 years) of performance times at least once per year ranging from 10 to 18 years; and, who were without a disability. Such criteria helped establish an accurate longitudinal estimate of performance change over time (i.e., across and within age-groups).

Procedure. Following University ethics approval (App No: 2017/650), an anonymised dataset containing N = 87,526 registered male swims in the 100 m Freestyle was provided by Swimming Australia. The 100 m Freestyle was sampled as it is one of the most competitive events (i.e., higher participation numbers) in Australia's age-group championship schedule. Performance in the event is also considered informative for athlete evaluation, selection and transfer (i.e., taking up other strokes) purposes.

Data-analysis. Extracted data was initially screened for outliers (i.e., residuals) using box plots. Outliers were removed if an input data error was apparent or if individual swim performance were ≥2 s slower than a previous year's performance. A normative distribution was checked for all those identified (i.e., N = 553). Then, swimmers' exact decimal age (i.e., years and days old) at respective competitive events was plotted against 100 m Freestyle performance time using a longitudinal growth curve model within a multi-level modelling framework[28,29]. Decimal age was centred to zero, representing the first point of observation (e.g., 10.00 years of age) and acted as the independent variable. A hierarchical method was used where repeated observations were nested within individual swimmers. An unstructured covariance type was applied and the fit of the models for fixed and random effects (e.g., intercept and slope) were assessed by comparing the log-likelihoods (-2LL) with changes in critical values for the chi-square statistic and degrees of freedom. The final fixed effect estimate model was a quadratic function ($y = ax^2 + bx + c$), summarising the expected decimal age — performance relationship across ages 10–18 years; this was subsequently used for corrective adjustment calculations.

2.2. Part 2: Testing and application of corrective adjustments on relative age distributions

Participants. To determine whether corrective adjustments could remove RAEs, an independent sample of swimmers (N = 2141 males, aged 13–16 years) who registered 100 m Freestyle performance(s) at state (N = 9) and/or national (N = 2) long course events from 2015 to 2017 in Australia were examined. Swimmers who competed at both state and national events in a given year were included, as dates used for annual-age grouping typically changed by five months as part of competition scheduling (i.e., creating different relative ages).

Procedure. Similar data collection, extraction and performance criteria procedures as outlined in Part 1 were implemented, with data reflecting performances at long-course state and national competitions. According to the respective swim events sampled and dates applied for annual-age grouping, participants were assigned to chronological age (e.g., 13 years old) and relative age quartiles given their decimal age. For example, at 13 years old, quartile categories were Q1 = 13.75–13.99 years; Q2 = 13.50–13.74; Q3 = 13.25–13.49 years and Q4 = 13.00–13.24. The number and percentage distributions of swimmers within each age group (13–16 years old) and according to relative age quartiles (Q1–Q4) were then determined (see Table 1), providing an assessment of relative age distributions for 'All' swimmer sampled at each age group. Next, for each age group examined (13–16 years), the relative age distributions of raw 100 m Freestyle swims were sub-examined according to the 'Top 50%', '25%' and '10%' of performance times. This step resembled the introduction of selection criteria, similar to event qualification and criteria for representative selection.

Table 1
Relative age distribution, chi-square and odds ratio analysis of male 100 m swimmers (aged 13–16 years) at state and national level championships for 2015–2017 (inclusive). Raw and correctively adjusted times presented for the Top 50%, 25% & 10% of 100 m Freestyle times.

Performance Level	Age-group	Total *N*	Q1%	Q2%	Q3%	Q4%	X^2	*P*	*V*	*ES cat.*	OR Q1 v Q4	(95%CI)	OR Q2 v Q4	(95%CI)	OR Q3 v Q4	(95%CI)
Raw All swimmers	13 years	488	39.10	27.30	16.00	17.60	66.34	0.0001*	0.21	Medium	2.22*	(1.55–3.18)	1.55*	(1.07–2.24)	0.91	(0.61–1.35)
	14 years	548	32.10	28.80	21.00	18.10	28.16	0.0001*	0.13	Small	1.77*	(1.26–2.50)	1.59*	(1.13–2.25)	1.16	(0.81–1.66)
	15 years	566	28.80	26.10	23.90	21.20	7.09	0.06	0.06	Small	1.36	(0.98–1.89)	1.23	(0.88–1.72)	1.13	(0.80–1.58)
	16 years	538	26.00	28.30	24.50	21.20	5.72	0.12	0.06	No	1.23	(0.87–1.73)	1.33	(0.95–1.88)	1.16	(0.82–1.63)
Raw Top 50% of swim times	13 years	244	43.00	30.30	15.60	11.10	61.85	0.0001*	0.29	Large	3.87*	(2.23–6.73)	2.73*	(1.55–4.81)	1.41	(0.77–2.58)
	14 years	275	36.40	30.50	18.20	14.90	33.93	0.0001*	0.20	Medium	2.44*	(1.49–4.00)	2.05*	(1.24–3.38)	1.22	(0.72–2.08)
	15 years	285	34.40	28.40	22.10	15.10	23.52	0.0001*	0.17	Small	2.28*	(1.40–3.70)	1.88*	(1.15–3.08)	1.46	(0.88–2.43)
	16 years	270	28.90	27.80	23.70	19.60	5.82	0.12	0.08	Small	1.47	(0.91–2.40)	1.42	(0.87–2.31)	1.21	(0.74–1.99)
Raw Top 25% of swim times	13 years	123	45.50	31.00	14.60	8.90	40.52	0.0001*	0.33	Large	5.11*	(2.26–11.59)	3.48*	(1.51–8.05)	1.64	(0.67–4.05)
	14 years	138	39.90	34.80	13.00	12.30	34.41	0.0001*	0.29	Medium	3.24*	(1.58–6.67)	2.83*	(1.37–5.86)	1.06	(0.47–2.39)
	15 years	142	43.00	29.60	16.90	10.50	35.27	0.0001*	0.29	Medium	4.10*	(1.97–8.52)	2.82*	(1.33–5.98)	1.61	(0.73–3.57)
	16 years	137	30.70	26.30	18.20	24.80	4.41	0.22	0.10	Small	1.24	(0.64–2.38)	1.06	(0.54–2.06)	0.73	(0.36–1.48)
Raw Top 10% of swim times	13 years	50	56.00	24.00	16.00	4.00	29.68	0.0001*	0.44	Large	14.00*	(2.73–71.80)	6.00*	(1.11–32.51)	4.00	(0.70–22.71)
	14 years	56	42.90	35.70	12.50	8.90	19.05	0.0001*	0.34	Large	4.82*	(1.43–16.27)	4.01*	(1.17–13.72)	1.40	(0.36–5.51)
	15 years	60	50.00	35.00	6.70	8.30	32.13	0.0001*	0.42	Large	6.02*	(1.84–19.76)	4.22*	(1.26–14.16)	0.81	(0.18–3.60)
	16 years	55	36.40	27.30	21.80	14.50	5.63	0.131	0.18	Medium	2.51	(0.83–7.62)	1.88	(0.60–5.88)	1.50	(0.47–4.83)
Corrected Top 50% of swim times	13 years	244	33.60	27.90	17.60	20.90	15.02	0.002*	0.14	Small	1.61	(0.98–2.65)	1.33	(0.80–2.22)	0.84	(0.49–1.44)
	14 years	275	29.10	28.40	20.30	22.20	6.41	0.09	0.09	Small	1.31	(0.82–2.10)	1.28	(0.80–2.05)	0.91	(0.56–1.50)
	15 years	284	26.70	25.40	24.30	23.60	0.62	0.89	0.03	No	1.13	(0.71–1.80)	1.08	(0.67–1.72)	1.03	(0.64–1.65)
	16 years	270	27.40	26.70	24.40	21.50	2.30	0.51	0.05	No	1.27	(0.79–2.06)	1.24	(0.77–2.01)	1.13	(0.70–1.85)
Correct Top 25% of swim times	13 years	123	32.50	27.60	21.10	18.80	5.74	0.12	0.12	Small	1.73	(0.85–3.54)	1.47	(0.71–3.04)	1.12	(0.53–2.38)
	14 years	138	26.80	31.10	19.60	22.50	4.19	0.24	0.10	Small	1.19	(0.61–2.33)	1.38	(0.71–2.67)	0.87	(0.43–1.75)
	15 years	142	24.70	27.50	23.90	23.90	0.50	0.91	0.03	No	1.03	(0.53–2.00)	1.15	(0.60–2.21)	1.00	(0.51–1.95)
	16 years	135	23.70	23.70	22.20	30.40	2.18	0.53	0.07	Small	0.78	(0.40–1.51)	0.78	(0.40–1.51)	0.73	(0.37–1.43)
Corrected Top 10% of swim times	13 years	50	26.00	22.00	30.00	22.00	0.88	0.83	0.08	Small	1.18	(0.38–3.63)	1.00	(0.32–3.15)	1.36	(0.45–4.12)
	14 years	56	21.40	33.90	16.10	28.60	4.13	0.24	0.16	Small	0.75	(0.26–2.15)	1.19	(0.44–3.21)	0.56	(0.19–1.69)
	15 years	58	22.40	31.00	22.50	24.10	1.16	0.76	0.08	Small	0.93	(0.33–2.65)	1.29	(0.47–3.53)	0.93	(0.33–2.66)
	16 years	55	30.90	21.80	21.80	25.50	1.22	0.74	0.09	Small	1.21	(0.43–3.39)	0.85	(0.29–2.50)	0.85	(0.29–2.50)

Tables Notes: Q1–Q4 = Quartile 1–4; Q1–Q4% = Relative age quartile (3 months combined) percentage of total number; χ^2 = Chi-Square value; *P* = Probability value; *V* = Cramer's *V* effect size; *ES cat.* = Effect size category; OR = Odds Ratio comparison; 95%CI = 95% Confidence intervals for quartile comparisons.

* Significance $p < 0.05$.

This permitted examination of whether RAE effect sizes changed according to selection level.

Finally, to test whether corrective adjustments could remove RAEs across age-groups (13–16) and according to performance level (i.e., 'Top 50%', '25%' and '10%'), all raw performance times were adjusted using expected within annual-age performance differences generated from the quadratic estimates described in *Part 1*. Thus, individual performance times registered at a given decimal age were adjusted based on the expected longitudinal trend line identified in *Part 1* to the relatively oldest decimal age within each age-group. For example, for two males in the 13 years age-group, one turning 13 years old on the first day of eligibility (i.e., 13.00) and the second who was 13.99 years on the day of competition, had their 100 m Freestyle times reduced by −3.50 s and 0.00 s respectively. The distribution of who made the 'Top 50%', '25%' and '10%' of performance times within each annual age group (13–16 years) were then re-examined using similar analytical steps.

Data-analysis. To examine and compare relative age distributions for 'All' swimmers, quartile distributions of 'Raw Top 50%–Top 10%' and the distributions of the 'Correctively Adjusted Top 50%–Top 10%' at each age-age group (13–16 years), chi-square tests (X^2) were applied with p set at 0.05. Post-hoc Cramer's V determined the magnitude of effect size between frequency count distributions, while Odds Ratios (ORs) provided more specific relative age quartile comparisons. For $df = 3$ which is the case for all comparisons of relative age quartiles, $0.06 < V \leq 0.17$ indicated a 'small effect'; $0.17 < V < 0.29$ a 'medium effect'; and, $V \geq 0.29$ a large effect.[30] Odds Ratios and matching 95% Confidence Intervals (CI) estimated effect sizes of specific comparisons (e.g., Q1 v Q4) with Q4 acting as the referent group.

3. Results

3.1. Part 1

Fig. 1 illustrates the curvilinear (quadratic) relationship between decimal age (i.e., including chronological and relative age) and 100 m Freestyle swimming performance. Decimal age significantly predicted 100 m Freestyle performance, $F(1, 455.16) = 2125.9$, $p < 0.001$. The final fixed and random effects model showed decimal age had a significant negative linear and positive quadratic relationship with performance time. Estimates of the relationship included intercept, linear and quadratic components. The quadratic relationship showed significant variance in intercepts ($\mathrm{Var}(u_{0j}) = 0.91$, $X^2(1) = 1470.35$, $p < 0.001$) and slopes ($\mathrm{Var}(u_{1j}) = 0.28$, $X^2(2) = 115.86$, $p < 0.001$) across individuals compared with fixed effects only. In addition, the slopes and intercepts negatively and significantly covaried ($\mathrm{Cov}(u_{0j}, u_{oj}) = -0.33$, $X^2(3) = 1{,}228.86$, $p < 0.001$).

3.1.1. Part 2–Raw distributions

Table 1 summarises results from the analysis of relative age distributions for 'All' sampled swimmers within the 13–16 year-old age groups and according to applied selection criteria for the raw (unadjusted) swimming times. For 'All' the sample, a classical RAE was evident at 13 and 14 years of age with a medium and small effect size respectively. RAEs then dissipated by 15 and 16 years of age. However, when applying selection criteria on raw swimming times (i.e., 'Top 50%–10%'), RAEs extended into 15 years-old (e.g., Top 50% - $X^2 = 23.52$, $p = 0.001$; Q1 v Q4 OR = 2.28) and effect sizes became substantially increased with each selection level step. Medium-large RAE effect sizes were evident for 13–15 year-olds in the 'Top 25%' and 'Top 10%' of raw race times (e.g., 15 years - Top 25% $X^2 = 35.27$, $p = 0.001$; Q1 v Q4 OR = 4.10; Top 10% $X^2 = 32.13$, $p = 0.001$; Q1 v Q4 OR = 6.02). At 16 years-old only descriptive (non-significant) RAE patterns were observed in the Top 50%–10% of raw swimming times; though it should be acknowledged that sample sizes became smaller with selection level.

3.1.2. Correctively adjusted distributions

Following adjustment of 'All' individual performance times based on the longitudinal trendline equation and re-tabulation of relative age distributions, Table 1 summarises results according to 'Top 50%–10%' of performance times. Critically, bar only one exception (i.e., Top 50% 13 year olds), there was no general RAEs apparent (i.e., Q1 distribution > Q2–Q4) across the age groups and selection levels examined. Further, there was no significant odds ratio comparisons for any particular quartile distribution comparison, whether Q1 v Q2–Q4 or otherwise (e.g., Q2 v Q4) for any age or selection level. In other words, corrective adjustments lead to a return of normative (expected) relative age distributions (≈25% per quartile). Only for the 'Corrected Top 50%' 13 year-old group did a general significant RAE remain (Q1 = 33.6%–Q4 = 15.02%; $X^2 = 15.02$, $p = 0.002$; ES = small). To graphically summarise changes in relative age distributions according to 'Raw' and 'Correctively adjusted' swim times, see Supplementary Material 1 which illustrates data related to (a) 13 years and (b) 16 years of age.

4. Discussion

The purpose of this study was first to generate accurate estimates of the longitudinal relationship between decimal age (i.e., chronological and relative age) and 100 m Freestyle swimming performance. The second purpose was to determine whether corrective adjustments could effectively remove RAEs previously identified across and within youth swimming.[14] In the original corrective adjustment study with sprinters,[12] a linear regression equation based on cross-sectional data estimated expected performance changes; however such data may not necessarily have accurately estimated developmental changes over time. The present study addressed this concern by examining a large (>550) longitudinal dataset which contained ≥ five data-points from each swimmer, permitting a growth modelling analysis to estimate performance change over time. While acknowledging inter-individual swimmer variability in intercepts and slope characteristics for performance change over time, findings identified that an overall significant and consistent curvilinear (quadratic) trend was apparent. Performance times were estimated to generally reduce from approximately 78.5 s at 10 years-old to 55.5 s by 18 years (see Fig. 1). Curvilinear slope characteristics were then utilised to generate expected performance differences within chronological age-groups, permitting more equitable performance comparisons between swimmers who may have competed in the same event on a given day, but who differed in terms of decimal age by a range of 1 day to almost a year (0.99 years).

When examining the relative age distributions of 'All' swimmers sampled from state and national level 100 m Freestyle events aged 13–16, findings expectedly identified typical RAE prevalence. RAEs with medium effect sizes were evident at 100 m Freestyle events for swimmers aged 13 years. However, RAE magnitude also expectedly dissipated with age (e.g., 'small effects' at 15 year-old; 'no effects' at 16 years-old). Correspondingly, Q1 v Q4 odds ratio comparisons also reduced with age, reducing from OR = 2.22 at 13 years to 1.23 at 16 years. These findings directly align with prior swimming-related data which highlighted RAE transiency across similar aged males who participated in 50 m and 400 m Freestyle events at Australian national level championships over a fifteen year period.[14]

When simulated selection/qualification criteria were applied to the sampled swimming times, the benefit of being relatively older became evident when examining RAE distributions in the

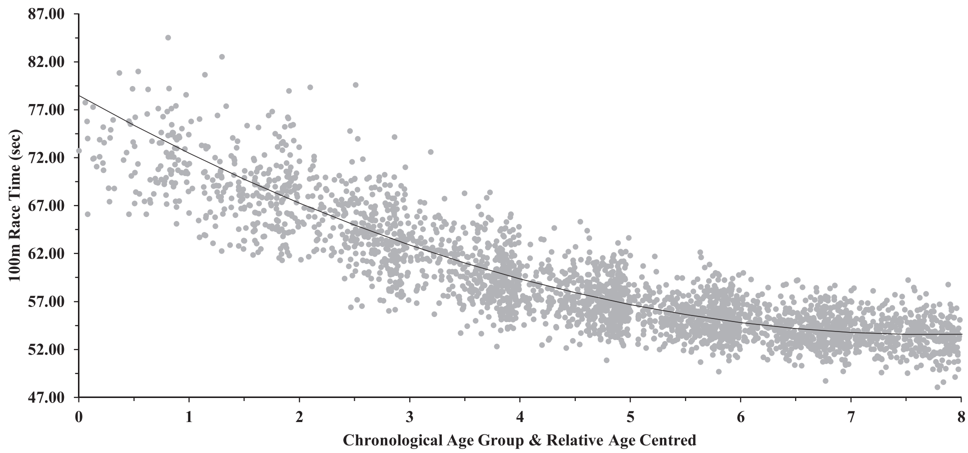

Fig. 1. Curvilinear relationship between chronological & relative age (centred 0–8 = 10–18 years respectively) and 100 m Freestyle swimming performance.

'Top 50%'–'Top 10%' for each age group. Each progressive selection criteria effectively magnified RAE bias. For instance in the 13 year-old 'Top 50%', Q1 v Q4 OR = 3.87; 'Top 25%' = 5.11; and in the 'Top 10%' = 14.00 (see also Supplementary Material 1). RAE magnification due to selection criteria was apparent for each age-group examined, albeit less substantial in terms of magnitude by 16 years of age. As there were only small samples in the 'Top 10%', this may account for why X^2 and OR comparisons were not significant and only descriptively apparent. Present findings are also consistent with previous trends observed in individual[12] and male team sport contexts[4] where being the relatively oldest and/or early maturing provide important, but potentially short-term, performance/selection benefits.[20,23,25]

Critical to this study, when corrective adjustments based on longitudinal curvilinear estimates were applied to all swimmers and the compositions of the "Top 50%"–'Top 10%' of swimming times at each age group were re-examined, RAE inequalities were removed irrespective of selection criteria and age-group (see Table 1; Supplementary Material 1). Given baseline RAEs and RAEs identified in raw (unadjusted) swim times, these findings highlight success in the application of corrective adjustment procedures. Only for the 'Corrected Top 50%' 13 year old group did a general RAE trend remain (X^2 = 15.02, p = 0.002; *ES* = small). This exception was likely due to the initial size of RAE bias in the original sample (e.g., see 'All' 13 years old), and so there was still more swimmers by proportion who would achieve applied selection criteria in correctively adjusted swim times.

As a method and based on study results, corrective adjustment procedures demonstrate the capability to more accurately compare between individuals based on their specific decimal age, swimming performance times, and given reference to a broader population dataset. If developed more extensively, consideration of relative age and maturation status would be beneficial as greater inter-individual variability resulting from growth and development could be considered. Likewise, onward development and testing will need to determine the validity and specificity (i.e., participant characteristics as well as stroke and distance variability demands) requirements for corrective adjustments. Practically, such information may better inform and assist swimmer performance evaluation, swimmer motivation as well as coach-athlete interaction particularly during occasions of competition dis-advantage. Determining the feasibility for how and when corrective adjustments can be applied in swimming, and whether positive outcomes can be attained (e.g., longer-term participation) are important future directions for young swimmers, practitioners (e.g., coaches) and swimming organisations alike.

5. Conclusion

Based on accurate longitudinal reference data summarising the relationship between decimal age (i.e., chronological and relative age), corrective adjustment procedures were able to remove RAEs from 100 m Freestyle swimming. Findings highlight the potential capability to remove relative age-related participation and performance inequalities from youth swimming events; improve youth swimming participation experiences; and, the potential for greater accuracy in performance evaluation.

Practical implications

- Swimming-associated sport systems and practitioners could potentially remove relative age-related participation and performance attainment inequalities at an individual-cohort level using corrective adjustment procedures.
- If practically utilised, corrective adjustment procedures in swimming need to be developed based on an accurate and substantial reference dataset matched in terms of participant sex as well as swim stroke and distance.
- Corrective adjustment procedures have the potential to improve youth swimming participation and competition experiences for swimmers disadvantaged by common annual-age grouping and standardised dates for competition.

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Appendix A. Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.12.013.

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Maximal Eccentric Hamstrings Strength in Competitive Alpine Skiers: Cross-Sectional Observations From Youth to Elite Level

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Franchi MV, Ellenberger L, Javet M, Bruhin B, Romann M, Frey WO and Spörri J (2019) Maximal Eccentric Hamstrings Strength in Competitive Alpine Skiers: Cross-Sectional Observations From Youth to Elite Level. Front. Physiol. 10:88. doi: 10.3389/fphys.2019.00088

Competitive alpine skiers are subject to substantial risks of injury, especially concerning the anterior cruciate ligament (ACL). During "landing back weighted" episodes, hamstrings may partially counteract the anterior shear force acting on the tibia by eccentrically resisting the boot-induced drawer of the tibia relative to the femur. The aim of the present study was to provide novel descriptive data and sport-specific reference values on maximal eccentric hamstrings strength (MEHS) in competitive alpine skiers from youth to elite level, and to explore potential relationships with sex, age and biological maturation. 170 competitive alpine skiers were investigated: 139 youth athletes (51 females, 88 males; age: 13.8 ± 0.59 years) and 31 elite athletes (19 females, 12 males; age: 21.7 ± 2.8 years). MEHS was assessed by the (Vald Performance, Newstead, Australia). U15 female skiers presented lower MEHS compared to female elite skiers for both limbs (R = 210 ± 44 N vs. 340 ± 48 N, respectively, $p < 0.001$, and L = 207 ± 46 N vs. 303 ± 35 N, respectively, $p < 0.001$). Similarly, lower MEHS was observed in U15 male skiers compared to male elite skiers for both limbs (R = 259 ± 51 N vs. 486 ± 62 N, respectively, $p < 0.001$, and L = 258 ± 57 N vs. 427 ± 54 N, respectively, $p < 0.001$). Correlations between MEHS and chronological age were modestly significant only for the U15 group (r = 0.37 and $p < 0.001$). When the correlations for the U15 group were performed between MHES and maturity offset (obtained from the calculation of biological age, i.e., age at peak height velocity), statistical significance was reached by all the correlations run for 3 variables (Males < 0: r = 0.59, $p < 0.0001$; Males > 0: r = 0.70, $p < 0.0001$; and Females > 0: r = 0.46, $p < 0.0001$, start of maturity offset = 0). This cross-sectional description of MEHS in alpine skiers from youth to elite level highlights the importance of biological maturation for MEHS values in youth athletes and presents novel data that may offer insights into new approaches for injury prevention.

Keywords: conditioning, physical fitness, neuromuscular performance, testing, biological maturity status, athletes, injury prevention, alpine ski racing

INTRODUCTION

Competitive alpine skiers are known to be subject to substantial risks of injury (Spörri et al., 2017). Although the rates for some injuries have been recently reported to show a decline as stated by Färber et al. (2018), the possibility for skiers to sustain an anterior cruciate ligament (ACL) injury during their sportive career is still very high (Pujol et al., 2007; Flørenes et al., 2009, 2012; Westin et al., 2012, 2018; Bere et al., 2013a; Stenroos and Handolin, 2014; Haaland et al., 2016; Müller et al., 2017b). Most of the ACL-injuries occur while the skier is turning or landing from a jump (i.e., before or without falling) (Bere et al., 2011, 2014). Typical ACL-injury mechanisms include excessive knee joint compression, knee valgus and internal rotation, or a boot-induced anterior drawer of the tibia relative to the femur (Bere et al., 2011, 2013b; Jordan et al., 2017; Spörri et al., 2017).

Physical aspects of the athlete have been suggested to be among the top 5 key injury risk factors in alpine ski racing (Spörri et al., 2012) and fitness parameters have been shown to be associated with injury risk (Raschner et al., 2012; Müller et al., 2017a). During typical ACL-injury mechanisms, such as the "landing back weighted" mechanism, hamstring muscles may act as an ACL-synergist by producing a posteriorly directed shear force to the tibia (i.e., by eccentrically resisting the boot-induced anterior drawer of the tibia relative to the femur while landing).

Considering that both quadriceps and hamstrings muscle groups are significantly activated during jump landings (Färber et al., 2018), it is reasonable to enquire whether enhanced co-activation of such muscle groups contributes to prevention strategies (Oberhofer et al., 2017). However, previous research and opinion targeting quadriceps functional features and ACL-injuries has been controversial, as Färber et al. (2018) pointed out. Instead, hamstrings strength capacity may be of importance for many typical injury situations (e.g., jump landings or backward falls) (Read and Herzog, 1992; Herzog and Read, 1993; Gerritsen et al., 1996; DeMorat et al., 2004; Koyanagi et al., 2006; Semadeni and Schmitt, 2009; Bere et al., 2011, 2014; Yeow et al., 2011; Heinrich et al., 2018). In fact, if hamstrings are pre-activated fast and high enough (Färber et al., 2018), tibial anterior translation relative to the femur might be reduced, consequently diminishing the risk of ACL-injury.

Eccentric muscle actions are an inherent part of skiing (Berg et al., 1995; Kröll et al., 2015a,b), and specifically, sufficient eccentric hamstrings strength is considered to be important for ACL-injury prevention in skiers (Jordan et al., 2017; Spörri et al., 2017) and in athletes in general (Bourne et al., 2018). However, to date, there is no study that comprehensively investigated maximal eccentric hamstrings strength (MEHS) neither in youth nor in elite competitive alpine skiers. Thus, although it could be of significant interest for injury prevention strategies, to our knowledge, there is no presence in literature of any observations regarding relationships between sex, sportive level, chronological age/ biological maturation and MEHS in competitive alpine skiers. Gaining further information on such parameters could help to identify potential new stratagems for ACL-injury prevention in youth and elite skiers and to better understand how to implement MEHS related prevention strategies effectively.

Accordingly, the sub-goals of the present study were: (1) to screen two distinct populations of competitive alpine skiers (including youth athletes and elite athletes) by assessing MEHS during Nordic Hamstrings Exercise (NHE), which has extensively been used in different sports such as Australian football, rugby, soccer and sprinting (Opar et al., 2013; Timmins et al., 2016); (2) to conduct a cross-sectional observation (from youth to elite level) on various relationships between sex, sportive level, age, biological maturation and MEHS. The overall aim of the present study was to provide novel descriptive data and reference values on MEHS in competitive alpine skiers, which could be of strategical interest for future novel injury prevention approaches starting from youth competitive level and age.

MATERIALS AND METHODS

Participants and Study Design

In total 170 competitive alpine skiers participated in the study: 139 U15 youth athletes (51 females, 88 males; mean age: 13.8 ± 0.6 years; range: 12.9 – 14.9 years) and 31 adult athletes (19 females, 12 males; mean age: 21.7 ± 2.8 years; range: 17.0 – 28.9 years). **Table 1** provides detailed anthropometric data separated by gender and groups of youth and adult elite skiers. Measurements were completed during the preseason (October 2017–November 2017) for youth elite alpine skiers and during off-season (May 2018–June 2018) for national level ski racers. This study was carried out in accordance with the recommendations of the institutional review board and local ethic committee with written informed consent from all subjects in accordance with the Declaration of Helsinki. Study approval was granted by the institutional review board and local ethic committee (KEK-ZH-NR: 2017-01395).

Maximal Eccentric Hamstring Strength During NHE

The maximal eccentric hamstring strength was assessed by using a NHE measurement device (Vald Performance, Newstead, Australia); its reliability and application on athlete populations is reported in several previous studies (Bourne et al., 2015; Opar et al., 2015; Timmins et al., 2016). Briefly, athletes knee on a padded board of the Norbord device with their ankles fixed by braces right above the lateral malleoli. The ankle braces contain integrated uniaxial load cells which are affixed to a pivot in order to ensure a constant force measurement through the longitudinal axis of the load cell. Directly prior to the measurement an investigator demonstrated the NHE to each athlete. The following verbal instructions were provided as previously described (Bourne et al., 2015; Opar et al., 2015): gradually lean forward at the slowest possible speed; maximally resist this movement with both legs; keep trunk and hips in a neutral position throughout the movement; hold hands crossed above the chest. A repetition was completed if the resulting forces overcame the athlete's resistance and pressurized a catch of the movement with the hands on the ground. All participants performed one set of three repetitions of NHE (5–10 s of rest between repetitions), whereby they were verbally encouraged to secure maximal exertion. Based on the previously described instructions a trial was considered valid if it demonstrated a constant increase of force progression culminating in a pronounced force peak, followed by a rapid decline. The best left and right maximum values of the three repetitions were used for further data analysis. The limbs asymmetry during MEHS production during NHE test was calculated as the difference between stronger and weaker leg expressed as percentage.

Biological Age and Maturity Offset Calculation

The biological age was calculated based on a formula by Mirwald et al. (2002) which provides a non-invasive and previously validated method to predict the age at peak height velocity (APHV) (Malina et al., 2007; Sherar et al., 2007) and moreover was validated for youth competitive alpine skiers (Müller et al., 2015). The gender-specific equations use anthropometric measures of body mass (0.1 kg, *Seca, Hamburg, Germany*), body height and sitting height (0.5 cm, determined by measuring tape), as well as chronological age at the time of measurement and sub-ischial leg length as the difference between body height and sitting height. Based on the collected data the prediction of an individual maturity offset is enabled, which marks a point in time before or after peak height velocity (PHV). The estimated APHV is given by subtracting the maturity offset from the actual chronological age (Mirwald et al., 2002).

Statistical Analysis

Data were reported as mean ± SD. Differences between groups were statistically analyzed for MEHS values using an unpaired Student's *t*-test. Correlations between sex, chronological age, biological age and MEHS and were tested by the Pearson's product moment correlation coefficient (r) and coefficient of determination (r^2). The level of significance was set at $p < 0.05$.

TABLE 1 | Anthropometric data for male and female athletes separated by groups.

	U15 athletes		Elite athletes	
	Female	Male	Female	male
	Mean (±SD) (min-max)	Mean (±SD) (min–max)	Mean (±SD) (min-max)	Mean (±SD) (min-max)
Age [y]	13.7 ± 0.6 (12.5–14.9)	13.9 ± 0.5 (12.9–14.8)	21.3 ± 2.7 (17–26.3)	22.4 ± 2.9 (18.3–28.9)
Body height [cm]	159.7 ± 6.3 (143–171.5)	161.4 ± 8.4 (145–185)	166.4 ± 5.7 (155–180)	176.3 ± 6.7 (166–189)
Body weight[kg]	48.4 ± 7.6 (35–66.5)	49.4 ± 10.3 (30–81)	65.5 ± 5.9 (50–82)	80.8 ± 6.2 (71–103)
BMI [kg/m^2]	18.9 ± 1.2 (14.4–25.9)	18.9 ± 1.2 (13–24.7)	23.6 ± 1.8 (20–26.3)	25.9 ± 1.3 (23.4–29)

SD, standard deviation.

RESULTS

Maximal Eccentric Hamstring Strength During NHE

A total of 170 competitive alpine skiers performed a maximal NHE-test. A comprehensive snapshot of the differences in strength between females and males for different limbs and at different age/sportive level is presented in **Figures 1A,B**. **Figure 1A** shows that U15 female skiers (n = 51) presented a significantly lower eccentric hamstrings strength compared to female elite skiers (n = 19) for both right and left limbs (R = 210 ± 44 N vs. 340 ± 48 N, respectively, $p < 0.001$, and L = 207 ± 46 N vs. 303 ± 35 N, respectively, $p < 0.001$). Similarly, **Figure 1B** shows that a significantly lower eccentric hamstrings strength was observed in U15 male skiers (N = 88) compared to male elite skiers (n = 12) for both limbs (R = 259 ± 51 N vs. 486 ± 62 N, respectively, $p < 0.001$, and L = 258 ± 57.2 vs. 427 ± 54 N, respectively, $p < 0.001$). Male skiers always presented significantly higher values of eccentric hamstrings strength irrespective of limb, age, or sportive level compared to female skiers ($p < 0.001$).

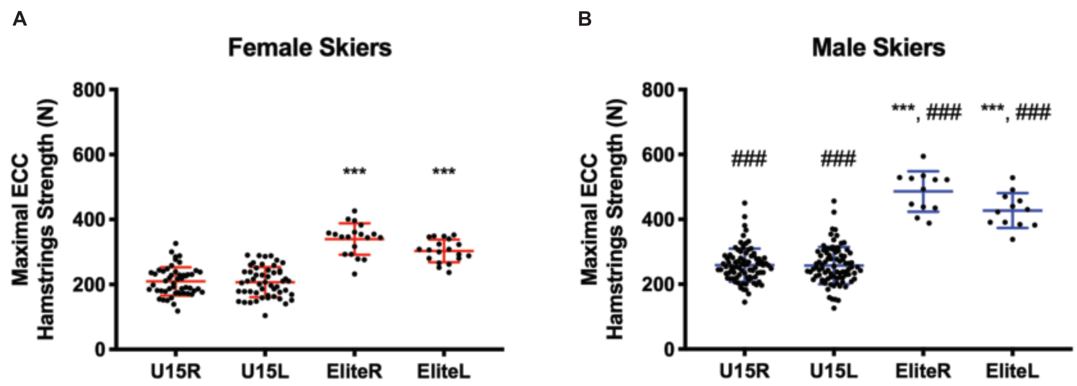

FIGURE 1 | Maximal eccentric hamstrings strength of right and left limbs for U15 and Elite athletes. *** = significantly different between Elite and U15 group of the same sex, $P < 0.001$; ### = significantly different between the same age/sportive level but of different sex, $P < 0.001$. **(A)** female, **(B)** male.

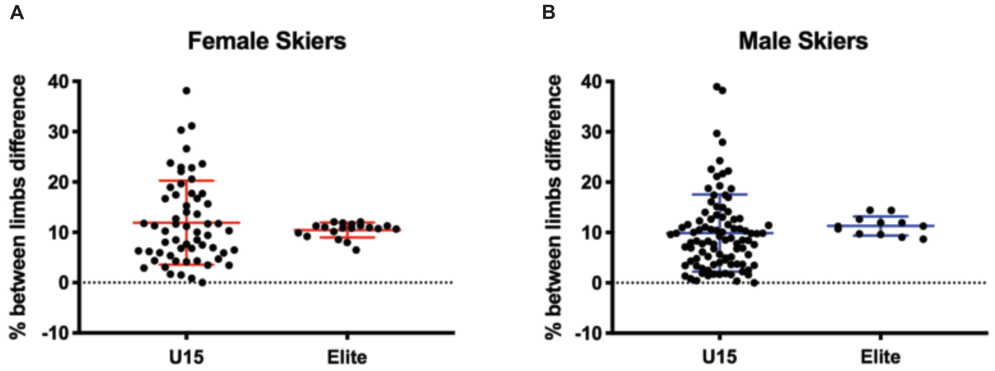

FIGURE 2 | Limbs asymmetry of MEHS production during NHE for female and male skiers of both sportive level groups. **(A)** female, **(B)** male.

Between Limbs Imbalance (Asymmetry) During NHE

Data for asymmetry of force production between right and left limb during NHE (difference between stronger and weaker leg expressed as percentage), are presented in **Figures 2A,B** for U15 and elite skiers, females and males, respectively. U15 female skiers presented similar values of asymmetry for eccentric hamstrings strength production compared to female elite skiers (11.91 ± 8.3% vs. 10.46 ± 1.47%, $p = 0.45$); in a very similar fashion, U15 male skiers showed no significant differences of asymmetry for eccentric hamstrings strength production when compared to male elite skiers (9.88 ± 7.67% vs. 11.31 ± 1.89%, $p = 0.52$). However, it is worth mentioning that compared to elite skiers, U15 skiers showed a higher variance in the asymmetry values observed.

Associations Between Maximal Eccentric Hamstrings Strength, Sex, Age and Maturity Offset

Correlations between MEHS and chronological age are presented in **Figure 3** for the elite skiers and in **Figure 4** for the U15 skiers, showed as grouped data (**Figures 3A**, **4A**), as well as the data obtained when accounting for sex differences (**Figures 3B,C**, **4B,C**). Pearsons' r and r^2-values, together with statistical significance, are shown in **Figures 3**, **4**.

Pearson's correlation between MEHS and chronological age did not reach any statistical significance in the elite group, neither for the grouped data ($r = 0.30$, $r^2 = 0.09$, $p = 0.1$) nor for female and male groups ($r = 0.14$, $r^2 = 0.01$, $p = 0.56$; $r = 0.40$, $r^2 = 0.16$, $p = 0.18$). Conversely, the correlations for the U15 group were observed to be statistically significant when the data were grouped ($r = 0.37$, $r^2 = 0.14$, $p < 0.001$) and when the data were expressed by sex (Females: $r = 0.26$, $r^2 = 0.07$, $p < 0.05$ and Males: $r = 0.40$, $r^2 = 0.16$, $p < 0.001$). When the correlations for the U15 group were performed between MEHS and maturity offset (**Figure 5**), statistical significance was reached by all the correlations run for 3 variables (Males < 0: $r = 0.59$, $r^2 = 0.35$, $p < 0.0001$; Males > 0: $r = 0.70$, $r^2 = 0.49$, $p < 0.0001$; and Females > 0: $r = 0.46$, $r^2 = 0.22$, $p < 0.0001$, where 0 represents the start of maturity offset).

Body Weight Normalized Maximal Eccentric Hamstrings Strength vs. Maturity Offset

In the group of U15 skiers, correlations between MEHS and maturity offset disappear when a normalization with body weight is performed (**Figure 6**) (Males < 0: $r = -0.1$, $r^2 = 0.01$, $p = 0.38$; Males > 0: $r = 0.20$, $r^2 = 0.04$, $p = 0.32$; and Females > 0: $r = -0.23$, $r^2 = 0.05$, $p = 0.08$, where 0 represents the start of maturity offset). Accordingly, a relative MEHS value-based ranking among the skiers is apparently different than an absolute value-based ranking (**Figure 5**).

DISCUSSION

The present investigation aimed to provide a cross-sectional observation of MEHS values in 170 competitive skiers (139 U15 athletes vs. 31 elite athletes). The main findings were the following: (1) greater MEHS during NHE was observed by the elite skiers compared to the U15 group and greater strength was developed by male compared to female skiers for both groups. (2) While no correlation was found between strength and chronological age in elite skiers, a weak to moderate association was found in the U15 group ($r = 0.37$ and $r^2 = 0.14$). However, when strength was correlated to maturation offset for the latter group, this association showed moderate to strong linear relationships in a gender dependent manner (Males < 0: $r = 0.59$, $r^2 = 0.35$; Males > 0: $r = 0.70$, $r^2 = 0.49$; and Females > 0: $r = 0.46$, $r^2 = 0.22$; where 0 represents the start of maturity offset). (3) In the U15 athletes, a body weight normalization of the MEHS values removes any relations to maturity offset.

Toward Alpine Skiing-Specific Reference Values of Maximal Eccentric Hamstrings Strength and Between-Limb Imbalance

The individual and average absolute values for MEHS for both limbs are presented in **Figure 1**. The mean value for the male elite

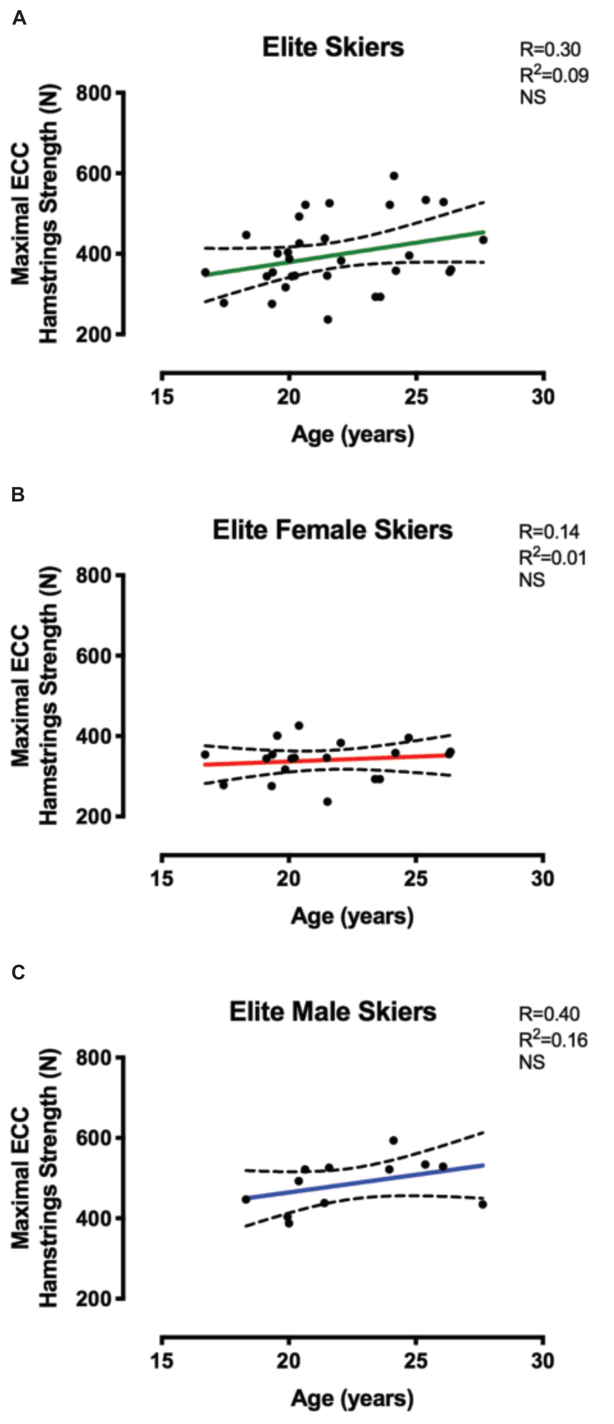

FIGURE 3 | Correlations between MEHS and chronological age for **(A)** Elite Swiss Teams skiers irrespective of sex, **(B)** Elite female skiers, and **(C)** Elite male skiers.

skiers was 486 ± 62.39 N for the right leg and 427.1 ± 53.62 N for the left one: compared to other previous studies, these values are considerably above the average found for elite Australian footballers (which did not sustain hamstrings injuries, average of left and right limbs = 301 ± 84 N, n = 159) (Opar et al., 2015), and for elite Rugby Union players (which did not sustain hamstrings injuries, average of left and right limbs = 367.7 ± 85 N, n = 158) (Bourne et al., 2015), and for football (soccer) players (which did not sustain hamstrings injuries, average of left and right limbs = 309.5 ± 73.4 N, n = 105) (Timmins et al., 2016). It must be stated that these higher force values may be also due to the high force production in the antagonists of the hamstring muscles (i.e., the knee extensors), which is typical for alpine ski racing and, therefore (Berg et al., 1995; Berg and Eiken, 1999), a priority in the conditioning of competitive alpine skiers. Lower values were observed for elite female athletes and U15 male and female skiers: however, to the best of our knowledge, no previous reports of MEHS (measured during NHE) were found comparable to these cohorts. The present study aimed purposely to provide the literature in sports medicine research with new sport-specific reference data on different cohorts of elite competitive skiers, also for multiple comparisons with different athletic populations.

Average values of between limb imbalance (asymmetry) for force developed during NHE was similar between the U15 and Elite groups and between sexes (F = 11.91 ± 8.3% vs. 10.46 ± 1.47%, respectively; M = 9.88 ± 7.67% vs. 11.31 ± 1.89%, respectively) (**Figure 2**). The present values are very similar to the ones previously showed for limbs in which no hamstrings injury had occurred in Australian footballers and rugby union players (Bourne et al., 2015; Opar et al., 2015). Moreover, it is worth highlighting that the individual values for U15 groups showed a great variability of between limb imbalance, possibly suggesting that U15 coordination strategies during NHE are not strongly consolidated.

The Unexplored Role of Maximal Eccentric Hamstring Strength and Between-Limb Imbalance for the Risk of ACL Injuries in Alpine Ski Racing

An indirect (i.e., etiology/injury mechanism-based) justification of why MEHS may be of importance for the purpose of ACL injury prevention in alpine ski racing can be found in the following theoretical considerations. During typical ACL-injury mechanisms, such as the "landing back weighted" mechanism, hamstring muscles may functionally counteract the anterior shear force acting on the tibia (i.e., by eccentrically resisting the boot-induced anterior drawer of the tibia relative to the femur while landing). This hypothesis is further supported by the simulation study findings of (Semadeni and Schmitt, 2009), the fact that hamstring muscle activation levels can be voluntarily increased during jump landing (Färber et al., 2018), as well as the evidence of multimodal neuromuscular injury prevention programs (and NHE in particular) being effective in the reduction of the risk of ACL injury in sports other than alpine ski racing (Petushek et al., 2018). Moreover, higher values of between-limb imbalance (i.e., ranging from 21.2 to a 13.1% between start and the end of pre-season) have been associated with a risk of hamstring injury in rugby (Bourne et al., 2015). At the same time, it is still unclear if MEHS and/or between-limb imbalance could represent a risk factor for (side-dependent) ACL-related injuries

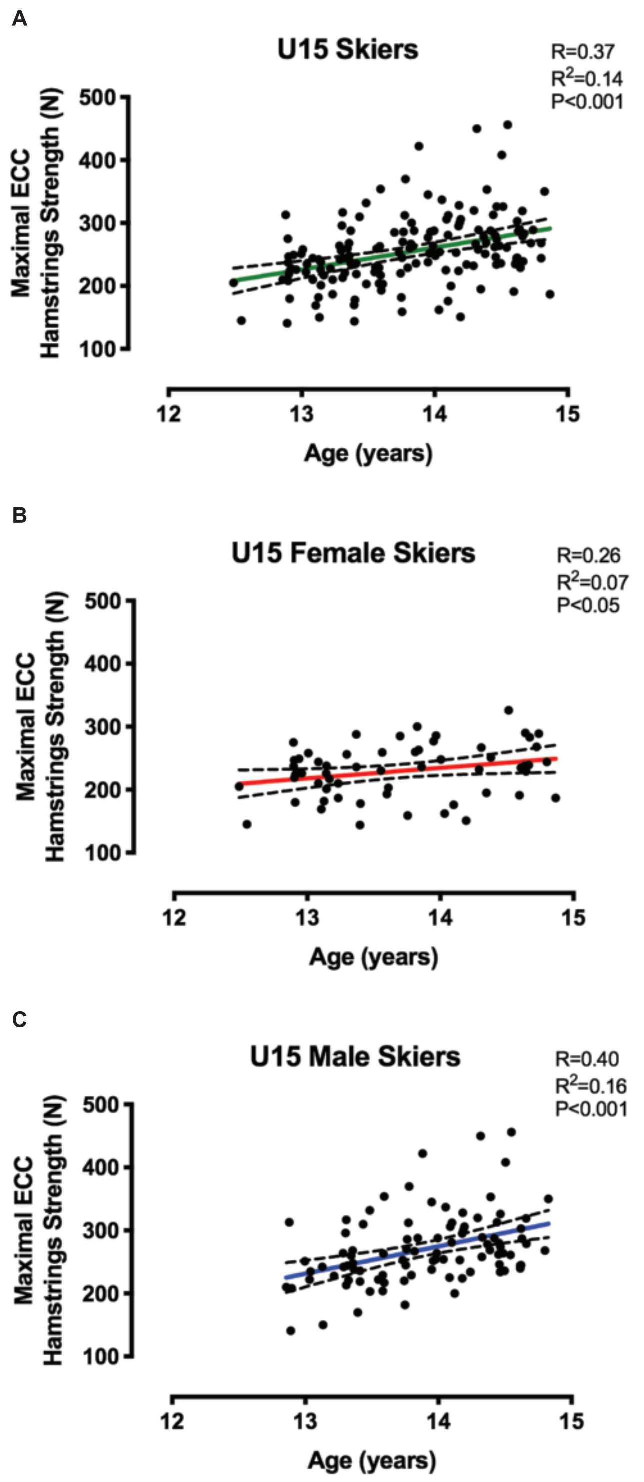

FIGURE 4 | Correlations between MEHS and chronological age for **(A)** U15 skiers irrespective of sex, **(B)** U15 female skiers, and **(C)** U15 male skiers.

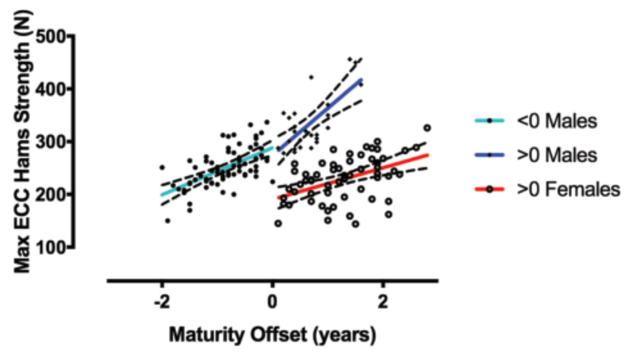

FIGURE 5 | Correlations between MEHS and maturity offset is represented by 0 value. Males < 0: $r = 0.59$, $r^2 = 0.35$, $p < 0.0001$; Males > 0: $r = 0.70$, $r^2 = 0.49$, $p < 0.0001$; and Females > 0: $r = 0.46$, $r^2 = 0.22$, $p < 0.0001$.

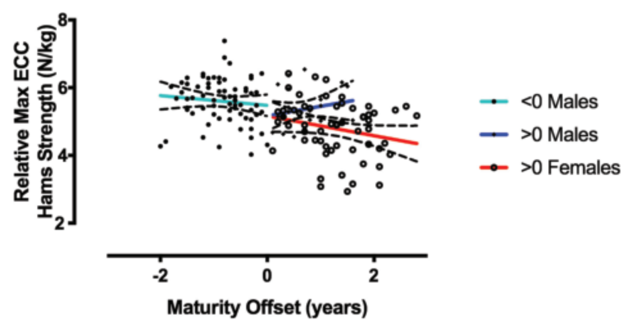

FIGURE 6 | Correlations between relative MEHS (N/kg) and maturity offset is represented by 0 value. No significant correlations observed.

in the sport of alpine ski racing. Accordingly, in a next step, longitudinal (i.e., epidemiology, etiology and/or intervention-related) studies are needed to verify the hypothesis of a direct association between MEHS, between limb imbalance and the risk of ACL injuries in the sport of alpine ski racing.

However, irrespective of these future aims, it is important to know about sport-specific reference values, potential age/maturity related influences and asymmetry problems in the corresponding populations, as being explored in the current study. Such information is essential for the interpretation of forthcoming longitudinal studies, and to better understand how to implement MEHS related prevention strategies effectively.

The Associations of Sex, Sportive Level, Chronological Age and Biological Maturation With Maximal Eccentric Hamstrings Strength

It was no surprise that elite skiers (ranging from 17 to 28 years old) showed greater MEHS compared to the younger cohort (ranging from 12 to 15 years old): however, we further aimed to clarify if such discrepancy was just due to the age difference or to the fact that the two groups belonged to two distinct sportive levels (**Figures 3–5**). MEHS was not associated to chronological age in elite skiers: this may indicate that the individual differences in strength between elite athletes were potentially more due to training-related than just temporal factors.

Conversely, U15 athletes showed significant correlations between MEHS and chronological age when subjects were grouped irrespectively of gender (r = 0.37) and when divided for sex (r = 0.26 for female skiers and r = 0.40 for male skiers). However, these correlations presented very low r^2-values (0.14, 0.07, and 0.16, respectively), thus explaining, in the best of the cases (i.e., for male skiers), only up to 16% of the variability of strength vs. age. Accordingly, we decided to investigate the relationship of eccentric hamstrings strength for female and male skiers in function of maturity offset (obtained from the calculation of biological age, i.e., age at peak height velocity). Interestingly, these relationships resulted in higher r^2-values (**Figure 5**): males presented the most significant relationships before (r^2 = 0.35) and after (r^2 = 0.49) peak height velocity, while females showed and r^2-value of 0.22 after peak height velocity. It must be specified that all of the female subjects have already reached their peak height velocity, so we could not present any relationship between maximal eccentric strength and maturity offset in the months/years before 0 value (i.e., the actual maturity offset). This is due to the fact that in this and other studies females reached their peak height velocity earlier than males (possibly around 11–12 years old) (Müller et al., 2017a,b).

The male subjects who already reached their peak height velocity were the ones that presented the higher absolute values for MEHS: while this was an expected finding, it is worth highlighting that few athletes within a year before PHV showed similar, if not greater, values of MEHS compared to other skiers which already passed PHV. In our opinion, these observations could be potentially regarded as selection criteria for either successive injury risk or general athletic performance, as young skiers that present such values of MEHS before complete maturation may start from a better overall condition compared to their peers, in a future perspective.

Future Perspectives

The aforementioned correlations between biological maturation and MEHS suggest that in younger cohorts is important to consider if an athlete has already reached her/his peak height velocity point, in order to better interpret force values in key of injury prevention and performance. In fact, the lower force values observed in the U15 male skiers' group were identified for athletes that were between 2 and 1 years before peak height velocity: if one would have considered just strength and/or chronological age for such subjects, potential misinterpretations could have been made for conclusions on risks of injury and/or selection criteria for high performance paths. One potential solution to better address the influence of biological maturation on MEHS in future might be found in a normalization with body weight (i.e., relative strength, N/kg). On the current study population such a normalization removed any relations between maturity offset and MEHS (**Figure 6**). However, for providing a deeper understanding of the long-term development of MEHS during the sportive career and/or over the entire life-span, future research should address the topic by the use of longitudinal study designs.

CONCLUSION

This study aimed on a cross-sectional description of MEHS in competitive alpine skiers from youth to elite level. It may provide reference values and background knowledge for the interpretation/implementation of future ACL-injury prevention and athletic conditioning studies/interventions in the sport of alpine ski racing. Moreover, it highlighted the importance of considering biological maturation for meaningful interpretations of force values of youth athletes that are close to their growth spurts. Future investigations of MEHS in the context of ACL-injury prevention and/or athletic conditioning should focus on longitudinal observations of the same athletes during their sportive career. More integrative approaches should be implemented, such as combining muscle function testing with ultrasound-based assessment of hamstrings muscle mechanical behavior, its architectural adaptations to longitudinal training and the investigation of potential underlying molecular mechanisms.

AUTHOR CONTRIBUTIONS

JS and WF conceptualized the study. JS, LE, and MJ conducted the data collection. MF and LE contributed to the analysis and interpretation of the data. MF, LE, and JS drafted the manuscript. All other authors revised it critically, and approved the final version and agreed to be accountable for all aspects of this work.

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RESEARCH ARTICLE

Relative Age Effects in Athletic Sprinting and Corrective Adjustments as a Solution for Their Removal

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Abstract

Relative Age Effects (RAEs) refer to the selection and performance differentials between children and youth who are categorized in annual-age groups. In the context of Swiss 60m athletic sprinting, 7761 male athletes aged 8 – 15 years were analysed, with this study examining whether: (i) RAE prevalence changed across annual age groups and according to performance level (i.e., all athletes, Top 50%, 25% & 10%); (ii) whether the relationship between relative age and performance could be quantified, and corrective adjustments applied to test if RAEs could be removed. Part one identified that when all athletes were included, typical RAEs were evident, with smaller comparative effect sizes, and progressively reduced with older age groups. However, RAE effect sizes increased linearly according to performance level (i.e., all athletes – Top 10%) regardless of age group. In part two, all athletes born in each quartile, and within each annual age group, were entered into linear regression analyses. Results identified that an almost one year relative age difference resulted in mean expected performance differences of 10.1% at age 8, 8.4% at 9, 6.8% at 10, 6.4% at 11, 6.0% at 12, 6.3% at 13, 6.7% at 14, and 5.3% at 15. Correction adjustments were then calculated according to day, month, quarter, and year, and used to demonstrate that RAEs can be effectively removed from all performance levels, and from Swiss junior sprinting more broadly. Such procedures could hold significant implications for sport participation as well as for performance assessment, evaluation, and selection during athlete development.

Introduction

The practice of annual age grouping occurs throughout and across youth sport and education. In sport, administrators typically categorise participants into annual age groups for logical logistical control purposes, and to reduce developmental differences during childhood and adolescence [1] in an attempt to help maintain a more equal and even playing-field. In regards to the latter, an unfortunate problem remains in that there is potential for up to 12 months of chronological age difference—and potentially more in terms of biological age difference—between individuals within an annual age-group cohort. These can lead to outcomes known as Relative Age Effects (RAEs) [2]. RAEs reflect the interaction between an athlete's birth date and the dates used for chronological age grouping, and whereby being relatively older compared to being relatively younger, generates consistent participation inequalities, selection biases, and attainment advantages in developmental ages and stages of sport [1].

RAEs are most highly prevalent across numerous male team sport contexts, and less consistently evident in female sport contexts [1,3]. For instance, participation ratios between the relatively oldest and youngest quartiles of annual-age groups have varied between 1.5 to as high as 9 to 1. These figures relate to studies in contexts of school, local junior league, representative, and youth international soccer [4,5], baseball [6], handball [7], both codes of rugby [8] and Australian rules football [9]. More recently, studies have also identified that individual, but still physically demanding sports are also affected. These include tennis [10], swimming [11], ski-jumping, cross-country, and alpine skiing [12,13], as well as a variety of other strength, endurance, and technique based events, as identified in a study of participants in the Youth Winter Olympic Games [14]. By contrast, sport contexts with a skill emphasis such as golf [15], and with less dependence on physical characteristics, appear immune to RAEs in participating samples; while the association between RAEs and dropout seems contextual and inconsistent [16,17].

Several inter-related hypotheses have been proposed to explain RAEs, but most prominently supported is the 'maturation-selection' hypothesis [1], which states that greater chronological age is equated with an increased likelihood of enhanced anthropometric characteristics from normative growth and development. Greater height and lean body mass are predictive of better physical capacities such as aerobic power, muscular strength, endurance and speed [18], so in turn these characteristics provide physical performance advantages in most sport tasks [19]. Also, during maturation, the relatively older are more likely to enter puberty earlier, and the tempo of maturation may generate further anthropometric and physical variation between individuals until its cessation [20]. Thus in the short-term, the relatively older and earlier maturing are more likely to be considered as better athletes, and be selected by coaches for higher levels of competition. Unfortunately, the relatively younger and later maturing are more likely to be overlooked and excluded [21] in the various participation stages of junior and youth sport, at least until the end of growth and maturation. The hypothesis thus can also account for why RAEs, albeit with smaller effect sizes, lag into adult and professional sport contexts.

With few studies to date examining individual sport contexts or testing underlying mechanistic hypotheses of RAEs; and, fewer still identifying or offering potential feasible solutions to eliminate RAEs (see Cobley et al., [1] for a summary) and their detrimental impact on sport participation and experience, we considered how an investigation of an athletics contexts could provide beneficial insight. Athletics has only partially been considered in RAE literature [3], yet events such as distance running, sprinting, and long jump generally demand advanced physical capabilities like high VO2 max; lower-leg muscle mass, strength and power for performance success, with lesser concern for extraneous or confounding inter-athlete variables like team formations, tactics, positional roles and selection as occurs in team sport contexts [9,22]. So RAEs should be hypothetically prevalent due to the benefits of advanced relative and biological age. Performance here can also be more objectively measured in terms of Centimetres, Grams, and Seconds (i.e., CGS Sports [23]), and quantifiable relationships between relative and chronological age and performance can be estimated. This then permits an assessment of whether the 'maturation-selection' hypothesis can consistently explain RAE outcomes across junior and youth athlete development, and whether this could be statistically controlled with a corrective adjustment procedure tested for RAE removal.

In Switzerland, track and field is the most popular individual summer sport [24]. For instance, in the 2013 season, 7761 male children and adolescents aged 8 – 15years participated in an official 60m sprint trial, and so this provided an appropriate context to firstly determine whether RAEs were prevalent within and across junior/youth sprinting, affecting participation and performance, and whether RAEs were amplified at higher performance levels. Then, relationships between relative age, chronological age, and physical performance could be determined; subsequently allowing us to test and apply a corrective adjustment procedure to remove RAEs.

Methods

Participants

This study was approved by an independent institutional ethical review board of the Swiss Federal Institute of Sport Magglingen, Switzerland and is in accordance with the principles expressed in the Declaration of Helsinki. Informed consent was not needed as the study analyzed and reported data was available online. However, all data is reported anonymously. Participants were $N = 7761$ male Swiss youth track and field 60m sprint athletes, aged 8–15, who participated in an official local, regional, or national trial event, and whose performance was recorded using electronically timed photo sensors (ALGE Timing OPTIc2, Switzerland). All recorded sprints conformed to standards of the International Association of Athletics Federations. Trials took place either in schools or track and field clubs and were open to all. An official registration or licence process was not required. During the 2013 competitive season, the personal best performance time, birth date, age group, and name of each participating athlete was recorded in the database of the Swiss Athletics Federation [25].

Part 1—procedures

For part one, participant age, date of birth, and sprint times were examined across the ages of 8 to 15. To determine whether RAEs existed, athletes were categorised according to annual-age year group and relative age quartile. For all track and field events in Switzerland, January 1st acts as the cut-off date for age-grouping; so, with this as a reference, athletes were ascribed to one of four relative age quartile categories (i.e., Q1 = born in January–March; Q2 = April–June; Q3 = July–September; and, Q4 = October–December). Relative age distributions across all athletes and age groups were then calculated and referenced against actual corresponding birth-distributions from the Swiss population using weighted mean scores. The corresponding Swiss population aged 8–15 years was defined as the number of official male residents ($n = 290,977$) registered with the Swiss Federal Statistical Office [26]. All relative age quartiles were approximately equally distributed (e.g., male: Q1 = 24.7%; Q2 = 25.2%; Q3 = 26.0%; Q4 = 24.1%), and these exact distributions in the broader population were used in data analyses. Within each age group, the sample was then subdivided into the fastest or Top 50%, 25% and 10% of sprint performance respectively to assess whether RAE effect sizes were related to performance level (Table 1).

Part 1—data analysis

For each annual age-group, chi-square tests assessed differences between the observed and expected relative age distributions. Post hoc tests determined differences in frequency counts between significant quartiles, and the magnitude of the effect size was measured using Cramer's

Table 1. RAE as a function performance level and annual age-group category.

Performance Level	Age Group	*n*	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	χ^2	*P*	V	Effect	OR	*P*	95%CI
all	8	578	33.4	27.2	23.9	15.6	37.8	**	0.15	small	2.11	*	(1.64–2.71)
	9	824	32.0	25.4	24.6	18.0	32.4	**	0.11	small	1.75	*	(1.43–2.15)
	10	1267	30.4	26.4	24.9	18.3	36.8	**	0.10	small	1.63	*	(1.38–1.93)
	11	1370	27.7	25.9	26.8	19.6	18.3	**	0.07	small	1.39	*	(1.19–1.64)
	12	1356	27.8	26.8	25.1	20.4	15.7	**	0.06	small	1.34	*	(1.15–1.60)
	13	1238	26.7	25.8	25.8	21.7	5.5		0.04	no	1.21	*	(1.02–1.42)
	14	649	30.4	23.3	25.9	20.5	13.4	**	0.08	small	1.46	*	(1.17–1.82)
	15	479	33.8	23.2	21.5	21.5	22.5	**	0.13	small	1.55	*	(1.21–1.98)
	8–15	7761	29.5	25.8	25.2	19.6	147.0	**	0.08	small	1.48	*	(1.16;1.90)
top 50%	8	288	43.4	26.7	20.5	9.4	71.2	**	0.28	medium	2.16	*	(1.42–3.28)
	9	412	38.8	26.7	22.8	11.7	62.7	**	0.23	medium	1.87	*	(1.35–2.58)
	10	633	33.5	29.4	23.9	13.3	57.1	**	0.17	medium	1.52	*	(1.18–1.96)
	11	685	33.6	27.6	25.0	13.9	54.5	**	0.16	small	1.71	*	(1.34–2.17)
	12	678	34.2	27.3	22.4	16.1	48.5	**	0.15	small	1.56	*	(1.24–1.60)
	13	619	33.9	27.8	19.7	18.6	41.0	**	0.15	small	1.49	*	(1.18–1.87)
	14	324	36.7	25.6	20.4	17.3	29.8	**	0.17	medium	1.43	*	(1.04–1.97)
	15	239	41.0	22.6	17.2	19.2	36.4	**	0.23	medium	1.35		(0.95–1.92)
	8–15	3878	35.7	27.2	22.1	15.0	361.9	**	0.18	medium	1.59	*	(1.44–1.76)
top 25%	8	144	44.4	32.6	14.6	8.3	48.4	**	0.33	large	2.49	*	(1.34–4.61)
	9	206	44.2	27.7	17.0	11.2	53.5	**	0.29	large	2.22	*	(1.40–3.51)
	10	316	38.3	33.2	19.9	8.5	68.6	**	0.27	medium	2.70	*	(1.78–4.10)
	11	342	36.0	30.4	24.0	9.6	52.1	**	0.23	medium	2.63	*	(1.79–3.86)
	12	339	41.9	26.8	20.6	10.6	71.1	**	0.26	medium	2.89	*	(2.00–4.17)
	13	309	39.5	28.8	18.1	13.6	51.2	**	0.23	medium	2.37	*	(1.67–3.37)
	14	162	45.1	25.3	17.9	11.7	42.1	**	0.29	large	2.59	*	(1.56–4.30)
	15	119	42.9	21.8	17.6	17.6	22.0	**	0.25	medium	1.54		(0.93–2.57)
	8–15	1937	40.6	28.9	19.5	11.0	384.3	**	0.26	medium	2.45	*	(2.10–2.86)
top 10%	8	57	49.1	29.8	12.3	8.8	24.15	**	0.38	large	2.61	*	(1.01–6.77)
	9	82	52.4	24.4	13.4	9.8	37.9	**	0.39	large	3.01	*	(1.42–6.41)
	10	126	40.5	34.1	19.0	6.3	35.8	**	0.31	large	3.84	*	(1.82–8.10)
	11	137	41.6	28.5	24.1	5.8	36.0	**	0.30	large	5.03	*	(2.40–10.54)
	12	135	45.2	25.2	18.5	11.1	35.7	**	0.30	large	2.98	*	(1.69–5.24)
	13	123	46.3	24.4	18.7	10.6	35.6	**	0.31	large	3.57	*	(1.96–6.53)
	14	64	45.3	23.4	18.8	12.5	16.2	**	0.29	large	2.45	*	(1.12–5.36)
	15	47	55.3	12.8	21.3	10.6	24.9	**	0.42	large	3.31	*	(1.27–8.61)
	8–15	771	45.7	26.5	18.8	9.1	227.6	**	0.31	large	3.34	*	(2.58–4.32)

Q1 to Q4 = Quartile 1 to 4; $\chi 2$ = Chi-Square Value; V = Cramer's V; P = Significance;
*$P<0.05$;
**$P<0.01$; OR = Odds ratio; 95% CI = 95% Confidence Interval.

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V. For $df = 3$ which is the case for all comparisons of relative age quartiles, $0.06 < V \leq 0.17$ indicates a small effect, $0.17 < V < 0.29$ a medium effect, and, $V \geq 0.29$ a large effect. Odds Ratios (OR) and matching 95% Confidence Intervals (CI) were also calculated between Q1 and Q4 to provide an indicator of effect size.

Part 2—procedures

For part two, in quantifying the relationships between relative and chronological age and sprint performance all data on the sample of athletes was utilised, specifically their exact decimal age in years and days old at the time for when competing at a sprint event and the electronically measured sprint time.

Part 2—data analyses

In the first step, a linear regression using sprint time (race performance in seconds and milliseconds) as the dependent variable and decimal age as the independent variable for each annual age group was conducted with Pearson's correlation coefficient (r), adjusted coefficients of determination (R^2), standard errors of the estimate (*SEE*) and analysis of variance calculated. Mahalanobis distances checked for the presence of outliers in the dataset using standard z-distribution cut-offs; no outliers were identified. Residuals were examined for normality, linearity, independence and homoscedasticity. All statistical assumptions for linear regression were met. The magnitude of the correlation coefficient of the regressions was initially qualitatively assessed, according to Hopkins [27] as follows: trivial $r < 0.1$, small $0.1 < r < 0.3$, moderate $0.3 < r < 0.5$, large $0.5 < r < 0.7$, very large $0.7 < r < 0.9$, nearly perfect $r > 0.9$ and perfect $r = 1$.

Expected performance differences within and across age-groups

Mean expected performance differences per day, per month, per quartile, and per year were calculated using respective regression equations in each annual-age-group,. For example, regressions (see results) indicated that the relatively oldest consistently had the fastest expected sprint time in any given age group, while the relatively youngest were generally expected to have the slowest sprint time. A sprinter born on January 1st (e.g., 8.99 in the Under 9's) was therefore theoretically expected to be the fastest and a sprinter born on 31st December is expected to be the slowest. The difference between expected sprint times of a sprinter born on January 1st and on 31st December provided the expected performance difference per year (i.e., 1036.8 ms—Under 9's). As the regressions were linear, we then used the mean difference values of one year to calculate expected differences per day (by dividing by 365), quartile (by dividing by 4) and month (by dividing by 12). From these values all percentage differences were calculated.

Corrective adjustments

To test whether corrective adjustments could remove RAEs from across the sample and at various performance levels (i.e. Top 50%, 25% and 10%), the linear regressions were used, as described in *Part 2—Data analyses*.. Raw (actual) sprint times were then adjusted to account for the influence of relative age with January 1st of each age group acting as the reference. For example, in the Under 9's a person born on January 2nd had their sprint time reduced by 2.84 ms; January 3rd = 2.84 x 2 etc.; until December 31st = 2.84 x 365 = 1036.8 ms. This process thus generated a correctively adjusted sprint time for all participants in their respective annual age-group (i.e., data from Table 2 and 3). With corrective adjustments were applied, distributions of who made the Top 50%, 25% and 10% of sprint times within each annual age group were re-examined using similar steps as that reported in Part 1—Data analysis.

Table 2. Linear regression equations and statistics for each annual-age group.

Age	Equation	*r*	R^2	SEE	*P*	Magnitude
8	y = -1.036x+19.649	0.379	0.144	0.694	**	moderate
9	y = -0.852x+18.605	0.335	0.112	0.696	**	moderate
10	y = -0.668x+17.101	0.303	0.092	0.602	**	moderate
11	y = -0.608x+16.770	0.275	0.076	0.604	**	moderate
12	y = -0.556x+16.446	0.255	0.065	0.601	**	small
13	y = -0.552x+16.525	0.265	0.070	0.576	**	small
14	y = -0.555x+16.625	0.295	0.087	0.524	**	small
15	y = -0.424x+14.741	0.283	0.080	0.437	**	small

r = correlation coefficient; R^2 = adjusted coefficient of determination; SEE = standard error of estimate; *P* = Significance;
*$P<0.05$;
**$P<0.01$.

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Results

Part 1

Table 1 shows the quartile distributions, chi-square, effect size estimation, including ORs (and 95% CIs) for all male participants in official local, regional, or national trial events in the 2013 competitive season sub-divided according to age group and our assigned performance levels. Results identify small but significant RAEs for all age groups (except the 13 year age group which was close to significance) when all athletes were included, and when compared against the Swiss national birth distributions for each respective year. ORs progressively decreased from 2.11 at age 8 to 1.21 at age 13, before increasing again at age 14 to 1.46 and to 1.55 at age 15 respectively. However, when looking at higher performance levels, such as the fastest Top 50% of athletes, RAEs increased markedly; showing higher effect sizes (ranging from 0.15 to 0.28) and higher ORs (ranging from 1.80 to 4.55) across all age categories. This trend continued for the fastest Top 25% of athletes, revealing medium to large effect sizes and ORs ranging from 2.86 to 5.25. Finally, the highest RAEs appeared in the fastest Top 10% of athletes, with large effect sizes in all age groups with ORs significant ranging from 3.57 to 7.01 (see Table 1).

Table 3. Mean expected performance differences (i.e., milliseconds & percentage figures) according to day, month, and quartile for each annual-age category.

Age	Δ day (ms)	Δ month (ms)	Δ Q (ms)	Δ year (ms)	Δ day (%)	Δ month (%)	Δ Q (%)	Δ year (%)
8	2.84	86.40	259.20	1036.80	0.028	0.837	2.512	10.049
9	2.33	70.97	212.90	851.61	0.023	0.703	2.110	8.441
10	1.83	55.63	166.89	667.55	0.019	0.570	1.710	6.841
11	1.67	50.69	152.06	608.26	0.018	0.535	1.606	6.422
12	1.52	46.37	139.12	556.48	0.017	0.503	1.510	6.041
13	1.51	46.00	138.00	552.00	0.017	0.523	1.569	6.275
14	1.52	46.23	138.69	554.77	0.018	0.557	1.670	6.681
15	1.16	35.32	105.97	423.86	0.015	0.444	1.331	5.326

Δ = mean expected performance difference in age group; ms = millisecond; Q = quartile.

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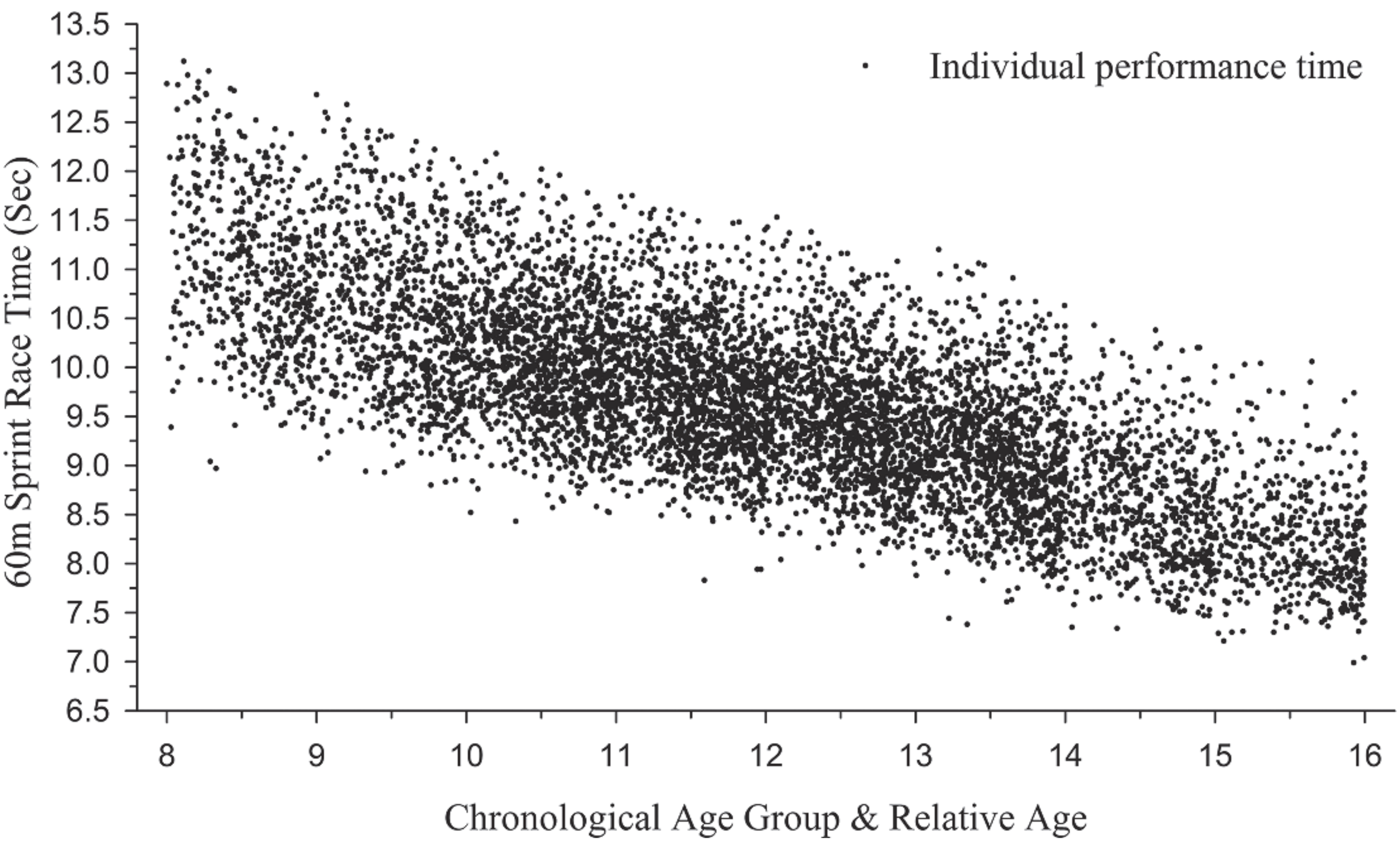

Fig 1. Raw 60m sprint race time performance according to chronological and relative age.

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Part 2

Fig 1 illustrates the relationship between 60m sprint performance according to relative and chronological age for every participant in the sample. The linear regressions within each annual age group suggest that significant proportions of the total variation of sprint performance are predicted by relative age (Table 2). Equations represent the estimated sprint time of a child or youth athlete using their exact decimal age (i.e., in years and days old) as the independent variable. Moderate to small correlations between decimal age and observed sprint times (i.e., $r = 0.379–0.283$) are shown [27]. R^2 indicates that approximately 14% of the variation in sprint times at the 8 year old age group was predicted by decimal age, which then decreased in subsequent age groups accounting for 8% of the variation in the 15 year olds.

Performance differences within and across age-groups

Mean performance differences per day, month, quartile, and year are shown in Table 3. The estimated maximal performance difference in an 8 year old (i.e., Under 9's age group) was 104 ms or 10.1% per year, 2.5% per Quartile, 0.84% per month, and 0.03% per day. Performance differences within one year decreased consistently across the age groups, until at the Under 13's the difference between times was 55 ms or 6.3% per year, 1.6% per Quartile, 1.7% per month, or 0.02% per day. The Under 14's differences were comparable to the Under 13's but again decreased at the Under 15's age group (Table 3).

Table 4. RAE prevalence within annual age-group categories after corrective adjustment.

Performance Level	Age Group	*n*	Q1%	Q2%	Q3%	Q4%	χ^2	*P*	V	Effect	OR	*P*	95% CI
top 50% corrected	8	288	30.6	26.7	24.7	18.1	9.0	*	0.10	small	1.66	*	(1.18–2.35)
	9	412	29.9	25.7	25.5	18.9	9.3	*	0.09	small	1.55	*	(1.17–2.06)
	10	633	27.2	28.1	25.9	18.8	11.2		0.08	no	1.42	*	(1.12–1.8)
	11	685	27.4	25.8	26.7	20.0	7.2		0.06	no	1.35	*	(1.08–1.69)
	12	678	28.5	25.4	24.5	21.7	6.5		0.06	no	1.29	*	(1.04–1.60)
	13	619	27.0	25.8	22.3	24.9	5.1		0.05	no	1.07		(0.86–1.33)
	14	324	30.2	24.4	22.5	22.8	6.1		0.08	no	1.30		(0.96–1.76)
	15	239	30.1	23.0	21.8	25.1	5.2		0.09	no	1.18		(0.84–1.66)
	8–15	3878	28.3	26.0	24.5	21.2	40.2	**	0.06	small	1.32	*	(1.20–1.45)
top 25% corrected	8	144	29.2	28.5	25.0	17.4	4.6		0.10	no	1.65	*	(1.01–2.71)
	9	206	28.2	25.7	27.7	18.4	4.0		0.08	no	1.50		(0.99–2.26)
	10	316	24.4	29.7	27.2	18.7	6.6		0.08	no	1.28		(0.91–1.80)
	11	342	21.6	28.9	28.7	20.8	5.6		0.07	no	1.03		(0.74–1.42)
	12	339	27.4	25.4	24.8	22.4	1.7		0.04	no	1.20		(0.89–1.63)
	13	309	29.4	25.9	20.7	23.9	6.5		0.08	no	1.21		(0.89–1.65)
	14	162	29.0	24.7	21.6	24.7	2.6		0.07	no	1.16		(0.76–1.76)
	15	119	30.3	19.3	21.8	28.6	5.0		0.12	no	1.04		(0.65–1.67)
	8–15	1937	26.6	26.8	25.2	21.3	11.9	**	0.05	no	1.23	*	(1.07–1.40)
top 10% corrected	8	57	22.8	28.1	24.6	24.6	0.3		0.04	no	0.91		(0.43–1.94)
	9	82	22.0	24.4	26.8	26.8	0.5		0.05	no	0.80		(0.43–1.50)
	10	126	23.8	28.6	25.4	22.2	0.8		0.05	no	1.05		(0.63–1.77)
	11	137	24.1	25.5	27.7	22.6	0.3		0.03	no	1.05		(0.64–1.71)
	12	135	26.7	24.4	26.7	22.2	0.5		0.03	no	1.18		(0.73–1.92)
	13	123	26.8	24.4	25.2	23.6	0.3		0.03	no	1.12		(0.68–1.85)
	14	64	23.4	25.0	26.6	25.0	0.1		0.02	no	0.92		(0.46–1.87)
	15	47	23.4	23.4	25.5	27.7	0.3		0.05	no	0.83		(0.37–1.86)
	8–15	771	24.5	25.6	26.2	23.7	1.0		0.02	no	1.02		(0.83–1.25)

Q1 to Q4 = Quartile 1 to 4; $\chi 2$ = Chi-Square Value; V = Cramer's V; *P* = Significance;
*$P<0.05$;
**$P<0.01$; OR = Odds ratio; 95% CI = 95% Confidence Interval.

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Corrective adjustments

When corrective adjustments were applied to raw sprint times and the distributions of performance levels re-examined, more equal relative age distributions (i.e., Q1—Q4) in each age-category and according to performance level were predominantly identified. For example, the corrected Top 10% in the 10 year age group showed no RAE ($p > 0.05$) and an OR of 1.05 (CI = 0.63–1.77), whereas in the original non-corrected data at the same age and performance level, a large RAE was evident (OR = 6.27, CI = 2.97–13.22). Table 4 summarises the distribution of athletes in the Top 50%, 25% and 10% following corrective adjustments. The table shows that for almost every age group in the corrected Top 50% sample, and for all age groups in both the corrected Top 25% and corrected Top 10% no significant RAEs remained ($p > 0.05$). Only in isolated cases, did small RAEs remain evident for specific age categories and performance levels (e.g., Under 9 & 10's in the corrected Top 50%) and when all age groups were included together (i.e., 8–15 year olds).

Discussion

Given the need to isolate and understand the mechanisms driving RAEs, and identify context appropriate solutions, researchers have highlighted the importance of broadening the scope of RAE investigations, notably to include physical demanding individual sport contexts. This study fulfilled these requirements, firstly assessing RAE prevalence across childhood and youth 60m sprinting, and by examining whether RAEs increased at higher performance levels. Secondly, it quantified the relationships between relative and chronological age with sprint performance, and tested whether a corrective adjustment procedure, which corrected for the influence of relative age at each chronological age group, identified a potential solution for RAE removal in sprinting.

Part 1

Aligned with recent studies in individual sport contexts, small to large RAEs across childhood and youth sprinting were detected [12, 13]. Further, results determined that variations in RAE effect size were associated with annual age group and performance level characteristics. When comparing between annual age-groups, RAE effect sizes progressively decreased from ages 8–13, followed by minor increases at 14–15. These findings align well to the maturation-selection hypothesis [1], and when compared to biological growth curves showing a progressive decline in anthropometrics (e.g., height gain) by proportion, prior to a final [puberty] growth spurt, coinciding with the 13–15 age range in males [28]. Data in Fig 1 and Tables 2 and 3 also evidence the additional benefit of time for growth—reflected by higher decimal age—in the earlier years (e.g., Under 10's) which then progressively reduce by proportion into the later years (i.e., Under 16's).

Irrespective of annual age group, the benefit of being relatively older was clearly shown when examining the constituents of the Top 50%—Top 10% sprint performers. Similar to findings in team sport contexts [e.g.,8] RAEs and their effect sizes here increased linearly according to the performance level criteria (see Table 1), even though no formalised selection process was apparent to regulate access to higher performance levels. For instance, being relatively older substantially increased the likelihood of making the highest levels of performance in a given age group (i.e., Top 10%; e.g., Under 15's—Q1 v Q4, OR = 3.31, CI = 1.27–8.61; across Under 8–15's—Q1 v Q4, OR = 3.34, CI = 2.58–4.32). Thus, advanced growth remain as important necessities in attainment of higher performance levels in sprint performance; and magnified RAEs could not be attributed to social processes such selection bias *per se*.

Social processes may still exert their influence however. For instance, when all participants who voluntarily entered a 60m sprint event across Switzerland were examined, significant but small RAEs were evident across annual age-groups, suggesting that a self-selection or matching process may have occurred. The relatively older were more likely to initiate early age group sprint participation, which could possibly be based on a combination of early sporting experiences, (dis)encouraging interactions and (non)reinforcement with others (e.g., parents & peers), as well as the alignment between perceived physical capability in sprinting relative to others. Social processes may also better explain, compared to the maturation-selection hypothesis, why small RAEs remained after corrective adjustments in isolated age-groups (e.g., Under 9's) as shown in part two of the study. For example, the greater total number of Q1's v Q4 participants at the Under 9's meant that it was impossible to have equal distributions even after corrective adjustments were applied to the Top 50% of sprint times, as Q1's and Q4's represented 33.4% and 15.6% of participants respectively (i.e., > 50% difference in numbers). In others words corrective adjustment was never going to, and neither did in intend, to totally correct for participation based RAEs.

Part 2

Linear regressions identified that the predictive influence of decimal age on sprint speed performance were moderate to small, and that performance differences per year decreased progressively from 10.1% to 5.3% approximately between 8–15 years of age. However, unique and novel here was that mean expected performance differences could also provide corrective adjustments figures. When appropriately applied to each individuals athlete's sprint time with January 1st as the reference (i.e., relatively oldest), a re-analysis of RAE distributions according to performance level identified that corrective adjustments were capable of generally removing RAEs from Swiss 60m sprinting. RAEs in each age group of the corrected Top 25% and Top 10% of athletes became completely absent (i.e., $p > .05$), with more even distributions across Q1-Q4 demonstrated, bar the few explained exceptions. To illustrate, in the thirteen year old age group a substantial difference existed between the fastest Top 10%, and the 'relative age corrected' distribution. In the fastest 10% of sprint times at that age, over 45% were from Quartile 1 reflecting a 20% overrepresentation (i.e., 45–20 = 25% per quartile) while only 11% were from Q4 indicating a 14% underrepresentation. However, after applying corrective adjustments, the corrected Top 10% included 27% from Q1 and 24% from Q4 showing no statistical RAE.

Corrective adjustments demonstrate the capability to more accurately compare between individuals, given their specific relative age, sprint times, and with comparison to a broader reference data set. For instance, in the data there was a 10 year old boy (boy 1) born on the 13th of February, and a boy (boy 2) born the 18th of November. Boy 1 had a race time of 8.92s, while boy 2 had a race time of 9.17. Boy 1 in real terms was 0.25s (i.e., 9.17s-8.92s) faster than boy 2. However, after adjusting sprint times (i.e., age difference of 0.87 years and expected performance difference of 5.21%), boy 1 actually had a corrected net sprint time of 8.85s, while boy 2 had a corrected net sprint time of 8.62s. This means that if the relative age advantage was correctly accounted for and adjusted, boy 2 actually had a better sprint time given their respective relative ages.

Implications

Findings challenge present norms and practice in both grass-roots sport participation and in athlete development systems. First, due to their comparatively later biological development, a substantial majority of relatively younger athletes in childhood and youth ages are likely to perform comparatively poorly in age-based competition, and may fail to meet selection requirements for athlete developmental systems. Over time though and as our data suggests, the disadvantage is likely to diminish by proportion; and other factors are likely to become more influential [29]. Thus, it seems that RAEs reflect a type of developmental barrier; one which is preventable if appropriate solutions can be implemented.

Corrective adjustments may hold significant implications for current childhood and youth sport contexts in both team and individual CGS sport contexts [1,30], where the influence of relative age is presently not considered or removed, resulting in what are consistent and sometimes large RAE effect sizes. In Swiss track and field, corrective adjustments can help ensure that potential sprinters are not ignored, missed, or lost on the basis of relative age or later growth. For team sports such as soccer and codes of rugby, where players are often assessed on standard multiple anthropometric and physiological/fitness tests (e.g., sprint times, vertical jump), corrective adjustments could help better inform and improve validity in player evaluation and selection procedures.

Although in alternative forms, corrective adjustments do already exist in other sport contexts and disciplines. Handicapping in golf [31] is a corrective adjustment method for skill level; while in standardised physiological performance tests, oxygen uptake and force production are often normalised for body weight [32]. So testing and application of corrective adjustments in specific CGS junior/youth sports, or in contexts where components of physical performance are measured in CGS, are important future directions. Whether sport coaches, sport federations/governing bodies, and athlete development systems perceive value in implementing such procedures remains to be determined. From our standpoint, the main challenge relates to the obtainment of a substantial reference data-set to generate accurate regressions and subsequent corrective adjustments. If overcome and applied, corrective adjustment are likely to help remove RAEs from affecting sport participation experience across childhood and youth sport, and help make long-term athlete development more legitimate and effective.

Conclusion

Overall findings identified small RAE effect sizes across age groups when all 60m sprinters were analysed. RAE effect sizes decreased as age-group increased, but regardless of age-group increased linearly according to performance level. Regression analyses between decimal age and sprint time identified that an almost one year relative age difference resulted in performance differences of 10.1% at age 8, 8.4% at 9, 6.8% at 10, 6.4% at 11, 6.0% at 12, 6.3% at 13, 6.7% at 14, and 5.3% at 15. Correction adjustments calculated according to day, month, quarter, and year showed that the influence of relative age—and thus normative growth and development—can be accounted for and RAEs removed from sprint performance. Corrective adjustments could also be considered and need to be evaluated for other disciplines in track and field (e.g., 100m+, long jump or throwing). Importantly, findings highlight a potential solution to help remove RAEs from CGS sports; help improve childhood and youth sport participation experience; and help improve inter-athlete evaluation assessment and selection.

Author Contributions

Conceived and designed the experiments: MR SC. Performed the experiments: MR SC. Analyzed the data: MR SC. Contributed reagents/materials/analysis tools: MR SC. Wrote the paper: MR SC.

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Influence of the Selection Level, Age and Playing Position on Relative Age Effects in Swiss Women's Soccer

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Abstract: Relative age effects (RAEs) refer to age differences in the same selection year. In this study, 6,229 female soccer players representing the entire Swiss female soccer population were evaluated to determine the prevalence of RAEs in Swiss women's soccer. Significant RAEs existed in the self-selected extracurricular (n = 2987) soccer teams and the subgroup of talent development teams (n = 450) in the 10 to14 age category. No significant RAEs were found for players 15 years of age or older (n = 3242) and the subgroup of all national teams (n = 239). Additionally, significantly stronger RAEs were observed in defenders and goalkeepers compared to midfielders in national teams. Our findings show that in Switzerland, RAEs apparently influence the self selection and talent selection processes of women's soccer in the 10 to 14 age category. However, in contrast to male soccer we found no RAEs in elite women's soccer teams.

Keywords:
talent development, selection, female soccer, birth date

Children are grouped by age for sport activities to reduce the effects of developmental discrepancies. However, this procedure leads to age differences between individuals in the same annual cohort. This can lead to an age difference of almost 12 months between the youngest and the oldest participants, known as relative age effects (RAEs). RAEs were initially observed in school settings, describing the link between the month of birth and academic success (Bigelow, 1934; Dickinson & Larson, 1963). In sports, RAEs have gained increasing awareness among sports scientists and coaches over the last three decades. Early research from 1984 until today has identified a consistent prevalence of RAEs within a variety of sports at the junior level (Cobley, Baker, Wattie, & McKenna, 2009). Soccer is among a group of highly popular sports, such as ice hockey, with the highest prevalence of RAEs (Cobley et al., 2009). In some exceptional activities like golf (Côté, Macdonald, Baker, & Abernethy, 2006), where physical attributes are less important, RAEs have not been identified. In dance and gymnastics, no or even inverse RAEs have been shown to exist (Baxter-Jones & Helms, 1996; Malina, Bouchard, & Bar-Or, 2004; van Rossum, 2006).

In male soccer, different mechanisms have been proposed for explaining the causes of RAEs. Maturational differences and physical attributes (e.g., greater aerobic power, muscular strength, and height) appear to be mainly responsible (Carling, le Gall, Reilly, & Williams, 2009). As RAEs are based on chronological age, relatively older children consistently have an advantage, favouring an advanced maturation (Schorer, Cobley, Busch, Brautigam, & Baker, 2009). It is also important to note that an even higher impact results from biological age differences, which refer to psycho-physical maturity and can lead to variations of more than two years (Malina & Bielicki, 1992). Additional explanations for relatively older children's superior performance involve psychological development,

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practice experience, and mechanisms related to the selection processes (Musch & Grondin, 2001). Once selected, the relatively older children also experience better coaching, more positive feedback, deeper involvement, and more intense competition, all of which enhance performance (Sherar, Baxter-Jones, Faulkner, & Russell, 2007). On the other hand, children with a relative age disadvantage play at a competitively lower level and have less support and training. As a consequence, those children are less likely to reach the highest levels in elite sports (Helsen, Starkes, & Van Winckel, 2000) and are more likely to drop out of a particular sport (Delorme, Boiché, & Raspaud, 2010a). Musch and Grondin (2001) described factors related to the sport setting that may increase RAEs in male sports, such as the sport's popularity, the level of competition, early specialization, and the expectations of coaches who are involved in the selection process. Generally, soccer's importance and popularity has increased during the last decade, resulting in a higher number of players who wish to play soccer (Cobley, Schorer, & Baker, 2008; Wattie, Baker, Cobley, & Montelpare, 2007). The increasing participation and infrastructure intensifies the competition to be selected for elite teams. Additionally, there has been an increasing emphasis of clubs to detect young players who are likely to become world-class performers (Wattie, Cobley, & Baker, 2008). Finally, in international junior soccer, there may be a focus on winning instead of developing talent for the elite stage (Helsen, Hodges, Van Winckel, & Starkes, 2000).

Most studies concerning RAEs in soccer, however, have been focused on male athletes and researchers still need to understand the mechanisms that affect RAEs, as well as confirm whether RAEs exist in female contexts (Cobley et al., 2009).

As part of the Training of Young Athletes (TOYA) longitudinal study, Baxter-Jones and Helms (1994) carried out a study examining RAEs in elite female athletes. The researchers showed that almost 50% of elite female swimmers and 8 to 16-year-old tennis players were born in the first quarter of the selection year. In the same way, Delorme and Raspaud (2009) observed a significant relative age effect in all female and male youth categories in French basketball.

Although there has been an exponential growth in the number of women playing soccer worldwide (Williams, 2007), Musch and Grondin (2001) observed that the effect of an athlete's gender on RAEs still remains neglected. To our knowledge, only three studies to date have investigated RAEs in women's soccer. On one hand, RAEs were observed among all registered female players in the French federation (Delorme, Boiché, & Raspaud, 2010b), but no RAEs were found among high-level female soccer players (Delorme, Boiché, & Raspaud, 2009). On the other hand, Vincent and Glamser (2006) compared the relative age effect among 1,344 male and female soccer players of the U.S. Olympic Development Program. In their study, marginal RAEs were shown for girls at the national and regional levels and no RAEs for those playing at the state level. However, the results revealed large RAEs for boys at all levels. Hence it can be stated, that the available data concerning RAEs in female soccer is sparse and reveals contradictory results.

In Switzerland, women's soccer is rapidly gaining popularity, which may be due to the success of the men's soccer team (Swiss Federal Office of Sport, 2010). Despite the country's small population (7.7 million), the Swiss male senior team was listed 13th in January 2010 in the FIFA world ranking, and the male Swiss U-17 team won the European Cup in 2002 and the World Cup in 2009. Due to these achievements, Tschopp, Biedert, Seiler, Hasler, and Marti (2003) assumed that the Swiss soccer federation may have a relatively efficient and successful talent development system. However, RAEs have still not been investigated in Swiss women's soccer.

In previous literature, links between male RAEs, maturation, and playing positions have been identified, which could have biased the talent identification process. More mature players with more experience in soccer perform better in ball control by using their body size. In addition, a player's level of maturity significantly contributes to variations in shooting accuracy (Malina et al., 2005). In boys' soccer, forwards were found to be significantly leaner than midfielders, defenders, and goalkeepers. A discriminating variable of male defenders compared to midfielders and strikers is their lower leg power (Gil, Gil, Ruiz, Irazusta, & Irazusta, 2007). Interestingly, in contrast to the selection bias of RAEs, senior male players born late after the cut-off date have been shown to earn systematically higher wages (Ashworth & Heyndels, 2007). This effect was reported as being strongest for goalkeepers and defenders, but not evident for forwards. It was speculated that this pattern could reflect a bias in talent scouts' selection of teams and playing positions. This finding is consistent with Grondin and Trudeau (1991), who demonstrated a link between male ice hockey players' RAEs and playing positions. In their analysis, the RAEs were strongest among defenders and goalkeepers. Moreover, physical attributes and playing positions are related to the magnitude of RAEs in both men's handball (Schorer, Cobley, Busch, Brautigam, & Baker, 2009) and men's rugby (Till et al., 2009). Whether there is a link between RAEs and playing positions in women's soccer has not been analyzed to date.

Given the relevance of RAEs and their potential for introducing a bias in talent identification, it is worth examining RAEs in the overall setting of Swiss women's soccer. Therefore, the purposes of this study were twofold: first, to examine the prevalence and size of RAEs at the different age and performance levels of Swiss women's soccer, and second, to identify if playing positions modify the prevalence and size of RAEs.

Methods

Participants

The Swiss system of talent identification, selection, and development is based on three levels of performance (Figure 1). The first level is a nationwide extracurricular program called *Jugend und Sport* (J+S), which is offered for all children interested in a specific sport. Soccer is one of 77 disciplines available. The minimum duration for a J+S course is at least 30 weeks per year with one training session per week. Every soccer training session has to last at least 60 minutes.

J+S contains $n = 6{,}157$ registered female soccer players ranging from 10 to 20 years of age, which is 1.4% of the female Swiss population ($N = 440{,}934$). The female Swiss population was defined as the number of live female births in Switzerland in the respective age groups. The second level is the national talent detection and development program of J+S. These players ($n = 1{,}067$) are assisted by licensed soccer trainers and are expected to train more than 400 hours per year (Swiss Federal Office of Sport, 2010). The Swiss Soccer Association and the Swiss Olympic Association jointly established the cut-off criterion for adoption into the program as 400 hours. All data for the Swiss population, J+S and the talent development program of J+S involve the 2009–2010 season. The national teams ($n = 167$) represent the third level. The inclusion criterion for a national team player was the selection to a Swiss national under-17 (U-17), under-19 (U-19), or the senior team (A team) in the 2007–2008, 2008–2009, and 2009–2010 seasons.

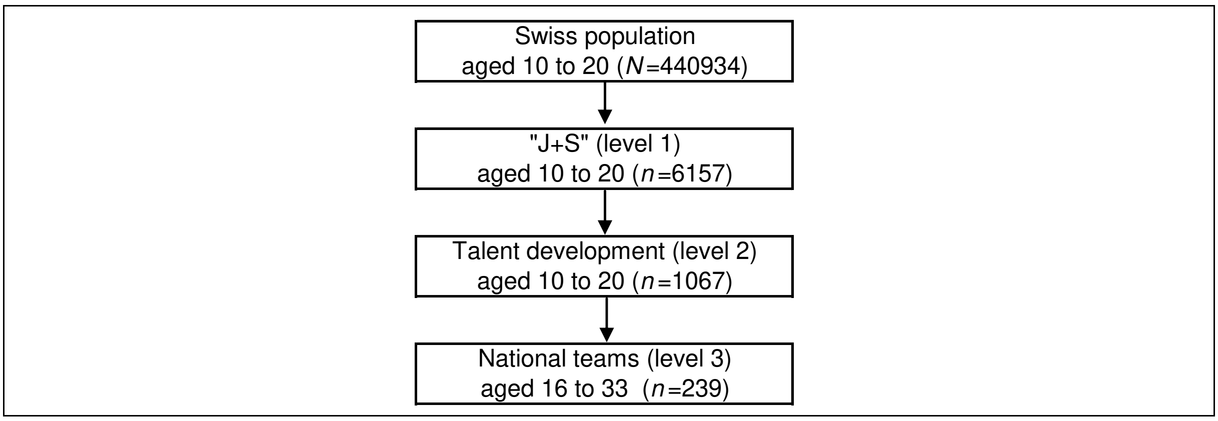

Figure 1. Overview of the different levels of selection in Swiss women's soccer.

In total, we examined the birth-date distributions of three Swiss national teams for each of three seasons (nine in total) in order to calculate the relationship between RAEs and playing positions. Comparisons were carried out between the datasets of the junior national teams, players in the talent detection (TD) program, all registered J+S players, and the entire Swiss population.

Procedure

All 6,229 female soccer players were grouped according to the month of the selection period. The birth month of each player was recorded to define the birth quarter (Q). The cut-off date for all soccer leagues in Switzerland is January 1st.

The year was divided into four quarters (Q1 represents January, February, and March; Q2 represents April, May, and June; Q3 represents July, August, September; and Q4 represents October, November, and December). The observed birth-date distributions of all players were calculated for each quarter. The expected birth-date distributions were recorded from the J+S database, where all players who participate in organized soccer activities are registered. Beforehand, the Swiss Youth Sport database was analysed in order to verify that there are no statistical differences between the birthdates of all registered J+S player's (aged 10–20 years) and all corresponding birth dates of the Swiss female population (aged 10–20 years). According to Delorme et al., (2010a) we used the distribution of J+S (all registered players) as a basis (expected distributions) to evaluate RAEs instead of the female Swiss population. If a biased distribution already existed among the entire population of registered players (J+S; level 1), the same pattern would arise among the elite (level 3) as well, and bias the conclusions drawn about RAEs among the elite.

From these original data, odds ratios (*OR*s) were calculated for Q1 versus Q4. All statistical analyses were carried out using SPSS 16.0. Chi-square tests were used to assess differences between the observed and expected birth date distributions. If the differences were significant then post hoc tests were used to determine the mean differences between the quarters. In addition, effect sizes were computed to qualify the results of the chi-square tests. The appropriate index of effect size is the phi coefficient (φ) if there is one degree of freedom (*df*), and Cramer's V (V) is appropriate if the *df* is above 1 (Aron, Aron, & Coups, 2002).

For the chi-square analyses, the magnitude of the effect size was measured using φ and V. According to Cohen (1977) and Cramer (1999), for $df = 3$ (which is the case for all comparisons of birth quarters), $V = 0.06$ to 0.17 described a small effect, $V = 0.18$ to 0.29 described a medium effect, and $V \geq 0.30$ described a large effect. An alpha level of $p < 0.05$ was applied as the criterion for statistical significance.

Results

Prevalence of RAEs in Swiss Women's Soccer

Significant RAEs were found already in the subgroup of all registered J+S players who were 10 to 14 years old (Table 1). The distribution showed a small but significant overrepresentation of Q1 elite players and a significant underrepresentation of Q4 elite players compared to the respective Swiss population. However, no significant RAEs were found for the 15- to 20-year-old age group of J+S players.

The analyses of talent development teams revealed similar findings as for the J+S players. There were significant RAEs in the 10- to 14-year-old age group and no RAEs in the 15- to 20-year-old age group. For all players in the 10- to 14-year-old age group, the chi-square and post hoc tests highlighted an overrepresentation of players born at the beginning of the selection year and a decreasing number of players born at the end of the year. For all national elite teams, no significant RAEs were identified.

The peak of the RAEs was found in the U-10 and the U-11 talent development teams, where 66.6% of the players were born in the first half of the year (Figure 2). This ratio is lower in the higher age categories, ranging from 59% to 49% in the U-12 to U-18 talent development teams.

Table 1. Birth-Date Distribution of the Swiss Female Soccer Population

Category	Q1	Q2	Q3	Q4	Total	χ^2	*p*	*OR* Q1/Q4	*V*	Effect
SP (10-20)	109682	111428	113838	105986	440934			1.03		
(%)	24.8%	25.3%	25.9%	24.0%						
J+S (10-14)	794	811	728	654	2987	16.08	< 0.001	1.21	0.04	no
(%)	26.6%	27.2%	24.4%	21.9%						
J+S (15-20)	781	856	831	774	3242	6.1	> 0.05	1.01	0.03	no
(%)	24.1%	26.4%	25.6%	23.9%						
TD (10-14)	135	123	119	73	450	16.9	< 0.001	1.85	0.11	small
(%)	30.0%	27.3%	26.4%	16.2%						
TD (15-20)	167	161	152	137	617	2.47	> 0.05	1.22	0.04	no
(%)	27.1%	26.2%	24.4%	22.3%						
U-17	20	29	23	15	87	4.7	> 0.05	1.33	0.13	small
(%)	23.0%	33.3%	26.4%	17.2%						
U-19	24	20	22	14	80	2.8	> 0.05	1.71	0.11	small
(%)	30.0%	25.0%	27.5%	17.5%						
A-Team	23	17	21	11	72	4.7	> 0.05	2.09	0.15	small
(%)	31.9%	23.6%	29.2%	15.3%						

Note. SP = Swiss population; J+S = Players of extracurricular soccer teams; TD = Players of talent development teams; *OR* = Odds ratio; *V* = Cramer's V.

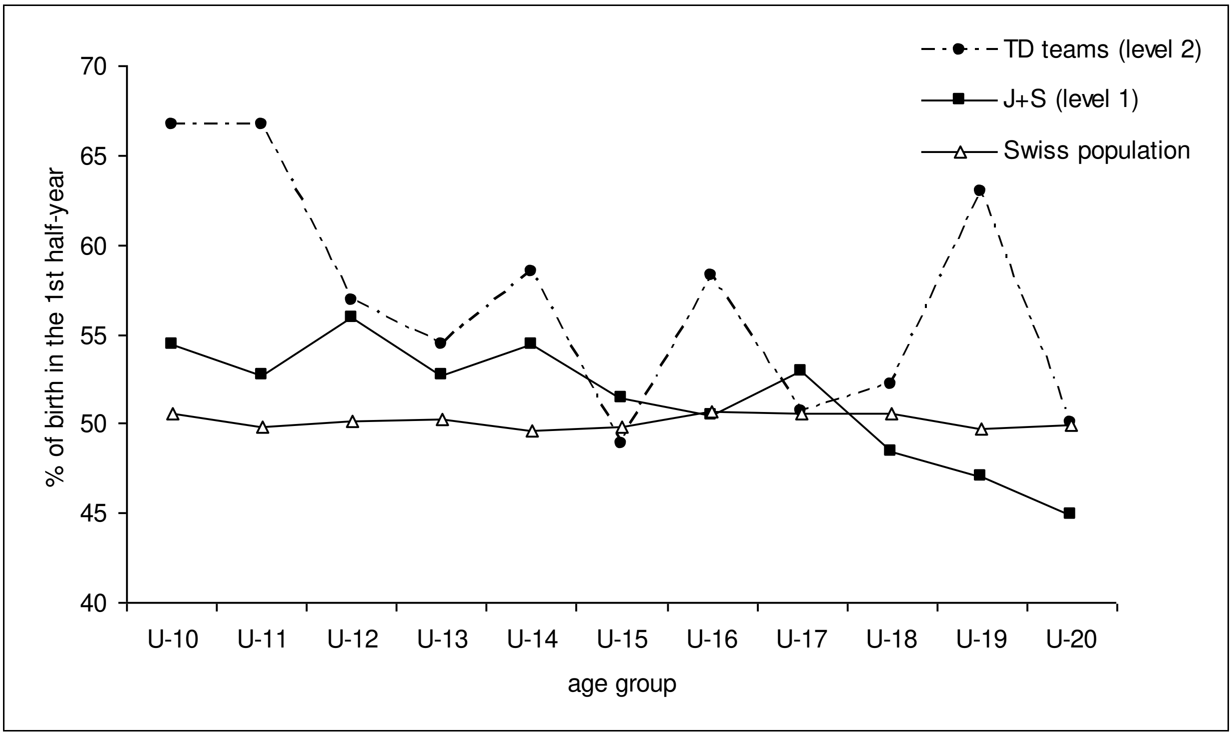

Figure 2. Distribution of births in the first half year of talent development teams (level 2) compared to the Swiss population and all registered J+S players (level 1).

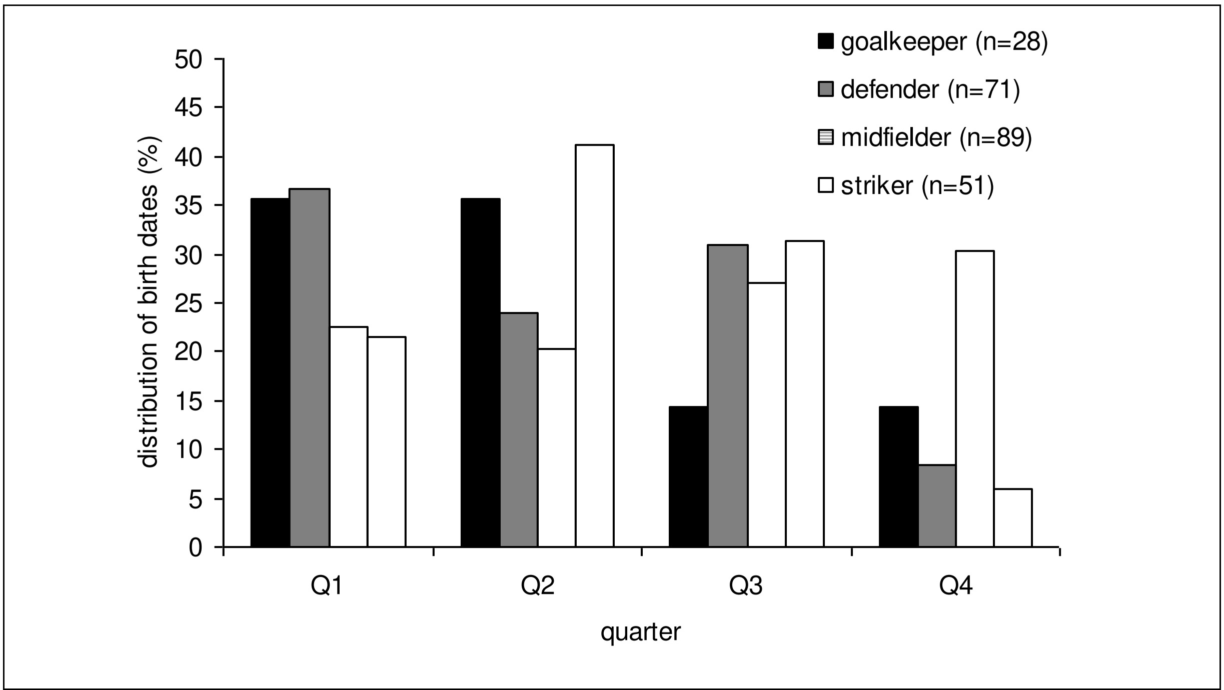

Figure 3. Distribution of playing positions and birth quarters in U-17 to A-teams (Level 3).

Playing Positions

The birth date distributions for playing positions in the national elite U-17 to A-teams are presented in Figure 3. Chi-square tests showed significant differences for defenders and strikers compared to the J+S distribution ($p < 0.05$). Defenders were overrepresented in Q1 (36.6%) and Q3 (31.0%), and underrepresented in Q4 (8.5%). Strikers were overrepresented in Q2 (41.2%) and Q3 (31.4%), and underrepresented in Q4 (5.9%).

In a second analysis, we calculated the distribution of birth dates between the different playing positions. Defenders and goalkeepers were significantly ($p < 0.05$) overrepresented in the beginning of the year compared to midfielders. The remaining comparisons were not significant.

Discussion

Prevalence of RAEs in Swiss Women's Soccer

Interestingly, the self-selected J+S players (Level 1, 10 to 14 years), which represent the respective regularly playing soccer population, already showed RAEs and differed significantly from the Swiss population's distribution. We found small but consistent RAEs in the 10- to 14-year-old age group of talent development players (Level 2). However no significant RAEs were found in the 15- to 20-year-old age groups at all levels (J+S, talent development and national level). Moreover, we demonstrated that playing positions are interrelated with the prevalence and size of RAEs in female soccer. In the present study, the defenders and goalkeepers showed significantly higher RAEs compared to midfielders.

In line with previous studies, no RAEs were detected in the highest selection levels of all female junior age categories (15- to 20-year-olds; Delorme et al., 2010b; Vincent & Glamser, 2006). A possible explanation might be that female anaerobic and aerobic characteristics, running speed and physical fitness performance reach a plateau shortly after menarche (Haywood & Getchell, 2001; Thomas, Nelson, & Church, 1991). Similar developments of gross motor skill performance, agility, jumping and kicking tests have been found for girls (Gabbard, 2000; Thomas & French, 1985). Therefore, some of the physiological benefits of being born early in the selection year might disappear in the 15- to 20-year-old age group. In fact, after menarche adolescent girls' athletic performance is poorly related to maturity status (Malina, 1994). Accordingly, late maturing girls frequently catch up with their peers who matured early and even produce superior athletic performances. In addition, late maturing girls generally have a more ectomorphic, linear physique with longer legs and relatively narrow hips, less body mass for their stature, and less adipose tissue (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004). In other words, early physical development is an advantage before and during puberty. However, early physical development acts as a socially constructed disadvantage for young women after puberty because a high relative age could facilitate their dropout from elite soccer (Delorme et al., 2010b). In addition, the physical characteristics needed for athletic performance are sometimes inconsistent with the stereotyped idea of an ideal female body (Choi, 2000). Traditionally, soccer as a contact sport has been considered gender-inappropriate for women. Researchers have argued that social pressures to conform to a socially constructed gender role, such as stereotyped ideas of femininity, could pressure early maturing girls to drop out of contact sports such as soccer, which may explain why the birth date distribution reveals no RAEs among elite players (Vincent & Glamser, 2006).

As pointed out, the self-selected J+S teams (level 1) in the 10 to 14 age group already showed small RAEs. In other words, girls born in the first half of the selection year are more likely to begin playing soccer compared with their younger counterparts. Those born in Q3 and Q4, probably because of their less advantageous physical and psychological attributes, show a kind of self-selection process before even trying to play soccer. One explanation could be that girls who mature early are generally taller and heavier, with more body mass for stature than late maturing girls (Baxter-Jones, Thompson, & Malina, 2002). This leads to athletic performance advantages early in puberty. It is important to note that, due to the possible self-selection (level 1), coaches of the talent development program (level 2) had to perform their selections using an unequally distributed pool of players, which could have increased RAEs in level 2.

In the present study, playing positions of all national players (level 3) were interrelated with the prevalence and size of RAEs in women's soccer. The defenders and goalkeepers showed significantly higher RAEs compared to midfielders. Recently, Schorer et al. (2009) showed that RAEs of male back court handball players on the left side are stronger than those on the right side. These results provide evidence that height, laterality and playing position affect the magnitude of RAEs in men's handball. This is in line with the observation that tall soccer players also tend to have an advantage, especially goalkeepers and central defenders (Di Salvo et al., 2007; Reilly, Bangsbo, & Franks, 2000). It can be speculated that Swiss coaches in women's soccer may also tend to select relatively older defenders and goalkeepers who are taller and more mature.

To optimize the talent development system in Switzerland further, the challenge seems twofold. On one hand, it seems important to include disadvantaged players due to RAEs in soccer activities at an early age. On the other hand, it is crucial to keep players involved in soccer after puberty ends.

Possible Solutions

Several solutions to reduce RAEs have been proposed in the literature. One solution is to establish "current" and "potential" teams: the "current" team contains the best players, both technically and physically, at the selection time, while the "potential" team contains players who are technically skilled, but who are lacking in terms of their physical development (Brewer et al., 1995). Barnsley and Thompson (1988) have suggested creating more age categories with a smaller bandwidth (e.g., six months rather than one year). This change would result in smaller RAEs and fewer physical differences between players within any specific age category. A single change in the selection date would result in an equal shift of RAEs (Helsen et al., 2000). Therefore, Grondin et al. (1984) recommended an alteration of the activity year's cut-off dates. A yearly rotation for the cut-off date might work, since all players would then experience the advantage of a higher relative age at some point in their soccer career (Hurley et al., 2001). One potential solution could be to change the mentality of youth team coaches (Helsen et al., 2000). Coaches should pay more attention to technical and tactical skills when selecting players, as opposed to over-relying on physical characteristics such as height and strength. Additionally, they should find a better balance between short-term success and a more process-oriented approach to instruction (Helsen et al., 2005).

The challenge for Switzerland will be to keep players who are physically or psychologically disadvantaged due to RAEs involved in the sport until they have fully matured. In the current Swiss system, players who are accepted on elite teams start benefiting quite early from receiving more support, a higher level of competition, increased training, longer playing times, more positive feedback and improved coaching. Alternatively, unselected players may tend to have lower self-esteem and show higher dropout rates (Helsen et al., 1998). Delorme et al. (2010a) illustrated that dropout rates result from two major processes. First, children born late in the selection year may be less likely to join a sport in which weight, height, or strength are seen as relevant for performance. It is important to note that the first phenomenon cannot be solved by federations reducing the RAEs. Second, those who are involved in a sport are more likely to drop out and have fewer chances to be selected.

The decrease in RAEs may substantially enhance performance at the elite senior level in the future, especially for Switzerland, which has a rather shallow talent pool due to the limited number of inhabitants. Interestingly, in the current Swiss coach education programme, only junior national level coaches are confronted with RAEs during their education. According to our data, the consequences of RAEs should be taught at all levels of coach education, particularly for coaches of talent development teams in the 10 to 14 age categories. Therefore, from our point of view, implementing rotating calendar cut-off dates and furthering the education of all soccer coaches may counteract future RAEs in Swiss soccer. Moreover, in Switzerland, talent identification and player development should be viewed as more long-term processes. In contrast to aspects of performance, assessments of skill and potential should be emphasised (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). In any case, it would be a significant step forward for coaches and federations to select the teams with the highest potential in future elite soccer instead of the team with the highest chance of winning in the present (Helsen et al., 2000).

Main Findings and Conclusion

Based on the present data, we argue that small, but significant RAEs bias the participation and the selection process of women's soccer in Switzerland up to the age of 14 years. However, our results indicate that RAEs do not influence the talent identification process of Swiss national elite teams. The RAEs seem to be largest already in the U-10 and U-11 squads, where three-quarters of the selected players were born in the first half of the year. Additionally, higher RAEs were observed in defenders and goalkeepers compared to midfielders. To minimize RAEs in Swiss women's soccer, a systematic education for all soccer coaches regarding RAEs could be established

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ORIGINAL ARTICLE

Relative age effects in Swiss junior soccer and their relationship with playing position

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Abstract
Relative age effects (RAEs) refer to age differences between children in the same selection year. The present study investigated the prevalence of RAEs and their link to playing positions in Swiss junior soccer. Swiss male junior soccer players ($n = 50{,}581$) representing 11% of the age-matched population – members of extra-curricular soccer teams – were evaluated to determine the influence of RAEs on Swiss junior soccer. Subgroups were the national talent development programme ($n = 2880$), and U-15 to U-21 national teams ($n = 630$). While no RAEs were found for the self-selected extra-curricular soccer teams or for the U-20 teams ($P > 0.05$), significant RAEs were found for talent development and the national U-15 to U-19 and U-21 teams ($P < 0.01$). Additionally, defenders born early in the year were significantly overrepresented compared with goalkeepers, midfielders and strikers ($P < 0.05$). In Switzerland, RAEs apparently have substantial influence on the talent identification process for U-15 to U-18 teams, significantly influencing the selection of players in talent development teams already at an early age, but do not influence self-selected participation in extra-curricular soccer. Additionally, the RAE bias may be a predictor of playing positions in national teams. To minimise RAEs in Swiss soccer, systematic education for all coaches regarding RAEs should be established, in addition to a slotting system with rotating calendar cut-off dates.

Keywords: *Junior soccer, birth date, player selection, playing position*

Introduction

For school or sport activities, children are grouped by age to reduce the effects of developmental differences. However, this procedure leads to age differences between individuals in the same annual cohort. This can lead to an age difference of almost 12 months between the youngest and the oldest participants in the same annual age category. The advantage of being born early within a cohort has been termed relative age effects (RAEs). Early research from 1984 until today has identified RAEs in a variety of sports, such as volleyball (Grondin, Deschaies, & Nault, 1984), baseball (Thompson, Barnsley, & Stebelsky, 1991), tennis (Edgar & O'Donoghue, 2005), ice hockey (Barnsley & Thompson, 1988) and soccer (Helsen, van Winckel, & Williams, 2005). In certain activities where physical attributes are less important, such as golf (Côté, Macdonald, Baker, & Abernethy, 2006), RAEs have not been identified. In dance, gymnastics and shooting, inverse RAEs have even been described (Baxter-Jones & Helms, 1996; Delorme & Raspaud, 2009; Malina, Bouchard, & Bar-Or, 2004). Soccer, however, is among a group of highly popular sports, such as ice hockey, with the highest prevalence of RAEs (Cobley, Baker, Wattie, & McKenna, 2009).

Different mechanisms have been proposed for explaining the causes of RAEs. Maturational differences and physical attributes (e.g. greater aerobic power, muscular strength and height) appear to be mainly responsible (Carling, le Gall, Reilly, & Williams, 2009). As RAEs are based on chronological age, relatively older children consistently have an advantage due to their extended age, favouring an advanced maturation (Schorer, Cobley, Busch, Brautigam, & Baker, 2009). It is also important to note that an even higher impact results from biological age differences, which refers to psycho-physical maturity and can lead to variations of more than 2 years

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(Malina & Bielicki, 1992). Additional explanations for relatively older children's superior performance involve psychological development, practice experience and mechanisms related to the selection processes (Musch & Grondin, 2001). Once selected, the relatively older children also experience better coaching, more positive feedback, deeper involvement and more intense competition, all of which enhance performance (Sherar, Baxter-Jones, Faulkner, & Russell, 2007). On the other hand, children with a relative age disadvantage play at a competitively lower level with less support and less training. As a consequence, those children are less likely to reach the highest levels in elite sports (Helsen, Starkes, & Van Winckel, 2000) and are more likely to drop out of a particular sport (Delorme, Boiché, & Raspaud, 2010a). In line with this assumption, Delorme et al. (2010a) observed an overrepresentation of male soccer player dropouts from the U-9 to U-18 age categories, who were born late in the selection year. Musch and Grondin (2001) described factors related to the sport setting which may increase RAEs in male sports, such as the sport's popularity, the level of competition, early specialisation, and the expectations of the coaches who are involved in the selection process. Generally, soccer's importance and popularity has increased during the last decade, resulting in a higher number of players who wish to play soccer (Cobley, Schorer, & Baker, 2008; Wattie, Baker, Cobley, & Montelpare, 2007). The increasing participation and infrastructure intensifies the competition to be selected for elite teams. Additionally, there has been an increasing emphasis on clubs to detect young players who are likely to become world-class performers (Wattie, Cobley, & Baker, 2008). Finally, in international junior soccer, there may be a focus on winning instead of developing talent for the elite stage (Helsen, Hodges, Van Winckel, & Starkes, 2000). RAEs in male soccer have been analysed in several countries, such as Belgium (Helsen et al., 1998), England (Helsen et al., 2005), Germany (Augste & Lames, 2011), France (Delorme, Boiché, & Raspaud, 2009), Spain (Jimenez & Pain, 2008). All of these studies have revealed significant RAEs in favour of players born in the first quarter of the selection year. Hence, RAEs in male soccer seem evident; therefore, young players with potential may be overlooked (Vaeyens, Philippaerts, & Malina, 2005). In previous literature, links between RAEs, maturation and playing positions have been identified, which could have biased the talent identification process. More mature players with more experience in soccer perform better in ball control by using their body size. In addition, a player's level of maturity significantly contributes to variations in shooting accuracy (Malina et al., 2005). In youth soccer, forwards were found to be significantly leaner than midfielders, defenders and goalkeepers. A discriminating variable of defenders compared to midfielders and strikers is their lower leg power (Gil, Gil, Ruiz, Irazusta, & Irazusta, 2007). Interestingly, players born late after the cut-off date have been shown to earn systematically higher wages (Ashworth & Heyndels, 2007). This effect was reported as being strongest for goalkeepers and defenders, but not evident for forwards. It was speculated that this pattern could reflect a bias in talent scouts' selection of teams and playing positions. This finding is consistent with Grondin and Trudeau (1991), who demonstrated a link between ice hockey players' RAEs and playing positions. In their analysis, the RAEs were strongest among defenders and goalkeepers. Moreover, physical attributes and playing positions have been found to be related to the magnitude of RAEs in both handball (Schorer et al., 2009) and rugby (Till et al., 2009). However, whether there is a link between RAEs and playing positions in male soccer has not been analysed to date.

In Switzerland, soccer is the largest sport federation with 50,581 registered male soccer players ranging from 10 to 20 years of age, representing 11% of the age-matched Swiss population. Despite the country's small population (7.7 million), the Swiss senior team was listed 13 January 2010 in the FIFA world ranking, and the Swiss U-17 team won the European Cup in 2002 and the World Cup in 2009. Due to this achievement, Tschopp, Biedert, Seiler, Hasler, and Marti (2003) assumed that the Swiss soccer federation may have a relatively efficient and successful talent development system. However, to our knowledge, RAEs in Swiss soccer have not been analysed to date.

Given the relevance of RAEs and their potential for introducing a bias to the talent identification process, an examination of RAEs in the entire setting of Swiss male junior soccer seems warranted. Therefore, the aim of this study was to examine the prevalence and size of RAEs at the different performance levels of Swiss junior soccer and their relationship with playing positions.

Methods

Participants

The Swiss system of talent identification, selection and development is based on three levels of performance (Figure 1). The first level is a nationwide extra-curricular programme (level 1) called 'Jugend und Sport' ('J + S'), which is for all children who are interested in a specific sport. Soccer is one of 77 disciplines available. The minimum duration for a 'J + S' course is at least 30 weeks per year with one

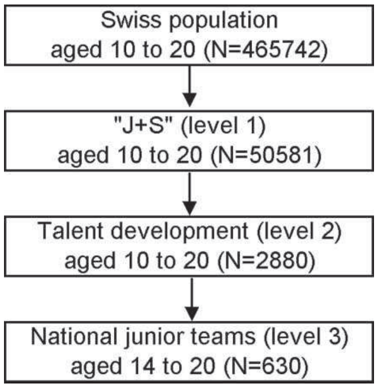

Figure 1. Overview of the different levels of selection in Swiss junior soccer.

training session per week. Every soccer training session has to last at least 60 minutes.

'J + S' contains $n = 50{,}581$ registered male soccer players ranging from 10 to 20 years of age, which is 10.8% of the male Swiss population ($n = 465{,}742$). Data for 'J + S' were obtained from the Swiss Federal Office of Sport. The Swiss population was defined as the number of live male births in Switzerland. All data for the corresponding Swiss population (10–20 years old) were obtained from the Swiss Federal Statistical Office.

The second level of performance is the national talent detection and development programme (level 2) of 'J + S'. These players ($n = 2880$), ranging from 11 to 20 years of age (U-12 to U-21), are assisted by licensed soccer trainers and are expected to train more than 400 hours per year (Swiss Federal Office of Sport, 2010). The cut-off criterion of 400 hours and the age range of 11–20 years for adoption into the programme were jointly established by the Swiss Soccer Association and the Swiss Olympic Association. The junior national teams ($n = 630$) represent the third level (level 3) of performance. The inclusion criterion for a national team player was being selected as a Swiss national under-15 (U-15), under-16 (U16), under-17 (U17), under-18 (U18), under-19 (U19), under-20 (U20) and under-21 (U-21) team member in the 2007–2008, 2008–2009 and 2009–2010 seasons. All data for the Swiss population, 'J + S' and the talent development programme of 'J + S' involve the 2009–2010 season. Each player was presented only once in the analysis.

In total, we examined seven Swiss national U-teams' birth date distributions for each of three seasons (21 in total) to calculate the relationship between RAEs and playing positions. Comparisons were carried out between the datasets of the junior national teams, players in the talent development programme, all registered players of 'J + S' and the entire male Swiss population.

Procedure

The 50,581 soccer players registered in the Swiss Youth Sport database were grouped according to the selection period's month. The birth month of each player was recorded to define the birth quarter (Q). The cut-off date for all soccer leagues in Switzerland is 1 January. Thus, the first selection year month was 'month 1' (January), while 'month 12' (December) represented the last month. The year was divided into four quarters (Q1 represents January, February and March; Q2 represents April, May and June; Q3 represents July, August and September; and Q4 represents October, November and December).

The observed birth date distributions of all players were calculated for each quarter. The expected distributions were recorded from representative birthdates of Swiss children using weighted mean scores (Helsen et al., 1998) and the Swiss Youth Sport database, where all players who participate in organised soccer activities are registered. The Swiss Youth Sport database was analysed to verify equal distribution between all registered 'J + S' players' birthdates (10–20 years of age) and all corresponding birthdates for the Swiss male population (also 10–20 years of age). Consistent with Delorme, Boiché, & Raspaud (2010b), we used the distribution of 'J + S' (all registered players) as a basis (expected distributions) to evaluate RAEs. If a biased distribution already existed among the entire population of registered players ('J + S'; level 1), the same pattern would arise among the elite (level 3) as well, and could bias the conclusions drawn about RAEs among the elite. From these original data, odds ratios (ORs) were calculated for Q1 versus Q4. When comparing quartiles in all OR analyses, 'J + S' were assigned as the referent group.

All statistical analyses were carried out using SPSS 16.0. χ^2 tests were used to assess differences between the observed and expected birth date distributions. When significant, post hoc tests were used to determine the mean differences between quarters. In addition, effect sizes were computed to qualify the χ^2 test results. The appropriate index of effect size is the phi coefficient (f) if there is one degree of freedom (df), and Cramer's V (V) is appropriate if the df > 1 (Aron, Aron, & Coups, 2002).

For the χ^2 analyses, the magnitude of the effect size was measured using f and V. According to Cohen (1977) and Cramer (1999), for df = 3 (which is the case for all comparisons of birth quarters), V = 0.06–0.17 indicated a small effect, V = 0.18–0.29 noted a medium effect, and V ≥ 0.30 illustrated a large effect. An alpha level of $P < 0.05$ was applied as the criterion for statistical significance.

Results

Prevalence of RAEs in Swiss junior soccer

As Table I shows, there were neither RAEs nor significant differences between the distribution of the Swiss population and all 'J + S' registered players (selection level 1) ($P > 0.05$). The birth date distributions of the talent development teams and of the national U-15 to U-21 selections are also presented in Table I. In all selected teams examined (except the U-20 team), Q1 elite players were significantly overrepresented and Q4 elite players were significantly underrepresented compared to 'J + S' ($P < 0.01$). The talent development teams showed a distribution of more than 35% in Q1, and less than 15% in Q4, which differs significantly from the 'J + S' distribution ($P < 0.001$). The RAE was large for U-15 to U-18 teams, medium for U-19 and U-21 teams, and small for U-20 teams. Significant RAEs were found for the national junior selections in the U-15, U-16, U-17, U-18 and U-19 groups. The peak of the RAEs was found in the U-18 team, where 76% of the players were born in the first half of the year. No RAEs were found for the teams in the U-20 age group. Apart from the 'J + S' players and the U-20 team, the χ^2 and post hoc tests highlighted an overrepresentation of players born at the beginning of the selection year and a decreasing number of players born in subsequent quarters.

While we found no RAEs in 'J + S' players (selection level 1), RAEs were present in the U-12 talent development team (selection level 2). Specifically, more than 70% of the players were born in the first half of the year, as shown in Figure 2. The RAEs decreased slightly in the U-14 talent development team. Afterwards, the RAEs increased to a peak value in the U-18 talent development team. Specifically, more than 75% of the players were born in the first half of the year. In the U-20 and the U-21 talent development teams, RAEs were no longer statistically significant (Figure 2).

Playing positions

The birth date distributions for playing positions in the elite U-15 to U-21 teams are presented in Figure 3.

Chi-square tests showed significant differences between defenders, goalkeepers, midfielders and strikers compared to the 'J + S' distribution ($P < 0.001$). Defenders, midfielders and strikers were overrepresented at the beginning of the selection year, and in each case, a decreasing number of players were born in the subsequent quarters. Only goalkeepers had a peak in birthdates in Q2. In a second analysis, we calculated the distribution of birth dates between the different playing positions. Defenders were significantly ($P < 0.05$) overrepresented in the first half of the year (79%) compared to strikers (57%). The remaining comparisons were not significant.

Discussion

Prevalence of RAEs in Swiss junior soccer

We found substantial and consistent RAEs as early as the second and third levels of junior soccer selections, that is, in the entire sample of talent development teams, and in all elite Swiss junior soccer teams with the exception of the U-20 teams. In addition, we demonstrated that there is link between RAEs and playing positions in Swiss junior soccer.

Despite a systematic, nationwide and multi-level talent identification and selection system in Switzerland, RAEs are not lower comparison to other nations described in the literature (Cobley et al., 2009). It seems that the national effort in talent development, with its particular focus on technical soccer skills, game intelligence and the weighting of physical attributes (e.g. leg power normalised for body weight), could not reduce the biological advantage of being older.

'J + S' teams, which represent the entire, regularly playing junior soccer population on selection level 1,

Table I. Birth date distributions of Swiss junior soccer teams, expressed as annual quarters (Q)

Team	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Total	χ^2	P	V	OR
SP(10–20)	115,494 (24.8)	119,738 (25.7)	119,626 (25.7)	110,884 (23.8)	465,742				
J + S(10–20)	12,801 (25.3)	12,980 (25.7)	12,942 (25.6)	11,858 (23.4)	50,581	7.2	>0.05	0.01	
TD(10–20)	1090 (37.8)	802 (27.8)	589 (20.5)	399 (13.9)	2880	366.4	<0.001	0.21	2.53
U-15	59 (52.7)	22 (19.6)	20 (17.6)	11 (9.8)	112	48.2	<0.001	0.38	4.97
U-16	43 (45.7)	26 (27.7)	14 (14.9)	11 (11.7)	94	26.9	<0.001	0.31	3.62
U-17	44 (52.4)	15 (17.9)	14 (16.6)	11 (13.1)	84	34.0	<0.001	0.37	3.71
U-18	43 (42.6)	34 (33.7)	15 (14.9)	9 (8.9)	101	30.1	<0.001	0.32	4.43
U-19	32 (39.5)	25 (30.9)	12 (14.8)	12 (14.8)	81	14.7	<0.01	0.25	2.47
U-20	18 (27.7)	16 (24.6)	18 (27.7)	13 (20)	65	1.0	>0.05	0.07	1.28
U-21	37 (39.8)	11 (11.8)	27 (29.0)	18 (19.4)	93	16.4	<0.001	0.24	1.90

Note: SP = Swiss population; J + S = Players of extra-curricular soccer teams; TD = Players of talent development teams; U-15 to U-21 = Players of national under-15 to under-21 teams; $\chi2$ = Chi-square; P = significance; V = Cramer's V; OR = Odds ratio of Q1 vs. Q4.

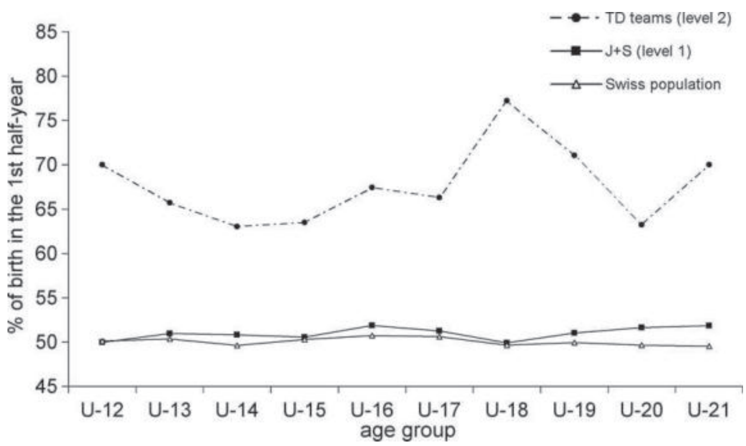

Figure 2. Distribution of births in the first half year of age-specific talent development teams (level 2) compared to the Swiss population and all registered 'J + S' players (level 1).

showed no evidence of RAEs and did not differ significantly from the Swiss population. In contrast to this finding, Delorme et al. (2010b) showed that RAEs exist among the entire population of French licensed players. Given that the Swiss population and all 'J + S' players are equally distributed, it can be assumed that talent is also equally distributed over time (Vaeyens, Lenoir, Williams, & Philippaerts, 2005). Our results support the presence of moderate RAEs in talent development teams, as 70% of these players were born in the first half of the year. Hence, in Switzerland, RAEs appear as soon as the first step of talent selection – out of the self-selected 'J + S' players' pool (level 1) – has been effected by the talent development team coaches (level 2).

At the junior national team level (level 3), Q2, Q3 and Q4 had a shortfall of 1%, 6% and 12% (in total 19%), respectively, compared to the Swiss population. As a consequence, it seems that in Swiss junior soccer, many talented players (19%) are not selected for the junior national team level and, therefore, get less support.

In particular, the RAEs influence the selection process of elite Swiss soccer, and affect the with large consequences for U-15 to U-18 teams. The ratio of being selected to a Swiss national U-15 team is 2.1 for a player born in Q1, and 0.4 for one born in Q4. Accordingly, the OR of being selected for the Swiss U-15 team for a player born in Q1 compared to Q4 is almost fivefold. This ratio is among the highest worldwide (Cobley et al., 2009; Helsen et al., 2005; Jimenez & Pain, 2008). In contrast, for the U-20 team, RAEs were not significant and the effect size was small. This may be due to statistical reasons, that is the small number of evaluated players ($n = 65$). Moreover, in the U-20 and U-21 teams, 98 of the 158 players (62%) were selected for the first time. We suppose that the high dropout rates for U-20 and U-21 players and the large number of new players may be an additional reason for the drop in

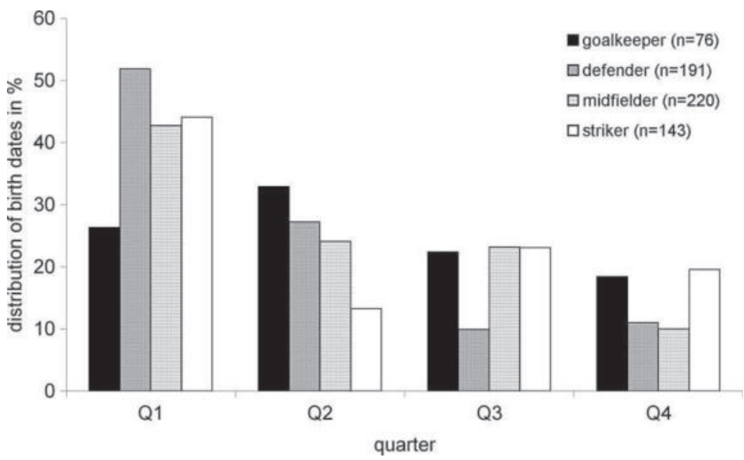

Figure 3. Distribution of playing positions and birth quarters in U-15 to U-21 teams (level 3). Significant overrepresention of early born defenders compared to strikers ($p < 0.05$).

RAEs. In this age group of U-20 teams, the majority of players are fully mature, which reduces RAEs (Cobley et al., 2009).

Our data suggest that playing positions are associated with the prevalence and size of RAEs in soccer. In the present study, we demonstrate that in Swiss junior soccer, defenders show a significantly stronger RAE compared to goalkeepers, midfielders and strikers. Previous research on ice hockey has suggested that the magnitude of RAEs may relate to the context's physical demand and the player's position (Grondin & Trudeau, 1991). Recently, Schorer et al. (2009) showed that the RAEs of handball players playing on the left wing are stronger than that of players on the right wing. These results provided evidence that height, laterality and position affect the magnitude of RAEs in handball. RAEs also appear to be inflated when positions or roles are physically intensive. This is in line with the observation that tall soccer players also tend to have an advantage, especially as goalkeepers and central defenders (Di Salvo et al., 2007). Swiss goalkeepers at the professional senior level are among the smallest in Europe (Besson, Poli, & Ravenel, 2010), which could partially explain why no differences between goalkeepers and other playing positions could be found in the present study. Sherar et al. (2007) suggested that maturational differences lead to an increased likelihood of being identified as talented and selected by coaches for higher tiers of competition. Additionally, Ashworth and Heyndels (2007) assumed that talent scouts looking for young talent are more biased in their evaluation of different playing positions. In line with these findings, Swiss coaches may tend to select relatively older players who are taller and more mature as defenders.

Possible solutions

Several solutions to reduce RAEs have been proposed in the literature. One solution is to establish 'current' and 'potential' teams: the 'current' team contains the best players, both technically and physically, at the selection time, while the 'potential' team contains players who are technically skilled, but who are lacking in terms of their physical development (Brewer, Balsom, & Davis, 1995). Barnsley and Thompson (1988) have suggested creating more age categories with a smaller bandwidth (e.g. half a year rather than one). This change would result in smaller RAEs and fewer physical differences between players within any specific age category. A single change in the selection date would result in an equal shift of RAEs (Helsen et al., 2000). Therefore, (Grondin et al., 1984) described an alteration of the activity year's cut-off dates. A yearly rotation for the cut-off date might work, because all players would then experience the advantage of a higher relative age at some point in their soccer career (Hurley et al., 2001). One potential solution could be to change the mentality of youth team coaches (Helsen et al., 2000). Coaches should pay more attention to technical and tactical skills when selecting players, as opposed to over-relying on physical characteristics such as height and strength. Additionally, they should find a better balance between short-term success and a more process-oriented approach to instruction (Helsen et al., 2005).

The challenge for Switzerland will be to keep players who are physically or psychologically disadvantaged due to RAEs involved in the sport until they have fully matured. In the current Swiss system, players who are accepted on elite teams start benefiting quite early from receiving more support, a higher level of competition, increased training, longer playing times, more positive feedback and improved coaching, as observed previously (Sherar et al., 2007). Further, unselected players may tend to have lower self-esteem and show higher dropout rates (Helsen et al., 1998). Delorme et al. (2010a) illustrated that dropout rates result from two major processes. First, children born late in the selection year may be less likely to join a sport in which weight, height or strength could be seen as relevant for performance. Second, those who are involved in a sport are more likely to drop out and have fewer chances to be selected. It is important to note that the first phenomenon cannot be solved by federations reducing the RAEs (Delorme et al., 2010a).

The decrease in RAEs may substantially enhance performance at the elite senior level in the future, especially for Switzerland, which has a rather shallow talent pool due to the limited number of inhabitants. Interestingly, in the current Swiss coach education programme, only junior national level coaches are confronted with RAEs during their education. According to our data, these coaches on 'level 3' already acquire some junior soccer players from 'level 2', that is, the talent development teams, a level that is clearly influenced by RAEs. Therefore, in our estimation, the consequences of RAEs should be taught at all levels of coach education. From our point of view, implementing rotating calendar cut-off dates and furthering the education of all soccer coaches may counteract future RAEs in Swiss soccer. In Switzerland, the talent identification and player development should be viewed as more long-term processes. In contrast to aspects of performance, skill and potential, assessments should be emphasised (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). In any case, it would be a significant step forward for coaches and federations to attempt to select the teams with the highest potential in future elite soccer instead of the team with the highest chance of winning at present (Helsen et al., 2000).

Limitations

Our study has several limitations. First, this study simply examines RAEs in Swiss soccer during the 2009–2010 season, which is not necessarily a reflection of the general situation over a longer time period. A second limitation is that our data did not include specific match-based values (e.g. the number of matches played). These data may provide a more complete picture of RAEs (Vaeyens et al., 2005).

Main findings and conclusion

Based on the present data, we argue that RAEs significantly bias the selection process of elite junior soccer in Switzerland as early as 10 years of age. Our results indicate that RAEs have a moderate to significant influence on the talent identification process. In addition, we have demonstrated that there is a link between RAEs and playing positions. Significantly higher RAEs were observed for defenders compared to goalkeepers, midfielders and strikers.

In particular, those born early in the calendar year are almost five times more likely to be selected to the Swiss national U-15 soccer team, which is one of the highest values reported in Europe. The RAEs are evident in talent development teams below 12 years of age, and seem to be greatest around 18 years of age (more than three quarters of the selected players were born in the first half of the year). To minimise RAEs in Swiss soccer, systematic training for all coaches regarding RAEs and a more equitable slotting system with rotating calendar cut-off dates should be established. Furthermore, the talent selection process should be optimised and developed into a more long-term and multidisciplinary approach.

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Influences of player nationality, playing position, and height on relative age effects at women's under-17 FIFA World Cup

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Abstract

Previous research has shown that young male soccer players who are born early in a cohort are overrepresented on elite soccer teams. Selection advantages such as this have been termed 'relative age effects' (RAEs). Few studies have examined RAEs in elite women's youth soccer. Therefore, the aim of this study is to investigate the occurrence of RAEs in the Fédération Internationale de Football Association (FIFA) U-17 Women's World Cup competition and their link to playing positions. In the entire cohort of 672 players, we found significant RAEs in the geographical zones of Europe and North and Central America, no RAEs in the zones of Asia, Oceania, and South America, and significant inverse RAEs in the zone of Africa. Additionally, significant RAEs were found for goalkeepers and defenders from Europe and North and Central America. Inverse RAEs occurred for African goalkeepers, defenders, and strikers. Goalkeepers of all zones were significantly taller than players of all other playing positions. The results of this study show that remarkable RAEs do exist at elite women's youth soccer. Similar to men's soccer, there is a bias toward the inclusion of relatively older players, and a link between RAEs and playing positions.

Keywords: *talent development, female soccer, birth date, playing position*

Introduction

During the early stages of life, children are grouped into age categories based on specific cut-off dates. In schools and in almost all organised-sports institutions, age groupings are established to ensure that every child has an equal chance of participation and success. For international youth soccer, the Fédération Internationale de Football Association (FIFA) uses a system with January 1 as the cut-off date to establish its age groups. However, such a procedure can result in large age differences of almost 12 months between the youngest and the oldest players in the same annual cohort. The consequences of such age differences are called relative age effects (RAEs).

Different mechanisms have been proposed to specify the causes of RAEs. Maturational differences and physical attributes (e.g., greater aerobic power, muscular strength, and height) appear to be mainly responsible (Cobley, Baker, Wattie, & McKenna, 2009). Since 1984, research has continued to identify the occurrence of RAEs within a variety of sports at the junior level (Cobley et al., 2009). While RAEs have been investigated extensively in male sports, only two per cent of such research has analysed RAEs in women's sports (Cobley et al., 2009). In the existing literature, inconsistent RAEs have been observed in elite women's sports. For example, RAEs have been reported in women's junior tennis (Baxter-Jones & Helms, 1996) and Canadian ice hockey (Weir, Smith, & Paterson, 2010); however, no RAEs were identified in a historical analysis of Canadian female ice hockey players (Wattie, Baker, Cobley, & Montelpare, 2007). Furthermore, it has been shown that no – or possibly inverse – RAEs exist for women participating in dance and gymnastics (Baxter-Jones & Helms, 1996; van Rossum, 2006).

Although there has been exponential growth worldwide in the number of women playing soccer (FIFA, 2008), it has been observed that research regarding the effect of an athlete's gender on RAEs remains neglected (Cobley et al., 2009; Musch & Grondin, 2001). To our knowledge, only four studies to date have investigated RAEs in women's soccer. In one, RAEs were observed among all registered female players ($n = 57{,}892$) in the French Football Federation (Delorme, Boiché, & Raspaud, 2010b). The study revealed significant RAEs in all

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youth categories ranging from under-8 to under-17 years, including all skill levels from amateur to elite players. In a second study, no RAEs were found among adult female soccer players ($n = 242$) playing in the highest league of French female soccer (Delorme, Boiché, & Raspaud, 2009). In another study, Vincent and Glamser (2006) compared RAEs among 1,344 elite male and female soccer players of the U-17 US Olympic Development Program. In their study, marginal RAEs were shown for girls at the national ($n = 39$) and regional ($n = 71$) levels, and no RAEs were shown for those playing at the state level ($n = 804$). Romann and Fuchslocher (2011) detected significant RAEs among all registered female soccer players ($n = 2987$) and a subgroup of players of a talent development program ($n = 450$) in the 10 to 14 years age category. It was speculated that the RAEs emerged by self-selection and the possible higher drop-out rate of players with a 'young' relative age. No significant RAEs were found among all registered female players aged 15 to 20 years ($n = 3242$) and the U-17 and U-19 national teams ($n = 167$).

In previous literature, links between male RAEs, maturation, and playing positions have been identified, which could have biased the talent-identification process. Players who are more mature and who have more experience in soccer demonstrate better ball control, because they are able to use their body size. In addition, a male player's level of maturity significantly contributes to variations in shooting accuracy (Malina et al., 2005). In boys' soccer, forwards have been found to be significantly leaner than midfielders, defenders, and goalkeepers. A discriminating variable of male defenders compared to midfielders and strikers is their lower leg power (Gil, Gil, Ruiz, Irazusta, & Irazusta, 2007). Interestingly, male soccer players with 'old' relative age have been shown to earn systematically higher wages (Ashworth & Heyndels, 2007). This effect was reported as being strongest for goalkeepers and defenders, but was not shown for forwards. It was speculated that this pattern could reflect a bias in talent scouts' selections of teams and playing positions. This finding is consistent with Grondin and Trudeau (1991), who demonstrated a link between male ice hockey players' RAEs and playing positions. In their analysis, the RAEs were strongest among defenders and goalkeepers. Moreover, in both men's handball (Schorer, Cobley, Busch, Brautigam, & Baker, 2009) and men's rugby (Till et al., 2009), physical attributes and playing positions are related to the magnitude of RAEs. To our knowledge, only one study has analysed the link between RAEs and playing positions in women's soccer. For Swiss elite women's soccer players, Romann and Fuchslocher (2011) identified RAEs among all playing positions. Defenders and goalkeepers had significantly higher RAEs compared to midfielders in junior and elite Swiss national teams.

Given the relevance of RAEs and their potential for introducing a bias in talent identification, it is worth examining RAEs within the setting of the FIFA under-17 soccer World Cup. The purposes of this study were twofold: first, to examine the occurrence and size of RAEs in national teams participating in the FIFA Women's World Cup and, second, to identify if playing positions modify the occurrence and size of RAEs.

Method

The past two FIFA U-17 Women's World Cup competitions, which took place in 2008 and 2010, were analysed. Rosters with player birth dates were obtained from the FIFA website (www.fifa.com). All team rosters and all players who were registered for the tournament were included. This comprised a total of 32 teams with 21 players each. Nine countries participated in both tournaments (2008 and 2010), 13 countries participated just once. For the purpose of analysis, the birth month, birth year, height, and playing position of all 672 female soccer players from 22 countries and six FIFA zones were recorded. All federations of each participating country accepted the FIFA regulations and confirmed to provide birth dates of players from official written records (FIFA, 2009).

Chi-square analyses were used to determine if observed distributions were statistically different from the expected distributions. National teams were sub-grouped using the FIFA-designated geographical zone, country, and playing positions. The FIFA zones and countries analysed were Africa (Ghana, Nigeria, and South Africa), Asia (Japan, Korea DVR, and the Korea Republic), Europe (Denmark, England, France, Germany, Ireland, and Spain), North and Central America (Canada, Mexico, Trinidad and Tobago, and the USA), South America (Brazil, Chile, Colombia, Paraguay, and Venezuela), and Oceania (New Zealand). According to Delorme et al. (2010b), generally the distribution of all registered players should be used to calculate the expected distributions for the analysis of RAEs. If a biased distribution already existed among the entire population of registered players, the same pattern would arise among the elite as well, and bias the conclusions drawn about RAEs among the elite. In this study, neither the birth dates of all registered players, nor the distribution of live births in the countries were available. In this case, currently published studies perform all analyses with the theoretical assumption that birth dates are equally distributed across all quarters (25 per cent per quarter) (Cobley et al., 2009; Helsen, van Winckel, & Williams, 2005). This assumption should be valid, because in most countries birth dates for humans are equally distributed over the year and do not have significant seasonal variations (Brewis, Laycock, & Huntsman, 1996; Lam & Miron, 1991; Pascual, 2000; Roenneberg & Aschof, 1990).

Procedure

The birth month of each player was recorded to define their birth quarter (Q). As the cut-off date in all FIFA soccer tournaments is January 1, the first month of the selection year was month one (January), while month twelve (December) represented the last month of the selection period. This procedure was performed for all players of the team rosters, like in the majority of existing RAEs studies (Cobley et al., 2009). In some team rosters, there were players younger than 16 years who were also included in the study. The year was divided into four quarters (Q1 represents January, February, and March; Q2 represents April, May, and June; Q3 represents July, August, and September; and Q4 represents October, November, and December). The observed birth date distributions of all players were calculated for each quarter.

From these original data, chi-square tests and odds ratios (ORs) were calculated (all statistical analyses were carried out using SPSS 16.0). Chi-square tests were used to assess differences between the observed and expected birth date distributions. Also, differences of body heights across birth quarters were analysed with one-way analysis of variance (ANOVA). If significant, Tukey's post-hoc tests were used to determine the mean differences. In addition, effect sizes were computed in order to qualify the results of the chi-square tests. If the *degree of freedom* is above 1, then the appropriate index of effect size is Cramer's V (V) (Aron, Aron, & Coups, 2002). For the chi-square analyses, the magnitude of the effect size was measured using V. According to Cohen (1977) for $df = 3$ (which is the case for all comparisons of birth quarters), $V = 0.06$ to 0.17 describes a small effect, $V = 0.18$ to 0.29 describes a medium effect, and $V \geq 0.30$ describes a large effect. An alpha level of $P < 0.05$ was applied as the criterion for statistical significance.

Results

As can be seen in Table I, in an analysis of all the national teams participating in the FIFA U-17 Women's World Cup, no significant RAEs occurred except for Ireland, Trinidad and Tobago, Ghana, and Nigeria.

Ireland and Trinidad and Tobago showed large, regular RAEs; players born at the beginning of the year being overrepresented. Ghana and Nigeria showed large, inverse RAEs, having an overrepresentation of players born at the end of the year. The subgroups of the FIFA geographical zones varied – from significant, medium RAEs among players from Europe and small RAEs among players from North and Central America, on the one hand, to a lack of significant RAEs among players in Asia, Oceania and South America (Table II) on the other. In contrast to these findings, the African players showed significant, inverse RAEs.

These inverse RAEs existed in the western African countries of Ghana and Nigeria, but not in South Africa. The birth dates of players from Nigeria were extremely different from the expected distribution, with 55% of the players having been born in Q4, and 43% having been born in the month of December.

Playing positions and RAEs

The analysis of playing positions was performed in three groups. The first group includes Europe and North and Central America, which show significant RAEs. The second group is comprised of Asia, Oceania, and South America, where no RAEs occur. The third group is formed by Africa, where significant inverse RAEs occur. Among European teams and North and Central American teams, we found significant RAEs regarding goalkeepers ($V = 0.38$) and defenders ($V = 0.21$) but no RAEs regarding midfielders and strikers (Table III). Among teams in Asia, Oceania, and South America, no significant RAEs were observed regarding any playing positions (Table IV). Among African teams, large, inverse RAEs occurred regarding goalkeepers ($V = 0.45$), defenders ($V = 0.37$), and strikers ($V = 0.36$), but there were no RAEs regarding midfielders (Table V).

Playing positions and height

Among all FIFA U-17 soccer players who were analysed, goalkeepers were significantly taller than defenders, midfielders, and strikers. Also, defenders were significantly taller than midfielders. Within the subgroups of the FIFA geographical zones, similar results were found. Goalkeepers from Africa, North and Central America, and Oceania were significantly taller than midfielders. Goalkeepers from Asia, Europe, and South America were significantly taller than defenders, midfielders, and strikers. Additionally, defenders from Asia were significantly taller than strikers.

In a second analysis, we compared players' heights among the different FIFA geographical zones

Table I. RAEs of national teams participating at FIFA U-17 World Cup.

Country	Q1	Q2	Q3	Q4	Total	χ^2	OR Q1/Q4	V	Effect
Brazil	15	11	8	8	42	3.1	1.88	0.2	no
(%)	35.7	26.2	19.0	19.0					
Canada	14	15	8	5	42	6.6	2.80	0.2	no
(%)	33.3	35.7	19.0	11.9					
Chile	4	6	8	3	21	2.8	1.33	0.2	no
(%)	19.0	28.6	38.1	14.3					
Colombia	9	5	4	3	21	4	3.00	0.3	no
(%)	42.9	23.8	19.0	14.3					
Costa Rica	7	5	7	2	21	3.2	3.50	0.2	no
(%)	33.3	23.8	33.3	9.5					
Denmark	6	9	4	2	21	5.1	3.00	0.3	no
(%)	28.6	42.9	19.0	9.5					
England	3	3	8	7	21	4	0.43	0.3	no
(%)	14.3	14.3	38.1	33.3					
France	6	9	4	2	21	5.1	3.00	0.3	no
(%)	28.6	42.9	19.0	9.5					
Germany	17	10	10	5	42	7	3.40	0.2	no
(%)	40.5	23.8	23.8	11.9					
Ghana	3	7	14	18	42	13	0.17	0.3	large
(%)	7.1	16.7	33.3	42.9					
Ireland	10	8	2	1	21	11	10.00	0.4	large
(%)	47.6	38.1	9.5	4.8					
Japan	12	12	12	6	42	2.6	2.00	0.1	no
(%)	28.6	28.6	28.6	14.3					
Korea DVR	10	13	10	9	42	0.9	1.11	0.1	no
(%)	23.8	31.0	23.8	21.4					
Korea Rep.	16	10	8	8	42	4.1	2.00	0.2	no
(%)	38.1	23.8	19.0	19.0					
Mexico	6	4	9	2	21	5.1	3.00	0.3	no
(%)	28.6	19.0	42.9	9.5					
New Zealand	8	13	9	12	42	1.6	0.67	0.1	no
(%)	19.0	31.0	21.4	28.6					
Nigeria	5	7	7	23	42	20	0.22	0.4	large
(%)	11.9	16.7	16.7	54.8					
Paraguay	3	6	6	6	21	1.3	0.50	0.1	no
(%)	14.3	28.6	28.6	28.6					
South Africa	7	2	6	6	21	2.8	1.17	0.2	no
(%)	33.3	9.5	28.6	28.6					
Spain	7	6	8	0	21	n.d.	n.d	n.d	no
(%)	33.3	28.6	38.1	0.0					
Trinidad and Tobago	11	2	2	6	21	10	1.83	0.4	large
(%)	52.4	9.5	9.5	28.6					
USA	5	8	5	3	21	0	1.67	0	no
(%)	23.8	38.1	23.8	14.3					
Venezuela	6	6	4	5	21	0.1	1.20	0	no
(%)	28.6	28.6	19.0	23.8					

Note: Q1 to Q4 = birth quarter 1 to 4; χ^2 = Chi^2-value; P = significance; OR = Odds ratio; V = Cramer's V; *$P < 0.05$; **$P < 0.01$.

grouped by playing position (Table VI). Goalkeepers from Africa were significantly shorter than goalkeepers from Europe, Asia, and South America. Defenders and midfielders from Africa were also shorter than defenders from all other zones.

Discussion

The results of this study show that no RAEs occurred in teams participating in the FIFA U-17 Women's World Cup except in Ireland, Trinidad and Tobago, Ghana, and Nigeria. However, remarkable RAEs existed within the FIFA geographical zones. Players from Europe and North and Central America showed significant RAEs, while no RAEs were found in Asia, Oceania, and South America. Significant inverse RAEs occurred in Africa. Additionally, RAEs and players' heights seem to be linked to playing positions in women's soccer.

As previously shown, no RAEs were observed in most of the elite national teams (Delorme et al., 2010b; Vincent & Glamser, 2006; Romann & Fuchslocher, 2011). One potential reason for the absence of RAEs may be that compared to male

Table II. RAEs of FIFA zones participating at the FIFA U-17 World Cup.

Zone	Q1	Q2	Q3	Q4	Total	χ^2	OR Q1/Q4	V	Effect
All players	190	177	163	142	672	7.5	1.34	0.06	no
(%)	28.3	26.3	24.3	21.1					
All players without Africa	175	161	136	95	567	26.1**	1.84	0.12	small
(%)	30.9	28.4	24.0	16.8					
Africa	15	16	27	47	105	25.2**	0.32	0.28	medium†
(%)	14.3	15.2	25.7	44.8					
Asia	38	35	30	23	126	4.1	1.65	0.10	no
(%)	30.2	27.8	23.8	18.3					
Europe	49	45	36	17	147	16.6**	2.88	0.19	medium
(%)	33.3	30.6	24.5	11.6					
North and Central America	43	34	31	18	126	10.2*	2.39	0.16	small
(%)	34.1	27.0	24.6	14.3					
Oceania	8	13	9	12	42	1.6	0.67	0.11	no
(%)	19.0	31.0	21.4	28.6					
South America	37	34	30	25	126	2.6	1.48	0.08	no
(%)	29.4	27.0	23.8	19.8					

Note: Q1 to Q4 = birth quarter 1 to 4; χ^2 = Chi^2-value; OR = Odds ratio; V = Cramer's V; $*P < 0.05$; $**P < 0.01$. † = inverse relative age effect.

Table III. Distribution of birth-dates subdivided by playing positions in Europe and North and Central America.

Playingposition	Q1	Q2	Q3	Q4	Total	χ^2	P	OR Q1/Q4	V	Effect
Goalkeepers	9	20	8	2	39	17.3**	<0.01	4.50	0.38	large
(%)	23.1	51.3	20.5	5.1						
Defenders	33	21	22	11	87	11.2**	<0.01	3.00	0.21	medium
(%)	37.9	24.1	25.3	12.6						
Midfielders	27	19	21	12	79	5.8	>0.05	2.25	0.16	no
(%)	34.2	24.1	26.6	15.2						
Strikers	22	19	16	10	67	4.7	>0.05	2.20	0.15	no
(%)	32.8	28.4	23.9	14.9						

Note: Q1 to Q4 = birth quarter 1 to 4; χ^2 = Chi^2-value; OR = Odds ratio; V = Cramer's V; $*P < 0.05$; $**P < 0.01$.

Table IV. Distribution of birth-dates subdivided by playing positions in Asia, South America and Oceania.

Zone	Q1	Q2	Q3	Q4	Total	χ^2	OR Q1/Q4	V	Effect
Goalkeepers	16	9	12	5	42	6.2	3.20	0.22	no
(%)	38.1	21.4	28.6	11.9					
Defenders	24	27	18	20	89	2.2	1.20	0.09	no
(%)	27.0	30.3	20.2	22.5					
Midfielders	30	27	26	25	108	0.5	1.20	0.04	no
(%)	27.8	25.0	24.1	23.1					
Strikers	14	19	13	10	56	3.0	1.40	0.13	no
(%)	25.0	33.9	23.2	17.9					

Note: Q1 to Q4 = birth quarter 1 to 4; χ^2 = Chi^2-value; OR = Odds ratio; V = Cramer's V; $*P < 0.05$; $**P < 0.01$.

soccer, there is less competition and less selection among girls to gain a position on an elite women's soccer team (Delorme et al., 2009). This is in line with Musch and Grondin (2001), who proposed that the high popularity of a sport and a high participation in that sport increase RAEs. It is important to note that the number of players in individual team rosters are very small, which may additionally explain why no significant RAEs occurred in most counties.

Nevertheless, four out of the 22 teams showed significant RAEs. Therefore, the analysis of the FIFA geographical zones with higher numbers of players may lead to a complementary interpretation of the data.

Table V. Distribution of birth-dates subdivided by playing positions in Africa.

Playing position	Q1	Q2	Q3	Q4	Total	χ^2	OR Q1/Q4	V	Effect
Goalkeepers	1	1	5	8	15	9.3*	0.13	0.45	large
(%)	6.7	6.7	33.3	53.3					
Defenders	8	4	5	18	35	14.0**	0.44	0.37	large
(%)	22.9	11.4	14.3	51.4					
Midfielders	4	7	9	8	28	2.0	0.50	0.15	no
(%)	14.3	25.0	32.1	28.6					
Strikers	2	4	8	13	27	10.5*	0.15	0.36	large
(%)	7.4	14.8	29.6	48.1					

Note: Q1 to Q4 = quarter 1 to 4; χ^2 = Chi^2-value; OR = Odds ratio; V = Cramer's V; *$P < 0.05$; **$P < 0.01$.

Table VI. Height of players classified by FIFA zones and playing positions.

Playing position	**G**	**D**	**M**	**S**	**Total**	**Anova**	**Post-hoc**
	height mean ± *s*						
All players	170 ± 5	165 ± 7	163 ± 5	164 ± 7	165 ± 6	**	G > D,M,S; D > M
Africa	165 ± 4	161 ± 6	159 ± 4	162 ± 6	161 ± 6	**	G > M
Asia	170 ± 4	165 ± 4	162 ± 5	161 ± 6	164 ± 6	**	G > D,M,S; D > S
Europe	172 ± 6	168 ± 7	166 ± 5	164 ± 7	167 ± 7	**	G > D,M,S
North and Central America	169 ± 4	166 ± 7	164 ± 5	166 ± 7	166 ± 6	*	G > M
Oceania	171 ± 2	168 ± 6	164 ± 4	166 ± 6	166 ± 5	*	G > M
South America	172 ± 6	165 ± 5	163 ± 5	163 ± 7	165 ± 6	**	G > D,M,S

Note: G = Goalkeeper; D = Defender; M = Midfielder; S = Striker; s = Standard deviation; *$P < 0.05$; **$P < 0.01$.

RAEs in European and North and Central American players

The analysis of the geographical FIFA zones revealed significant RAEs for Europe and North and Central America. One explanation could be that relatively older players are more likely to be identified by coaches as 'talented' and to be selected for all-star or representative teams (Helsen, Starkes, & Van Winckel, 1998). Selection for an elite team is often linked to more positive effects, including more opportunities to play and practise, better coaching, higher competition, and a greater amount of positive feedback (Cobley et al., 2009). These positive effects are increasingly advantageous for the relatively older players: early success often promotes the athlete's further physical and psychological investment in the sport, resulting in a greater likelihood of continuing to play. Other psychological effects, such as increased perceptions of competence (Vincent & Glamser, 2006), higher involvement, and increased self-esteem (Thompson, Barnsley, & Battle, 2004) are positively related to an 'old' relative age.

It is important to note that due to possible self-selection, coaches of talent-development programmes may need to carry out their selections using a pool of players whose birth dates are already unequally distributed, which could increase RAEs at elite levels. This phenomenon has been shown in French women's soccer for all youth age categories and in Swiss women's soccer in the 10 to 14 years age category (Delorme et al., 2010a; Romann & Fuchslocher, 2011). In other words, female players born in the first half of the selection year may be more likely to begin playing soccer compared to their younger counterparts. Those born in Q3 and Q4 show a kind of self-deselection process before even trying to play soccer. Additionally, they are more likely to drop out and become unavailable for selection (Delorme et al., 2010a). Given that France is just one out of 22 participating countries from which the data of all registered players in the federation is published, no conclusions can be drawn to the whole sample of all participating countries. Therefore, more research is needed to investigate the impact of RAEs among all registered players on the respective elite teams.

A possible explanation for the absence of RAEs in the zones of Asia and Oceania might be that soccer is less popular and there is a lack of opportunity to play at a professional level and in professional leagues compared to in Europe and North and Central America. In Asia and Oceania just 2.2% and 4.7% respectively of the total population are registered soccer players, while in Europe and in both North and Central America and South America 7.3% and 7.4% respectively are registered (FIFA, 2008). Additionally, it can be speculated that early talent detection and early streaming into talent-development programmes is carried out more often in Europe and North and Central America compared to the other FIFA zones, which could cause an increase in RAEs (Vaeyens, Lenoir, Williams, & Philippaerts, 2008).

Inverse RAEs in western Africa

An essential finding of the present study is the inverse RAEs within the western African zone. This phenomenon is recognised as existing in men's soccer, but it has never been shown in women's soccer (Williams, 2009). Studies of vital registration in African countries indicate that only 19 to 57% of people have official birth certificates (Akande & Sekoni, 2005; Dow, 1998; Morris, Black, & Tomaskovic, 2003; Ndong, Gloyd, & Gale, 1994). Therefore, the speculation by Williams (2009) that there may be errors in the reporting of valid birth dates seems reasonable. Interestingly, the birth date distribution in Nigeria, with 43% of all players being born in the month of December, is remarkable and extremely different from the expected distribution. In addition, the analysis of all players shows no RAEs, but when calculated without African players small RAEs exists (Table II). According to Onis et al. (2007), it can be expected that 16-year-old players born at the beginning of the selection year (Q1) are approximately two centimetres taller than those born at the end of the selection year (Q4). This assumption is true for the mean height of players from non-African countries, who are 166 $\pm$ 7 cm if born in Q1 and 164 $\pm$ 6 cm if born in Q4. Contrary to this, African players born in Q1 are 162 $\pm$ 5 cm and have the same height as those players born in Q4 (162 $\pm$ 5 cm). Thus, the potential for error in the reported birth dates of African players may be large. However, it has to be mentioned that height is just an approximation of age and maturation. As suggested by Williams (2009), more work is needed in order to understand the atypical distribution of birth dates in African countries.

Waste of potential talent

To optimise talent-development systems in women's soccer, the challenge is twofold. On one hand, it seems important to include players in soccer activities at an early age if they have a 'young' relative age. On the other hand, it is crucial to keep players involved in soccer after puberty ends. Regarding senior elite women's youth soccer, there are a number of negative consequences of RAEs. Many relatively younger players, who have the potential to be elite adult players, may drop out before their full potential is realised. This seems to be the case in women's youth soccer (Delorme et al., 2010b; Romann & Fuchslocher, 2011) as well as in women's youth ice hockey (Weir et al., 2010). Jimenez and Pain (2008) argued that the current identification and development process, which allows age bias, results in 'wasted potential'. It could be assumed that if women's soccer grows in popularity and if talent-development programmes become increasingly structured, RAEs will increase too. In any case, it would be a significant step forward to select players who will have the greatest potential in elite soccer in the future, instead of selecting players with the highest chance of winning in the present (Helsen et al., 1998).

RAEs and playing positions

In the present study, playing positions were interrelated with the occurrence and size of RAEs in women's soccer. Goalkeepers and defenders in the European and North and Central American zone showed large RAEs. Recently, Romann and Fuchslocher (2011) observed significant RAEs among Swiss female soccer players in all playing positions – RAEs of defenders and goalkeepers were significantly higher than those of midfielders in junior and elite national teams. It was speculated that the coaches of Swiss women's soccer teams may tend to select relatively older goalkeepers and defenders, who are taller and more mature. In the present study, goalkeepers from all zones were significantly taller than players of all other playing positions. Additionally, defenders were taller than midfielders. This is in line with an observation by Di Salvo et al. (2007), who demonstrated that tall male soccer players tend to have an advantage, especially if they are goalkeepers or central defenders. Similarly, Baker, Schorer, Cobley, Brautigam, and Busch (2012) examined US national-level female youth and adult soccer players. For the youth athletes, RAEs were found for all player positions (goaltending, midfield, forward, and defence), but for the adults, RAEs emerged only for the goalkeepers and defenders. Interestingly in the present study, it was most common for goalkeepers to be born in Q2. This confirms the findings by Baker et al. (2012) and those by Weir et al. (2010), who described an overrepresentation of elite female goalkeepers in Q2. This phenomenon may result from a skewed basic population of female soccer players like in France and Switzerland, where the basic population of registered female soccer players shows an overrepresentation of players born in Q2 (Delorme et al., 2010a; Romann & Fuchslocher, 2011). In these studies, it is speculated that soccer as a contact sport may be considered gender-inappropriate for women and that social pressures may prevent females from achieving excellence in competitive sport. In addition, the physical characteristics needed for athletic performance are sometimes inconsistent with the stereotyped idea of an ideal female body which is expected to be thin and tiny in western countries (Choi, 2000). This conflict could lead elite female players to drop out from soccer. Vincent and Glamser (2006) suggested that especially early maturing and relatively 'older' (Q1) females trying to conform to gender-based stereotypes could drop out from elite sports.

In brief, early physical development may act as a socially constructed disadvantage for young women during puberty and may result in a higher dropout rate of Q1 players. Nevertheless, this interpretation remains speculative, and more research is needed to examine the 'ifs' and 'why' Q1 female players are underrepresented in basic populations of soccer players.

Our study has several limitations. First, this study simply examines RAEs in the national teams during the 2008 and 2010 World Cup, which is not necessarily a reflection of the general situation over a longer time period. A second limitation is that the sample size in several teams is low; therefore we included all players in the analysis and combined the teams into the geographical FIFA zones. FIFA uses January 1 already in younger age categories in all the FIFA zones, but especially in the African zone only a small proportion of the players are registered, therefore the cut-off dates for talent development remain uncertain (FIFA, 2004). A final limitation is the assumption that birth dates in the basic population are equally distributed, but this procedure is generally used in RAEs studies when data of the distribution of all licensed players and the population data are not available (Cobley et al., 2009).

Main findings and conclusion

Overall, the current results demonstrate that RAEs do exist in elite women's youth soccer in Europe, in North and Central America and (inversely) in Africa, but do not occur in Asia, Oceania and South America. Based on the present data, we argue that RAEs bias the selection process of elite under-17 women's soccer players in Europe, North and Central America, and (inversely) Africa. It could be assumed that if female soccer grows in popularity and if talent-development programmes become increasingly structured, RAEs will also increase. RAEs may bias the talent selection of women's soccer, and it seems evident that in Europe and North and Central America Q1 and Q2 players are overrepresented, whereas Q4 players are underrepresented. This may lead to a loss of potential players in the elite stage. Additionally, significant RAEs were observed in goalkeepers and defenders from Europe and North and Central America. Moreover, goalkeepers of all zones were significantly taller than players of all other playing positions. These data suggest that, similar to men's soccer, there is a bias toward the inclusion of relatively older players and there is a link between RAEs and playing positions in elite women's soccer.

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THE NEED TO CONSIDER RELATIVE AGE EFFECTS IN WOMEN'S TALENT DEVELOPMENT PROCESS[1]

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Summary.—Relative age effects (RAEs) refer to age differences among athletes in the same selection year. This study analyzed birth date distributions of 301,428 female athletes (aged 10–20 yr.) in Swiss Youth sports and the subgroup ($n = 1{,}177$) of the National Talent Development Program (TDP) in individual sports. Comparisons showed significant RAEs in the distribution of athletes' birth dates in alpine skiing, tennis, athletics, fencing, and snowboarding. Significant "reverse" RAEs with an overrepresentation of athletes at the end of the year were found in table tennis. In the TDP, significant RAEs were found in alpine skiing and tennis. No RAEs were detected in athletics. In table tennis, fencing, and snowboarding, "reverse" RAEs were found. Clearly, RAEs are complex and vary across individual sports for females.

Age is a very important criterion for inclusion in many organizations and institutions within our society. The practice of age grouping is widely used in education and youth sports. Sports policy makers and sports federations typically group children by annual age categories to reduce the effects of developmental discrepancies. Although this strategy is well-intended, it leads to significant age differences of almost 12 mo. between children in the same annual age group. Being 'relatively older' compared to a 'relatively younger' peer leads to consistent participation inequalities and selection biases in youth and developmental ages and stages of sport. A high relative age in combination with higher physical (e.g., greater height, more strength) and psychological attributes provides performance advantages in the majority of sports. This advantage and the resulting skewed birth date distributions among participants in youth sport and professional sport has been termed the relative age effect (RAE) (Cobley, Baker, Wattie, & McKenna, 2009). In some technical sports where low weight and height is an advantage, an overrepresentation of athletes born at the end of the competition year has been observed. This special phenomenon of RAEs has been termed "reverse" or "inverse" RAE in the current literature, to emphasize the reversed trend compared to the traditional RAE (Baxter-Jones, Helms, Maffulli, Baines-Preece, & Preece, 1995; Delorme & Raspaud, 2009; Romann & Fuchslocher, 2011, 2013a; Gibbs,

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Jarvis, & Dufur, 2012; Coutts, Kempton, & Vaeyens, 2014; Wattie, Tietjens, Cobley, Schorer, Baker, & Kurz, 2014).

Until now, RAEs have been identified within a variety of youth sports and have been consistently noted in male youth team sports like basketball, baseball, ice hockey, rugby, soccer, and volleyball (Cobley, *et al*., 2009). In addition, most studies concerning RAEs in sports have been focused on male athletes and Cobley, *et al*. (2009) showed that existing literature about RAEs in female athletes only comprises 2% of the all participants investigated. Therefore, the existence of RAEs in female athletes is still a matter of debate. Furthermore, the majority of participants have been analyzed from team sports, while there are few studies examining RAEs in individual sports (Cobley, *et al*., 2009; Baker, Janning, Wong, Cobley, & Schorer, 2014).

In the few rare cases where female athletes in individual sports were investigated, significant RAEs have been shown in tennis (Baxter-Jones & Helms, 1996; Edgar & O'Donoghue, 2005), cross-country skiing, and alpine skiing (Baker, *et al*., 2014). However, no RAEs were found in several female individual sports like swimming, gymnastics (Baxter-Jones & Helms, 1995), tennis (Edgar & O'Donoghue, 2005), taekwondo (Albuquerque, Lage, da Costa, Ferreira, Penna, de Albuquerque Moraes, *et al*. 2012), figure skating, ski jumping (Baker, *et al*., 2014), badminton, and athletics (Nakata & Sakamoto, 2012). Interestingly, in shooting, jockeys in horse racing, and female snowboarding, significant "reverse" RAEs, with an overrepresentation of athletes born in the end of the year, have been observed (Delorme & Raspaud, 2009; Nakata & Sakamoto, 2011; Baker, *et al*., 2014). Hence, there has been much less research on individual female sports, and the results have been inconsistent and even contrary, especially for female athletes.

Different explanations have been proposed for the RAE in sports. The effects are seen primarily in youth, and certainly among equally mature adult athletes. One would not consider a few months' difference in age to yield large differences in physical attributes (e.g., greater height and muscular strength). As RAEs are based on chronological age, relatively older children consistently have the advantage of advanced age, which favors advanced maturation (Schorer, Cobley, Busch, Brautigam, & Baker, 2009). As a consequence, adolescents born at the end of the selection year are less likely to reach the highest levels in elite sports and are more likely to drop out (Helsen, Starkes, & Van Winckel, 2000). Delorme, Boiché, and Raspaud (2010a) illustrated that dropout rates result from two major processes. First, adolescents born late in the selection year may be less likely to join a sport in which weight, height, or strength are important for performance. Second, those who are involved in a sport are more likely to drop out and have fewer chances to be selected because they tend to be smaller, less strong, and less physically mature. Additional explanations for relatively older children's superior performance involve the amount of practice experience and also psychological development (Musch & Grondin, 2001). They described factors related to the sports setting that may increase RAEs, such as the level of competition, the sport's popularity, early specialization, and the expectations of coaches who are involved in the selection process. In the majority of male sports, the level of competition and the popularity of the sport are higher compared to female sports. This is due to higher participation rates, more media attendance, and more funding in male sports, which affects the prevalence of RAEs (Swiss Federal Office of Statistics, 2013).

To date in Switzerland, significant RAEs have been detected in soccer for both sexes (Romann & Fuchslocher, 2011, 2013b). No data is available in other Swiss team sports or in any Swiss individual sport. The Swiss Federal Office of Sport (FOSPO) and Swiss Olympic (SO) invest approximately 20 million Swiss Francs (22 million US$) in individual youth sports, and there is a major concern about funding reaching athletes with the most potential and effective investment. Given the presence of these well-funded and well-organized programs and the potential for introducing bias into talent selection of sports, it is worth examining female individual sports that have high participation and receive the most governmental funding. In Switzerland, these sports are alpine skiing, tennis, athletics, table tennis, fencing, and snowboarding. Therefore, the purposes of this study were twofold: first, to examine the prevalence and size of RAEs in these female individual sports; and second, to identify whether the selection level modifies the prevalence and size of the RAEs.

Method

Participants

The Swiss youth sport system is based on two levels of performance. The first level is a nationwide extracurricular program called Youth and Sport (J+S), which is offered for all children and adolescents ages 10 to 20 yr. interested in a specific sport. The second level is the National Talent Detection and Development Program (TDP) for athletes from 10 to 20 yr. old. All female athletes who participated in the seasons from 2009 to 2011 were included in the analysis. For this period of time, J+S contained 186,468 females actively registered in alpine skiing, 58,155 in tennis, 47,580 in athletics, 3,675 in table tennis, 3,372 in fencing, and 2,178 in snowboarding. Participants can only register once per year for a J+S program in a specific sport, but it is possible to participate in more than one sport.

The minimum duration for a J+S course is at least 30 wk. per yr. with one training session per wk. Every training session has to last at least

60 min. Athletes of TDP are assisted by licensed coaches and are expected to train more than 400 hr. per yr. (Swiss Federal Office of Statistics, 2013). The FOSPO and SO jointly established the cut-off criterion for adoption into the program as 400 hr. In total, 301,428 datasets of three different sports were examined to calculate RAEs in Swiss individual sports. Comparisons were carried out between the datasets of all registered J + S athletes and athletes in the TDP.

Procedure

All athletes were grouped according to the birth month of the selection period, sport, and selection level. The cut-off date for all analyzed sports was January 1st. As in prior RAE studies, the year was divided into four quarters (Q) to analyze RAEs. Q1 represented January, February, and March; Q2 represented April, May, and June; Q3 represented July, August, and September; and Q4 represented October, November, and December. The observed birth date distributions were calculated for each quarter. The expected birth date distributions of J + S were the distributions of all corresponding birthdates of the Swiss population (ages 10–20 yr.), obtained from the Swiss Federal Office of Statistics (2013). Beforehand, the respective age categories of the Swiss population were analyzed to verify the equal distribution of relative age quartiles. All relative age quartiles of Swiss resident females were similarly distributed (Q1 = 24.6%; Q2 = 25.2%; Q3 = 26.0%; Q4 = 24.2%). According to Delorme, Boiché, and Raspaud (2010b), instead of the entire Swiss population the distribution of J + S (all registered athletes) was used as a basis (expected distribution) to evaluate RAEs of TDP. The expected birth date distributions of the TDP were the distributions of all athletes who were participating in the specific sport program of J + S. If a biased distribution already existed among the entire basic population of registered athletes of J + S, the same pattern would arise among the TDP as well, and influence the conclusions drawn about RAEs.

Analysis

From these original data, odds ratios (ORs) and 95% confidence intervals (*CI*) were calculated for Q1 vs Q4. All statistical analyses were carried out using SPSS 18.0. Chi-square tests were used to assess differences between the observed and expected birth date distributions. If the differences were significant, then *post hoc* tests were used to calculate the mean differences between the quarters. In addition, effect sizes were computed to qualify the results of the chi-squared tests. The appropriate index of effect size is Cramer's V (V) if the *df* is above 1 (Aron & Aron, 2003). According to Cramer (1999), for $df = 3$ (which is the case for all comparisons of birth quarters), V = 0.06 to 0.17 described a small effect, V = 0.18 to 0.29

described a medium effect, and $V \geq 0.30$ described a large effect. An alpha level of $p < .05$ was applied as the criterion for statistical significance.

Results

Compared to the respective Swiss female population, significant RAEs were found in all registered J+S athletes of alpine skiing, tennis, athletics, snowboarding, and fencing. An exception was table tennis where significant "reverse" RAEs were detected with an overrepresentation of athletes born in the end of the year (Table 1). However, calculations of effect sizes showed that the RAEs have no practical relevance for the participation of all analyzed sports.

Compared to the distribution of all registered J+S athletes, the athletes of the TDP showed significant RAEs in alpine skiing and tennis. In athletics, no RAEs were detected. In contrast, female snowboarders, table tennis players, and fencers showed significant inverse RAEs (Table 2). RAEs were small in alpine skiing and medium in tennis. Inverse RAEs were small in female table tennis and medium in female snowboarding and fencing.

Discussion

RAEs in Individual Sports

RAEs have traditionally been observed among male athletes of the elite level in team sports where physical attributes such as weight, height, and strength represent key factors for success. As shown, the self-selected J+S athletes of alpine skiing, tennis, athletics, fencing, and snowboarding showed statistically significant RAEs. In other words, female adolescents born in the beginning of the selection year are more likely to participate in these individual sports compared with their younger counterparts. Those born in Q3 and Q4, possibly because of their less advantageous physical and/or psychological attributes, showed a kind of self-selection process and apparently did not participate in these sports. It is important to note that coaches of the TDPs have to select from the pool of athletes participating in J+S. This distribution of athletes of J+S influences the prevalence of RAEs in the TDP in these individual sports.

Table tennis seems to be an exception, showing "reverse" RAEs in the basic population of all J+S participants. However, van Rossum (2006) showed that if motor skills are a fundamental asset for success and the relevance of physical factors is low, no RAEs can be expected in certain sports. Compared to the study of van Rossum (2006) which compared only 56 athletes, the sample size is much bigger ($n = 3{,}675$). There are Swiss sports like soccer where RAEs have been found in the basic population of active female soccer players (Romann & Fuchslocher, 2011). If there is no

TABLE 1

RAEs in the Female J+S Population

Sport	*n*	Q1	Q2	Q3	Q4	χ^2	V	OR Q1/Q4	95% *CI*
Swiss population	319,480	78,592	80,509	83,065	77,314				
%		24.6	25.2	26.0	24.2				
Alpine skiing	186,468	46,521	46,809	48,360	44,778	31.0†^{R}	0.01	1.02	(1.00, 1.04)
%		24.9	25.1	25.9	24.0				
Tennis	58,155	15,033	14,787	14,604	13,731	84.4†^{R}	0.02	1.07	(1.04, 1.10)
%		25.8	25.4	25.1	23.6				
Track and field	47,580	12,870	12,375	11,709	10,626	237.6†^{R}	0.04	1.19	(1.14, 1.23)
%		27.0	26.0	24.6	22.3				
Table tennis	3,675	795	975	990	915	17.7†^{R}	0.04	0.85	(0.77, 0.94)
%		21.6	26.5	26.9	24.9				
Fencing	3,372	921	792	933	726	27.6†^{R}	0.05	1.24	(1.10, 1.41)
%		27.3	23.5	27.7	21.5				
Snowboard	2,178	564	609	522	483	16.2†^{R}	0.05	1.14	(0.99, 1.32)
%		25.9	28.0	24.0	22.2				

Note.—For the analysis of all J+S participants, this study normalized according to the basic population (national distribution). For the analysis of TDP participants this study normalized according to the respective J+S distribution (according to Delorme, 2010). The reason for this approach is that only active participants of J+S (first level) can enter in the TDP (second level). Q1 to Q4=quarter 1 to 4; V=Cramer's V; $*p<.05$. $†p<.01$. ^{R} = reverse RAEs; OR=Odds ratio; 95% *CI*=95% Confidence Interval.

TABLE 2

RAEs in the Female Talent Development Program ($N = 1{,}177$)

Sport	*n*	Q1	Q2	Q3	Q4	χ^2	V	OR Q1/Q4	95% *CI*
Alpine skiing	508	165	141	107	95	23.9†	0.13	1.67	1.19, 2.16
%		32.5	27.7	21.1	18.7				
Tennis	156	62	31	31	32	15.9†	0.18	1.77	1.15, 2.71
%		39.7	19.9	19.9	20.5				
Track and field	227	69	62	55	41	3.0†	0.07	1.39	0.94, 2.05
%		30.4	27.3	24.2	18.1				
Table tennis	111	22	19	40	29.97	7.0*^{R}	0.15	0.84	0.49, 1.46
%		19.8	17.1	36.0	27.1				
Fencing	88	13	19	25	31	12.9†^{R}	0.22	0.33	0.17, 0.63
%		14.8	21.6	28.4	35.2				
Snowboard	87	11	19	30	27	14.1†^{R}	0.23	0.35	0.17, 0.70
%		12.7	21.8	34.5	31.0				

Note.—Q1 to Q4 = quarter 1 to 4; $\chi 2$ = Chi2-value; V = Cramer's V; ^{R} = reverse RAEs; OR = Odds ratio; 95% *CI* = 95% Confidence Interval; expected frequencies were taken from respective sports (shown in Table 1). *$p < .05$. †$p < .01$.

RAE in the general participation in sports, there should be some sports where a "reverse" trend of the RAE exists; table tennis seems to be one of these sports. A possible reason for the existence of inverse RAEs in table tennis could be that this sport is a sport attracting those who drop out of tennis (Worek, 2013). Elite youth tennis requires high physical and cognitive demands. A high relative age is an advantage, and therefore high RAEs are found in tennis (Edgar & O'Donoghue, 2005). Players who are not selected in elite groups tend to be smaller, less strong, and less physically mature and might change to a racket sport with less physical demands. But this is speculative, and further research is needed to explain the mechanisms of "reverse" RAEs in table tennis.

RAEs in Talent Development Programs

In the subgroups of talent development programs, statistically significant RAEs were found in alpine skiing and tennis. No RAEs were detected in female athletics; in female table tennis, fencing, and snowboarding, "reverse" RAEs were found. In alpine skiing and tennis where strength, weight, or height are seen as relevant for performance, children born late in the competition year may be less likely to be selected. In contrast, in sports like table tennis, fencing, or snowboarding, which require high technical skill or aesthetics for performance, relatively younger, smaller, less strong, and less physically mature individuals may have an advantage and are more likely to be selected (Baker, *et al*., 2014).

The existence of RAEs in male sports where physical factors are fundamental for success are well documented in the literature (Cobley, *et al*., 2009). However, in female sports, RAEs are more variable when compared to males. In some sports like alpine skiing, volleyball, and soccer, RAEs were found, although they were always smaller than those observed in the male athletes of the same selection level (Nakata & Sakamoto, 2012; Baker, *et al*., 2014; Romann & Fuchslocher, 2014). In other sports like ski jumping, figure skating, and taekwondo, no RAEs were found (Albuquerque, *et al*., 2012; Baker, *et al*., 2014). In snowboarding and gymnastics, "atypical" distributions with the highest proportions in Q3 were reported (Schorer, *et al*., 2009; Baker, *et al*., 2014). The mechanisms explaining the inconsistency of RAEs in females are largely unknown. Previous research has suggested that lower participation in female sports may reduce the depth of competition for females and thereby moderate the size and strength of RAEs (Schorer, *et al*., 2009). The absence of RAEs in female and male taekwondo was explained by grouping youth participants into competitive or weight categories (Albuquerque, *et al*., 2012). A categorization by weight removes the effects of greater strength, size, and weight due to maturational differences. Therefore, according to recent literature, weight categories seem to eliminate RAEs (Albuquerque, *et al*., 2012; Albuquerque, Tavares, Lage, de

Paula, da Costa, & Malloy-Diniz, 2013; Delorme, 2013). Additionally, Albuquerque, *et al*. (2013) showed that only in extra-light to middle-weight judo athletes there are no RAEs because technical demands are important for performance. The existence of RAEs in half-heavy and heavy athletes was explained by the high physical demand in heavy categories.

Additionally, the varying cultural importance of different sports might affect the number of participating athletes, with the most capable athletes competing in sports with the highest cultural relevance (Weir, Smith, & Paterson, 2010). This can be confirmed in the current data, given that alpine skiing and tennis were the individual sports with the highest popularity, the largest amounts of sponsoring money, highest media attendance, and largest numbers of participants in Switzerland (Swiss Federal Office of Sport, 2013). The existence of "reverse" RAEs in female table tennis, fencing, and snowboarding might show a contrary phenomenon. Female athletes who are not successful or drop out of culturally important sports might transfer to less competitive and more technical sports like snowboarding, fencing, and table tennis. A second possible explanation might be that the physical characteristics needed for athletic performance are sometimes inconsistent with the stereotyped ideal representation of the female body, which is expected to be thin and petite (Choi, 2000). Researchers have argued that social pressures, such as stereotyped ideas of femininity, could pressure early-maturing girls to drop out of sports where physical attributes are important (Vincent & Glamser, 2006). This might favor a transfer to a sport that integrates aesthetics and high technical skill into performance (e.g., from tennis to table tennis or from alpine skiing to snowboarding). Moreover, previous studies have suggested that sports that depend heavily on the technical skills or motor skills of the participant will produce no RAE (van Rossum, 2006; Schorer, *et al*., 2009) or even "reverse" RAEs as shown in the current data. In sports where aesthetics and technical skill determine performance, "reverse" RAEs seem to be more prevalent.

Possible Solutions

To further optimize the talent development system in Switzerland and retain youth in sport, the challenge seems twofold. On one hand, it seems important to include athletes disadvantaged due to RAEs in individual sports at an early age. On the other hand, it is crucial to keep athletes involved in talent development programs after puberty ends. Barnsley and Thompson (1988) have suggested creating categories by weight, height, or age categories with a smaller bandwidth (e.g., 6 mo. instead of one yr.). This change would result in smaller RAEs and fewer physical differences between athletes within any specific age category. As shown by Albuquerque, *et al*. (2012) and Delorme (2013), the implementation of weight categories may counteract RAEs in sports. Grondin, Deschaies, and Nault (1984) recommended an alteration of the activity year's cut-off dates. A yearly rotation for the cut-off date might work since all athletes would then experience the advantage of a higher relative age at some point in their careers (Hurley, Lior, & Tracze, 2001). Albuquerque, *et al*. (2012) showed that the absence of RAEs in taekwondo can be explained by grouping youth participants into competitive and weight categories. Therefore, weight categories instead of age categories might be an approach to reduce RAEs.

An additional potential solution could be to change the attitudes of youth team coaches (Helsen, *et al*., 2000). In selections of long-term talent development programs, assessments of future potential should be emphasized in contrast to aspects of performance (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). An additional goal for coaches might be introduced, which is that they should pay more attention to technical aspects when selecting athletes for talent development programs and should not overrate physical characteristics such as height and strength. This procedure would lead to two performance groups: one "potential" group which is likely to succeed in the future and one "competition-winning" group for immediate success. The likelihood of RAEs in talent development programs may be reduced by emphasising technical skills as criteria of performance and reducing the influence of rankings in competitions (Wattie, *et al*., 2014).

An additional approach could be the implementation of correction factors. First, a normalization of the performance by weight could reduce RAEs (Albuquerque, *et al*., 2012; Delorme, 2013). Second, in sports assessed in centimeters, grams, and seconds (like alpine skiing, swimming, or track and field), correction factors could be calculated. For example, in athletics a correlation between race time and relative age within each age category could show and eliminate the influence of RAEs on performance. However, on the one hand, this type of solution may be costly (each sport and age category needs specific correction factors), time consuming, and would need the complete support of the federation and coaches (Romann & Fuchslocher, 2014). The feasibility of such an approach would require additional research and discussion with all relevant stakeholders.

In the current Swiss system, a decrease in RAEs may substantially enhance retention and performance at the elite senior level in the future. Athletes with high potential for future success would not be excluded early and could fulfill their potential in senior categories. According to the data, the consequences and implications of RAEs should be taught at all levels of coaching education, particularly for coaches of TDPs. Therefore, from the authors' point of view, furthering the education of all coaches may counteract future RAEs in Swiss female individual sports. Moreover, in Switzerland, talent identification and athlete development should be viewed as a long-term process. In contrast to aspects of performance, assessments of future potential should be emphasized (Vaeyens, *et al*., 2008). In any case, it would be a significant step forward for the sporting system, federations, and coaches to select athletes with the highest potential for the future instead of the athletes with the highest chance of winning in the present.

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Survival and Success of the Relatively Oldest in Swiss Youth Skiing Competition

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ABSTRACT
Relative age refers to age differences between children in the same selection year. The present study investigated the prevalence of relative age effects (RAEs) at the Grand Prix Migros (GPM), which is the most popular alpine skiing race for children aged 7 to 14 years in Europe. In total, 17,992 Swiss junior alpine skiers, separated into female skiers (n = 7,227) and male skiers (n = 10,765), were evaluated in the 2010, 2011, and 2012 races. Chi-square analyses revealed no RAEs ($p > 0.05$) for the entire group of finishers in the qualification race for females in the Under U-8 to U-13 categories (n = 7,010) and all males (n = 10,410). Significant inverse RAEs were detected in the qualification race among female skiers in the U-14 and U-15 age categories ($p < 0.01$; odds ratio OR = 0.79; 95% confidence interval (CI) [0.64-0.98], and among disqualified male skiers ($p < 0.01$; OR = 0.54; [CI, 0.40-0.74]. However, significant RAEs were found for the entire group of both female and male skiers who qualified for the final race ($p <$ 0.01; OR = 1.49; [CI, 1.28-1.73] of females, respectively OR = 2.18; [CI, 1.87-2.53] of males). RAEs were additionally apparent in all age categories of female and male finalists. The GPM is apparently influenced by RAEs, which may be an initial step towards RAEs in youth sports and may lead to an unequal participation in Swiss skiing.

Key words: Alpine Skiing, Gender, Relative Age Effect, Youth Sport

INTRODUCTION

Age is a very important criterion for inclusion in many organisations and institutions within our society. The practice of age grouping is involved in education and youth sports. Sport administrators typically categorise participants of youth competitions by annual age groups to reduce the developmental differences between athletes during childhood and adolescence

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[1]. Although this strategy is well-intended, it leads to significant age differences of almost 12 months between individuals in the same annual age group [2]. The advantage of being born early within a single age category has been termed relative age effect (RAE) [3]. In sports, RAEs have gained increasing awareness among sports scientists and coaches over the last three decades. Early research from 1984 until today has identified RAEs in a variety of sports at the junior level, with significant overrepresentations of athletes born in the first quartile (i.e., the first three month after the official cut-off date) [1]. It is apparent that within a specific birth year, there is considerable variation in the growth and biological maturity of individuals. This may lead to a biological mismatch between children within the same chronological age categories [4, 5]. Often these relatively older athletes are erroneously identified as having superior sporting prowess. Athletes who may be potentially skilled but lack the physical characteristics needed for performance at this developmental stage are often excluded [4, 6, 7]. The primary causes of RAEs appear to be maturational differences and physical attributes (e.g., greater aerobic power, muscular strength, and height) [1, 8]. Additional explanations for relatively older children's superior performance involve psychological development, practice experience, and mechanisms related to selection processes [1]. Once selected, the relatively older children generally experience much higher quality sport environments including better coaching, more positive feedback, and more intense levels of training and competition, all of which enhance performance [4]. On the other hand, children with a relative age disadvantage participate at a comparatively lower level of competition and have less support and training. As a consequence, these children are less likely to reach the highest levels in elite sports and are more likely to drop out of a particular sport [9].

To date, the majority of participants have been analysed in team sport contexts [1], such as soccer [9] and ice hockey [2]. Fewer studies have considered RAEs in individual sports and the influence of RAEs on children's and youth competitions. In sports like gymnastics, however, where late maturation is a performance advantage, no RAEs [10] or inverse RAEs - with an overrepresentation of female gymnasts born at the end of the selection year - have been described [11]. These results were explained with the emphasis of creativity and aesthetics in gymnastics and figure skating. Moreover, previous work suggested that sports that depend mainly on technical or motor skills show no RAEs [10]. In contrast Baxter-Jones and Helms [12] examined RAEs in tennis and swimming. They showed that almost 50% of elite female swimmers and tennis players aged 8 to 16 years were born in the first quartile of the selection year. Edgar and O'Donoghue [13] found significant RAEs among both the women's and men's elite junior tennis players participating at the junior competition circuit or a Grand Slam tournament of the International Tennis Federation. To our knowledge there is only one systematic study about RAEs in skiing [11], despite this sport attracting large amounts of children and adolescents [14]. Recently Baker et al. [11] analysed RAEs in alpine skiers, ski jumpers, cross-country skiers, snowboarders, and Nordic combined athletes. They found significant RAEs in cross-country skiing, snowboarding and alpine skiing of both genders. The existence of RAEs in alpine skiing were explained by physical variables, anthropometry and learned skills which are important predictors of performance [11, 15]. The researchers concluded that sport-specific contextual factors are important elements in understanding RAEs in individual sports and that further work, particularly in the under-researched female contexts, is necessary to validate the described findings.

In Switzerland skiing is the most popular individual sport [16]. Every year more than 7,600 children and adolescents, of both genders and aged between 7 and 14 years, register for one of 13 Grand Prix Migros (GPM) events, making it the most popular alpine skiing race in Europe. Through these popular sports events, children and adolescents can subsequently qualify for the nationwide final race. Given the relevance of RAEs and their potential for introducing a bias to participation and the selection process, an examination of RAEs in children and youth competitions in the individual sport of alpine skiing seems warranted.

Therefore, the aim of this study was to examine the prevalence and size of RAEs among the participants of the GPM, subdivided by gender and age groups. We hypothesised that RAEs would be absent in the qualification event which is open to all nominees, but would be prevalent within the finalists, especially the males.

METHODS

PARTICIPANTS

Every year around 7,600 children and adolescents register for the GPM skiing race. We analysed all 17,992 participants (from 22,484 registered) who started at the ski race in the 2010, 2011, and 2012 competitions. All persons who did not start were excluded from the analysis. In total n = 7,227 female skiers and n = 10,765 male skiers in the U-8 to U-15 age categories were evaluated. All races are performed separately for females and males and in each of the eight age categories (U-8 to U-15). The type of race is a giant slalom event which requires the participant to negotiate perfectly, alternating red and blue gates as fast as possible. This is typically completed in around one to two minutes depending on athlete age, gender and specific course. The qualification races take place in 13 different regions of Switzerland. Every participant who lives in Switzerland can start and qualify in one single qualification race (independent of place of residence) for the separate nationwide final race. The participants can only start in one single qualification race, and qualify for the final race if they are one of the five fastest skiers in their age group [14].

PROCEDURE

All participating skiers of the GPM were grouped according to gender, age, relative age, finishers and disqualified skiers (did not finish or missed a gate). All data were obtained from the website of the GPM which is provided by the Swiss Ski Federation (Swiss-Ski) [14]. As the cut-off date for all skiing categories in Switzerland is the 1st of January, the year was divided into four quartiles (Q1 represents January, February, and March; Q2 represents April, May, and June; Q3 represents July, August, and September; and Q4 represents October, November, and December). The observed relative age distributions of all skiers were calculated for each quartile. The expected distributions for the qualification races were recorded from representative birthdates of the corresponding Swiss population using weighted mean scores (Helsen, et al., 1998). The corresponding Swiss population (aged 7 to 14) was defined as the number of official residents (n = 722,881) registered with the Swiss Federal Statistical Office [17].

Beforehand, the respective age categories of the Swiss population were analysed to verify the equal distribution of relative age quartiles. All relative age quartiles of both genders were equally distributed (female: Q1 = 24.6%; Q2 = 25.2%; Q3 = 26.0%; Q4= 24.2%; male: Q1 = 24.7%; Q2 = 25.2%; Q3 = 26.0%; Q4 = 24.1%). The expected distributions of the final race were recorded from birthdates of the all participants who started at the qualification race. From these original data, chi-square tests were used to assess differences between the observed and expected relative age distributions, and post-hoc tests were used to determine the differences in frequency counts between significant quartiles. Odds ratios (OR) and matching 95% confidence intervals (CI) were calculated between Q1 and Q4. When comparing quartiles in all OR analyses, the corresponding Swiss population (for the qualification race) and all participants of the GPM (for the final race) were assigned as the reference group. In addition, effect sizes were computed to qualify the chi-square test results. For the chi-square analyses, the magnitude of the effect size was measured using Cramer's V [18]. According to Cramer [18], for $df = 3$ (which is the case for all comparisons of relative age quartiles), 0.06 < V (0.17 indicates a small effect, 0.17 < V < 0.29 a medium effect, and V (0.29 a large effect. All statistical analyses were carried out using SPSS 16.0. An alpha level of $p < 0.05$ was set as the criterion for statistical significance.

RESULTS

RAES OF FEMALE AND MALE PARTICIPANTS AT THE GRAND PRIX MIGROS

As indicated in Table 1, no RAEs were found for female and male finishers of the qualification race, or the disqualified female skiers ($p > 0.05$). However, female and male finishers of the final race were significantly overrepresented in Q1, and significantly underrepresented in Q4 (p < 0.01; OR = 1.49 [CI, 1.28-1.73] of females; respectively OR = 2.18 [CI, 1.87-2.53] of males). RAEs and effects were small for both females and males. Male skiers who were disqualified in the qualification race were more likely to be relatively younger. Those born at the end of the year (Q4) were overrepresented ($p < 0.01$; OR = 0.54 [CI = 0.40-0.74]; small effect). The groups of skiers disqualified from the final race were too small to consider.

RAES IN DIFFERENT AGE GROUPS AT THE GRAND PRIX MIGROS

In the subgroups of female U-8 to U-13 age categories and all male skiers we found no RAEs in the qualification race (Table 2). However in the U-14 and U-15 age category, more female skiers who were relatively younger, showed significant inverse RAEs (p < 0.05; OR = 0.79 [CI, 0.64-0.98] respectively OR = 0.85 [CI, 0.68-1.07]). In the final race, skiers of all age categories and both genders showed significant RAEs (p < 0.01). The strongest RAEs of female skiers appeared in the U-11 age group (p < 0.01; OR 2.01 [CI, 1.32-3.07]), while the strongest RAEs of male skiers were detected in the U-14 age category (p < 0.01; OR = 2.90 [CI, 1.87-4.51]). For females in the U-9, U-12, and U-13 age categories, the analysis revealed an atypical distribution, with the highest percentage of athletes born in the second quartile (Table 2). All remaining chi-square and post-hoc tests of the final competition highlighted an overrepresentation of participants born at the beginning of the year, and a decreasing number of participants born in subsequent quartiles.

DISCUSSION

RAEs have traditionally been observed in team sports and among male athletes at the elite level. Given the prevalence of RAEs in high-performance sport and the need to understand the mechanisms of RAEs researchers have emphasised the importance of broadening the scope of investigations to specifically consider the individual sports and female contexts [1]. To date very little is known about RAEs in individual sports, such as alpine skiing, or in children's and youth competitions that include both genders. Our data show that significant RAEs occur in the most popular alpine skiing race for children and young adolescents aged 7 to 14 years in Europe in all age categories, and for both male and female participants.

RAES OF FEMALE AND MALE PARTICIPANTS AT THE GRAND PRIX MIGROS

We found no RAEs in the GPM qualification race of all male starters and U-8 to U-13 female

Table 1. RAEs of Female and Male Participants at the Migros Ski Grand Prix

race type	status	Q1	Q2	Q3	Q4	Total	χ^2	V	Effect	OR Q1/Q4	95% CI
quali-	finisher	1763	1754	1731	1762	7010	8.9	0.02	no	0.98	(0.92, 1.05)
fication	(%)	25.1%	25.0%	24.7%	25.1%						
female	disqualified	61	49	58	49	217	1.9	0.05	no	1.22	(0.84, 1.78)
	(%)	28.1%	22.6%	26.7%	22.6%						
final	finisher	549	531	388	363	1831	58.3**	0.10	small	1.49*	(1.28, 1.73)
female	(%)	30.0%	29.0%	21.2%	19.8%						
quali-	finisher	2666	2688	2598	2458	10410	11.8	0.02	no	1.07*	(1.01, 1.13)
fication	(%)	25.6%	25.8%	25.0%	23.6%						
male	disqualified	61	80	103	111	355	16.6**†	0.12	small	0.54*	(0.40, 0.74)
	(%)	17.2%	22.5%	29.0%	31.3%						
final	finisher	639	463	448	289	1839	109.1**	0.14	small	2.18*	(1.87, 2.53)
male	(%)	34.7%	25.2%	24.4%	15.7%						

*Note: Q1 to Q4 = quartile 1 to 4; χ2 = Chi2-value; V = Cramer's V; *P<0.05; **P<0.01. † inverse RAEs; OR = Odds ratio; 95% CI= 95%-Confidence Interval. Quartiles of Swiss population: Q1=24.6%; Q2=25.2%; Q3=26.0%; Q4=24.2% (female); Q1=24.7%; Q2=25.2%; Q3= 26.0%; Q4=24.1% (male).*

Table 2. RAEs of Participants at the Migros Ski Grand Prix by Age Category

race type	age cat.	n	% Q1	% Q2	% Q3	% Q4	χ^2	V	Effect	OR Q1/Q4	95% CI
qualification female	U-8	747	25.3	28.1	24.9	21.7	5.3	0.05	no	1.14	(0.92, 1.41)
	U-9	897	25.6	26.0	24.1	24.3	2.2	0.03	no	1.03	(0.86, 1.25)
	U-10	1097	24.6	24.8	24.7	25.9	2.2	0.03	no	0.93	(0.79, 1.10)
	U-11	1065	26.5	25.2	24.6	23.8	2.7	0.03	no	1.09	(0.92, 1.30)
	U-12	1021	25.0	25.1	24.4	25.6	2.0	0.03	no	0.96	(0.80, 1.14)
	U-13	917	24.2	23.9	24.8	27.2	4.5	0.04	no	0.87	(0.73, 1.05)
	U-14	688	23.4	22.2	25.4	28.9	9.0*†	0.07	small	0.79	(0.64, 0.98)
	U-15	574	24.9	22.6	24.4	28.1	6.6*†	0.07	small	0.85	(0.68, 1.07)
final female	U-8	225	31.6	26.7	21.3	20.4	5.5*	0.09	small	1.32	(0.86, 2.03)
	U-9	257	31.1	33.1	18.7	17.1	16.8**	0.15	small	1.72*	(1.14, 2.60)
	U-10	245	28.5	27.3	23.7	24.4	4.0*	0.07	small	1.23	(0.84, 1.80)
	U-11	242	34.3	31.0	19.4	15.3	20.9**	0.17	medium	2.01*	(1.32, 3.07)
	U-12	237	26.7	29.1	17.7	26.4	6.3*	0.09	small	1.04	(0.70, 1.53)
	U-13	218	28.4	30.3	21.6	19.7	10.7*	0.13	small	1.62*	(1.05, 2.48)
	U-14	206	30.7	25.2	25.2	18.8	12.5**	0.14	small	2.01*	(1.28, 3.16)
	U-15	201	31.8	28.4	22.9	16.2	16.2**	0.16	small	2.22*	(1.38, 3.59)
qualification male	U-8	1214	26.2	26.9	24.5	22.3	5.9	0.04	no	1.15	(0.98, 1.36)
	U-9	1540	27.6	25.3	24.4	22.7	9.2	0.04	no	1.19*	(1.03, 1.38)
	U-10	1657	26.6	25.7	25.4	22.3	6.1	0.04	no	1.18*	(1.02, 1.35)
	U-11	1620	25.5	24.8	26.7	23.0	1.8	0.02	no	1.09	(0.94, 1.26)
	U-12	1481	24.4	26.8	24.6	24.2	2.9	0.03	no	0.99	(0.85, 1.15)
	U-13	1242	24.6	26.9	23.4	25.1	5.4	0.04	no	0.96	(0.82, 1.13)
	U-14	927	25.4	23.2	25.6	25.9	2.8	0.03	no	0.96	(0.80, 1.16)
	U-15	729	23.0	27.0	24.6	25.4	2.8	0.04	no	0.89	(0.72, 1.10)
final male	U-8	265	34.0	30.9	19.2	15.8	15.7**	0.14	small	1.83*	(1.22, 2.73)
	U-9	224	35.3	23.2	26.3	15.2	11.2**	0.13	small	1.91*	(1.25, 2.93)
	U-10	238	38.2	21.8	26.1	13.9	21.1**	0.17	medium	2.31*	(1.51, 3.52)
	U-11	237	37.6	24.9	22.4	15.2	21.5**	0.17	medium	2.23*	(1.48, 3.37)
	U-12	230	33.5	21.7	29.6	15.2	14.2**	0.14	small	2.18*	(1.43, 3.34)
	U-13	227	28.6	28.6	28.2	14.5	11.8**	0.13	small	2.01*	(1.29, 3.15)
	U-14	215	42.3	20.9	21.9	14.9	36.2**	0.24	medium	2.90*	(1.87, 4.51)
	U-15	203	29.5	28.5	21.6	20.4	7.1*	0.11	small	1.59*	(1.02, 2.49)

Note: Q1 to Q4 = quarter 1 to 4; $\chi 2$ = Chi2-value; V = Cramer's V; *P<0.05; **P<0.01. † inverse RAEs; OR = Odds ratio; 95% CI=95% -Confidence Interval. Quartiles of Swiss population: Q1=24.6% ; Q2=25.2% ; Q3=26.0% ; Q4=24.2% (female); Q1=24.7% ; Q2=25.2% ; Q3= 26.0% ; Q4=24.1% (male).

age categories. This means that the participants did not differ significantly from the Swiss population and there is no self-selection bias in the GPM ski race. This result was expected given that the qualification event is open to all nominees and there is no form of selection to be fulfilled. In the final race, where the fastest skiers of the thirteen qualification races were selected, significant RAEs occurred. Q1 skiers were significantly overrepresented, and Q4 skiers were significantly underrepresented, compared to the distribution of participants in the qualification races. Hence, relatively older skiers are more likely to qualify for the final race, compared to their younger counterparts. Similar to most team sports, relatively older alpine skiers of the GPM race seem to have an advantage in anthropometric and physical variables which support their performance [15]. Those born in Q3 and Q4 are significantly disadvantaged, probably because of their less advantageous physical attributes. Underlining this fact, we found a significant inverse RAE among the disqualified male skiers in the qualification race, showing an overrepresentation of disqualified participants born at the end of the year (Q4) compared to the distribution of starters in the GPM. Being relatively younger may provide disadvantages in skiing such as being physically and cognitively less mature and having less experience in decision-making than relatively older peers in the age category [11]. These factors may alter the possibility of missing a gate or to finish the race and the relatively younger may perceive that they need to push themselves more forcefully in order to post a qualifying time.

RAES IN DIFFERENT AGE CATEGORIES AT THE GRAND PRIX MIGROS

In the qualification race, all male participants of the U-8 to U-15 year age categories did not differ significantly from the Swiss population. This is in line with findings in soccer, where no RAEs have been detected in the basic population of all registered male Swiss soccer players in the 10-15 year age group [20]. In the final race, skiers of all age categories and both genders showed significant RAEs. Baker et al. [11] found significant RAEs among all elite female and male alpine skiers registered in the database of the International Ski Federation. In the same study no RAE was detected for female gymnasts in the U-12 to U-15 year age group. These differences between alpine skiing and gymnastics were explained by sport-specific contextual factors. In alpine skiing where RAEs occur, physical and anthropometric variables are important predictors of performance, on the contrary in gymnastics the emphasis on technical and motor skills may be the reason for the lack of RAEs [11, 15]. Additionally, RAEs in the final race were stronger in all male age categories compared to females. This finding is in line with previous studies, where RAEs were weaker and more variable for female athletes compared to males [1].

RAES IN FEMALE PARTICIPANTS

As suggested by Vincent and Glamser [21], there may be additional factors determining RAEs in female sports. Firstly, in some sports, young females born in Q1 and Q2 are more likely to participate compared with their younger counterparts. Those born in Q3 and Q4 show a kind of self-selection process before even trying the activity, potentially because of their less advantageous physical attributes [22]. In the female U-14 and U-15 age categories of the MGP, significant inverse RAEs occurred in the qualification race, which means that there was greater participation by girls born in Q4 than those born in Q1. A possible explanation might be that female anaerobic and aerobic characteristics, speed, and physical fitness plateau shortly after menarche [23]. Therefore, some of the physiological benefits of being born early in the competition year might disappear in the U-14 and U-15 age categories. Accordingly late maturing females frequently catch up with their peers who matured early, and can even produce superior athletic performances [7]. This may influence their participation in ski racing. During and after puberty, physical characteristics needed for athletic performance are sometimes inconsistent with the stereotyped idea of an ideal female body, which is expected to be thin and petite in western countries [24]. Accordingly, social pressures may prevent females from achieving excellence in competitive sports and could lead elite female skiers to drop out of sports like alpine skiing [22, 25]. In brief, during and after puberty, Q1 female skiers could be more likely to drop out from ski racing than Q4 female skiers. In line with this finding, in the final race of the GMP, female skiers of Q2 were overrepresented in the 8-year, 11-year and 12-year age categories. Similar distributions have been reported in female handball, soccer, and ice hockey [22, 26-28]. In these studies, several possible explanations for this trend are described. These include the cultural importance of different sports, the transfer of relatively older athletes to other sports, and socially constructed gender roles which may provoke a dropout of Q1 athletes [21, 24, 25].

POSSIBLE SOLUTIONS

Several ways to avoid RAEs in selections have been suggested [1], including creating categories based on biological age rather than chronological age, using chronological age categories that are based on intervals of less than a year [1, 29] and implementing quotas where specified relative age distributions must be met [2]. All these suggestions could be used in popular youth competitions as well. However, these changes require cooperation and coordination among sport administrators, federations and coaches. A special challenge in individual sports is that usually athletes are not selected by coaches as in team sports. In individual sports selections are mostly based on competition results. Therefore suitable measures to counteract RAEs in youth skiing competitions have to change the current competition system and rules.

Theoretically, categories based on height or weight could reduce RAEs in youth skiing competitions [5]. This type of solution may be costly, time consuming, and would need the complete support of the federation and coaches. In addition it is unproven in their value for resolving RAEs [1]. Another suggestion could be to change the starting order in the qualification races. Usually the racing conditions are better at the beginning of the race, because the track is perfectly prepared and conditions become worse as more athletes ski down the track [30]. According to this fact a starting order beginning with the relative youngest participant and ending with the relative oldest participant may help mitigate against RAEs influencing race time performance in alpine ski races.

The likelihood of RAEs in youth competitions may be reduced by emphasising technical skills as criteria of performance and reducing the influence of race time [31]. This could be carried out by implementing competitions which includes these elements and/or a correction factor. These correction factors could be calculated by correlating race time with relative age within each age and gender category in order to reduce RAEs and propagate fairer competition within ski races. However, the feasibility of such an approach would require additional research and discussion with relevant stakeholders.

CONCLUSION

While there are many other potential solutions or variations to deal with RAEs, it is strongly encouraged that coaches and sporting federations generate their own unique approaches to improve the fairness of age category competitions. The ultimate challenge is to keep those athletes who are physically or psychologically disadvantaged due to RAEs involved in the sport, until they have fully matured [5]. From our point of view, athlete selections that favour more technical skills, or competitions which may consider correction factors in the final results or other modified competition rules levelling the playing field should be seriously considered.

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Assessment of skeletal age on the basis of DXA-derived hand scans in elite youth soccer

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ABSTRACT

Physical performance is highly dependent on maturity. Therefore, consideration of maturity is recommended in the talent identification process. To date, skeletal age (SA) is assessed using X-ray scans. However, X-rays are associated with a 10-fold higher radiation compared to dual-energy X-ray absorptiometry (DXA). The aim of the study was to validate SA assessments in male soccer players with the DXA technique. Paired X-ray and DXA scans of the left hand of 63 Swiss U-15 national soccer players were performed. SA assessments were performed twice by two blinded raters using Tanner and Whitehouse' reference technique. Intrarater and interrater reliability as well as agreement between both techniques were tested. Intrarater and interrater reliabilities were excellent. Bland-Altman plots showed that SA assessments between X-ray and DXA differed by −0.2 years and 95% limits of agreement were ±0.6 years. Therefore, DXA offered a replicable method for assessing SA and maturity in youth soccer players.

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Bone age; maturity classification; talent identification; young athletes

Introduction

In youth sports, grouping by chronological age (CA) is the customary procedure for separating young athletes into age-related training and competition groups. However, individuals in the same age category can vary by as much as 4 years in biological age (Malina, Bouchard, & Bar-Or, 2004). Variations in performance like speed and endurance are highly dependent on biological age especially during the transition into and during male adolescence (Malina et al., 2004; Malina, Coelho-e-Silva, & Figueiredo, 2012). Therefore, elite youth athletes in several sports tend to be advanced in biological maturity during late childhood and adolescence for female and male athletes (Gil et al., 2014; Idrizovic, 2014; Malina, Coelho-e-Silva, & Figueiredo, 2012; Ostojic et al., 2014; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). Specifically, data in soccer suggests that a disproportionately large amount of late maturing players is excluded and average and early maturing players are favoured. As a consequence, maturation characteristics should be considered in any talent identification or development programme to provide fair selection and to invest available resources appropriately (Vaeyens et al., 2008).

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Amongst different methods, skeletal age (SA) is said to be the best indicator of biological maturity and is more meaningful than CA for the evaluation of the performance of young athletes (Malina et al., 2004; Tanner, Healy, Goldstein, & Cameron, 2001). The classical method for assessing SA is based on the comparison of actual bone characteristics and maturity indicators in hand-wrist X-rays with reference images from Greulich and Pyle (Greulich & Pyle, 1959), Tanner and Whitehouse (Tanner et al., 2001) or the Fels method (Roche, Chumlea, & Thissen, 1988). The Tanner–Whitehouse 3 method is commonly used outside of the United States and more applicable to European athletes (Gordon et al., 2008).

In modern technology, the assessment of SA by X-ray entails a contained risk. A hand-wrist radiography requires 1 μSv of radiation, which is the equivalent of less than 4 hours of natural background radiation or 10 minutes on an intercontinental flight (Mettler, Huda, Yoshizumi, & Mahesh, 2008). Nevertheless, to avoid possible detrimental effects of cumulative radiation exposure, children and adolescents should only be exposed to a minimal amount of radiation (Hall & Brenner, 2008; Radiological & America, 2012). Additionally, the International Atomic Energy Agency (IAEA) of which all European countries are members demands that the dose of radiation has to be minimised in every use of radiological devices (International Atomic Energy Agency [IAEA], 2006). Consequently, reducing the radiation dose when assessing SA is an important issue, and methods involving less radiation are generally preferable, particularly in childhood and adolescence.

Dual-energy X-ray absorptiometry (DXA) is the most commonly used bone densitometric technique for children worldwide (Gordon et al., 2008) and the use of DXA is common for body composition measurements in elite sport settings (Guppy & Wallace, 2012). Compared to X-ray, computerized axial tomography and magnetic resonance imaging, the main advantages of the DXA method are a high safety and significantly lower exposure to radiation (Coelho e Silva et al., 2013; Gordon et al., 2008). DXA-derived hand-wrist scans recently have become available and could be an approach to adjust for factors related to growth and puberty (Heppe et al., 2012; Płudowski, Lebiedowski, & Lorenc, 2004). Evaluating SA via hand-wrist radiographs using DXA produces one-tenth of the effective radiation dose (0.1 μSv) compared to X-rays (1 μSv) (Gordon et al., 2008; International Atomic Energy Agency [IAEA], 2006). In Switzerland, X-ray and DXA scans have to be supervised by a medical doctor. However, an additional advantage of the DXA technique is that every person can perform the scan who completed a 1-day qualification course. In contrast, X-ray scans can only be performed by medical staff who are qualified to perform the X-ray technique.

To the best of our knowledge, only two studies have investigated the agreement between DXA and X-ray hand-wrist imaging as methods for assessing SA (Heppe et al., 2012; Płudowski et al., 2004). The first study was performed in a paediatric population of 24 girls (age range: 5–17 years) and 26 boys (age range: 5–20 years). The results suggested that SA assessments using DXA are similar to those performed by X-ray (Płudowski et al., 2004). However, the statistical analyses employed in that study – *t*-tests and correlation coefficients – are questionable (Kottner et al., 2011). The second study of Heppe et al. (2012) showed a mean difference between the X-ray and DXA assessments of 0.11 years, with a 95% limit of agreement (LoA) (−0.85 to 1.05). The authors concluded that DXA seemed to be an alternative for the assessment of SA in paediatric hospital-based patients, and that the results should be validated in different populations. The results of Heppe et al. (2012) are not transferable to elite sport settings, because all participants in this study had various medical indications. Diseased persons significantly differ to a normal population and even more to an elite sport cohort (Malina et al., 2004; Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010), which justifies a separate analysis with a sample of youth national athletes.

To date, no study using appropriate statistical methods has investigated the agreement between DXA and X-ray hand-wrist imaging as a method for assessing SA in healthy participants. In addition, no studies have been conducted in sport settings, where the assessment of SA and the classification of maturity play a very important role (Malina, Coelho, Figueiredo, Carling, & Beunen, 2012; Tanner et al., 2001). Given the relevance of using DXA scans due to lower qualification requirements for staff members, significantly lower radiation emissions and legal requirements, this study first aimed to evaluate the reliability of SA assessments using DXA, which is an important prerequisite for validity analysis. Secondly, it sought to validate DXA as a method for assessing SA in order to classify the maturity of soccer players under 15 years of age.

Methods

Sample

Participants were recruited among all male soccer players who were invited to the national selection day of the Swiss Soccer Association. The players were selected from local clubs in 13 regional squads (n = 226). From the regional squads, 72 players were selected to participate during the national selection day. Selections on all levels were based on coaches' evaluation of players' technical skills, game intelligence, personality and speed (Tschopp, Biedert, Seiler, Hasler, & Marti, 2003). All 72 players were offered participation in the study by one of the authors, the leader of the project. Sixty-five parents and participants returned written informed consent. The participants were informed that participation was voluntary and that they could withdraw from the study at any time. After SA assessment, two of 65 players were excluded from the study because they were assessed as skeletally mature. The final cross-sectional sample included 63 (87.5%) participants, aged 14.0 ± 0.3 years. All of the participants were in good health and free of acute or known chronic diseases at the time of the study. The study was approved by the responsible research ethics committees (Kantonale Ethikkommission Bern, Switzerland, No. 022/13) and in line with the Declaration of Helsinki.

Measures

Weight, height, CA and SA were measured. Descriptive statistics of participants are shown in Table 1. Height was measured with a fixed stadiometer (Seca 217; Seca, Hamburg, Germany), and weight was measured with calibrated scales (Tanita WB-110 MA; Tanita, Tokyo, Japan). Weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively. Players wore shorts and a T-shirt, and shoes were removed. Two measurements were taken for each anthropometric variable on the same day as the

Table 1. Subject characteristics.

Characteristic	Mean (SD)	95% CI		Range	
Height	164.9 (8.4)	162.8,	167.0	150.1	−184.4
Weight	53.0 (8.7)	50.8,	55.2	37.8	−73.4
CA	14.0 (0.3)	13.9,	14.1	13.3	−14.3
Observer 1					
SA (X-ray)	13.9 (1.1)	13.5,	14.2	11.7	−16.4
SA-CA (X-ray)	0.0 (1.1)	−0.3,	0.2	−2.3	−2.6
SA (DXA)	14.0 (1.2)	13.7,	14.3	11.7	−16.4
SA-CA (DXA)	0.1 (1.1)	−0.2,	0.4	‘2.3	−2.8
Observer 2					
SA (X-ray)	13.8 (1.4)	13.5,	14.1	10.9	−16.4
SA-CA (X-ray)	−0.1 (1.4)	−0.5,	0.2	−3.1	−3.1
SA (DXA)	13.8 (1.4)	13.5,	14.1	10.8	−16.4
SA-CA (DXA)	−0.2 (1.4)	−0.6,	0.2	−3.2	−2.7

SA, skeletal age; CA, chronological age; CI, confidence interval.

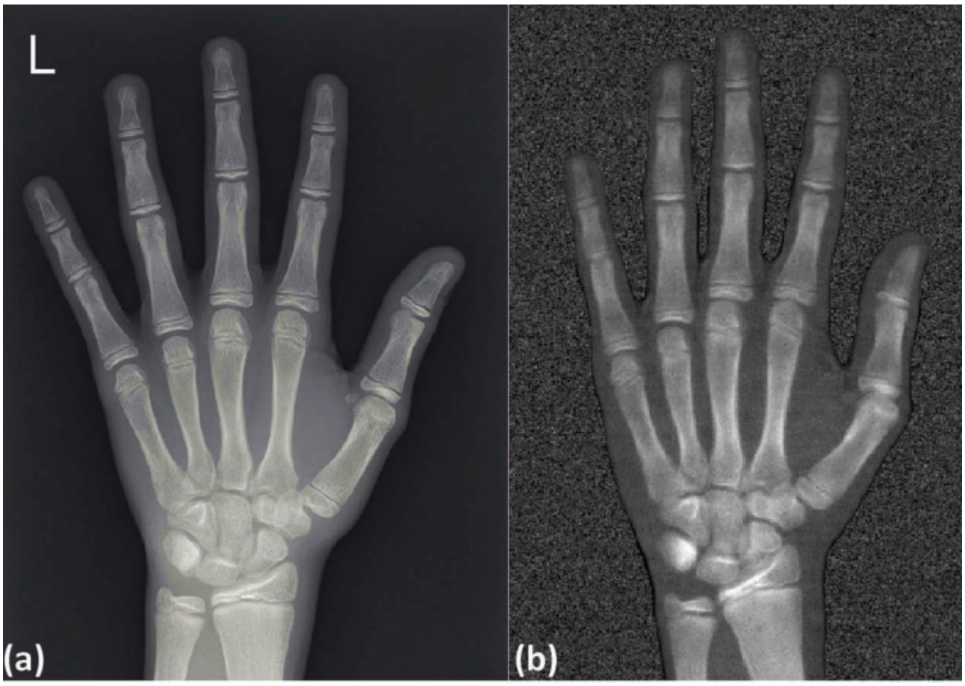

Figure 1. Hand-wrist scan of a national soccer player with chronological age of 14.2 years derived by (a) X-ray and (b) DXA.

radiograph. If the results differed by more than 4 mm for height and 0.4 kg for weight, we started the procedure again. The two measurements for each anthropometric measure were averaged. All hand-wrist X-rays and DXA scans were performed at the Swiss Olympic Medical Centre Magglingen according to hand-wrist guidelines for SA. Examples of an X-ray and DXA digital scan are given in Figure 1.

Procedure

With the participants sitting beside the X-ray device (Stadler SE 4600; Stadler, Littau, Switzerland), the left hand-wrist was placed on a double-layered phosphor cassette without any radial or ulnar deviance. In order to assess all epiphyses, the X-ray tube was focused on the metacarpus. Using this standardization, posterior–anterior radiographs of the left hand-wrist were taken with an X-ray device. A standardized modus of 42-kV tube voltage and 1.60 mA, with a radiation time of 0.78 s, was used. Subsequently, on the same day, each participant underwent a DXA scan (iDXA; General Electric Lunar, Madison, WI) of the left hand-wrist. All scans were performed by one investigator using a standardized modus of 100 kV tube voltage and 0.19 mAs. For scans of the left wrist-hand, the participants were seated parallel to the side of the scanning table. It was ensured that the hand was placed along the longitudinal line of the scan field and that the hand was flat on the device. The beam was focused on the hand-wrist starting 4 cm below the radiocarpal joint in order to obtain an image of all epiphyses, the distal radius, the wrist and all of the hand bones. All X-ray and DXA images were saved without any participant characteristics to blind the assessments. Two experienced and specialized raters (R1, R2) rated all scans in a randomized order. R1 and R2 independently assessed all of the participants' SAs by X-ray and by DXA a first time (t_0). The same procedure was performed a second time (t_1) after 4 weeks to evaluate intrarater and interrater reliability and to minimize recall bias. Skeletal age was assessed by comparing the maturity indicators on each participant's X-ray or DXA scan to the standardized reference pictures according to the TW3 radius, ulna and short bone method (Tanner et al., 2001). SA was assessed with a maximum precision of 0.1 years. X-rays and DXA scans were assessed using optimal brightness and contrast.

Statistical analysis

Intrarater and interrater reliability were analysed using the intraclass correlation coefficient (ICC) with a 95% CI. Additionally, mean SA and difference between the two measurements were reported. For the calculation of interrater reliability, both assessments (t_0 and t_1) of R1 and R2 were analysed separately. Values of less than 0.40 indicated poor reliability, values of 0.40–0.60 indicated fair reliability, values of 0.60–0.75 indicated good reliability and values greater than 0.75 indicated excellent reliability (Rosner, 2011).

To compare the two methods of assessing SA, we used the statistical plotting methods described by Bland and Altman (1999) in order to visualize the differences between the X-ray and DXA scans and their distribution. Beforehand residuals were examined for normality, linearity and homoscedasticity. All assumptions were given. We calculated the mean, the mean difference in years and in percentage, SD of the mean difference, 95% LoA and standard error of estimate (SEE) (Kundel & Polansky, 2003). The difference between the X-ray and DXA assessments was plotted against the mean of both assessments (Figures 3 and 4). In accordance with previous studies, we decided to accept the mean difference between the two techniques to deviate a maximum of 5% from the mean of both techniques and to accept LoA within a range of ±1 year (Heppe et al., 2012; Malina, Coelho, Figueiredo, Carling, et al., 2012).

The players were classified as early, on-time (average) or late maturing on the basis of the difference between SA and CA with each method. On-time was defined as an SA within 1.0 year of CA. Early maturing was defined as an SA older than CA by more than 1.0 year. Late maturing was defined as an SA younger than CA by more than 1.0 year. The classification procedure for early, on-time and late corresponded to previous studies that used SA to classify youth athletes into maturity categories (Malina, Coelho-e-Silva, & Figueiredo, 2012; Sherar et al., 2010). Kappa coefficients (κ) and proportions of agreement were calculated to estimate the agreement between classifications assessed by X-ray and DXA. κ-values >0.80 denoted excellent agreement, values >0.6 and <0.8 denoted good agreement, values >0.4 and <0.6 denoted fair agreement and values <0.4 denoted poor agreement (Kundel & Polansky, 2003). Values are expressed as mean ± SD. Statistical analysis was performed using SPSS version 21 (IBM SPSS, Chicago, IL, USA).The level of significance was set at $P < 0.05$.

Results

Intrarater and interrater reliability

Table 2 shows the intrarater reliability and the interrater reliability of assessments using X-ray and DXA. For R1, the intrarater difference between the two assessments using X-ray was −0.7% (−0.1 years) with a SEE of 0.2 years. Using DXA, the difference was +0.7% (0.1 years) with a SEE of 0.2 years. For R2, there was no intrarater difference between the two assessments for both X-ray and DXA. SEE for X-ray was 0.3 years and 0.4 years for DXA. The intrarater reliabilities of both raters were excellent.

At t_0, the interrater difference between the assessments using X-ray was −0.7% (−0.1 years) with a SEE of 0.5 years. The interrater difference between the assessments using DXA was −2.1% (−0.3 years) with a SEE of 0.4 years. At t_1, the interrater difference between the assessments using X-ray was 0.7% (−0.1 years) with a SEE of 0.5 years and an ICC of 0.90 (0.86–0.93). The interrater difference between the assessments using DXA was −2.1% (−0.3) years, with a SEE of 0.4 years and an ICC of 0.92 (0.88–0.95). The interrater reliabilities were excellent with both assessment techniques at both t_0 and t_1.

Agreement

Figure 2 shows a plot of the SA assessments by X-ray and DXA against the line of identity. Bland–Altman plots (Figures 3 and 4) demonstrated the agreement between assessment methods with the mean difference and LoAs. Differences between X-ray and DXA assessments were normally distributed (D = 0.08; P > 0.05). The mean difference between R1's measurements was −0.2 years (−1.1%), with a SEE of 0.2 years and an ICC of 0.98 (0.97–0.99). The 95% LoAs were ±0.6 (±4.4%). The mean

Table 2. Intrarater and interrater reliabilites for X-ray and DXA assessments.

Reliability	Rater	Method	Mean (SD) (years)	Δ (years)	ICC (95% CI)	Classification
Intrarater	R1	RX1 vs. 2	13.9 (1.1)	−0.1	0.98 (0.97–0.99)	Excellent
	R1	DXA1 vs. 2	14.0 (1.2)	0.1	0.97 (0.96–0.98)	Excellent
	R2	RX1 vs. 2	13.8 (1.4)	0.0	0.98 (0.97–0.99)	Excellent
	R2	DXA1 vs. 2	13.8 (1.4)	0.0	0.95 (0.93–0.97)	Excellent
Interrater[a]	R1 vs. R2	RX	13.9 (1.3)	−0.1	0.92 (0.89–0.95)	Excellent
	R1 vs. R2	DXA	13.9 (1.3)	−0.3	0.93 (0.90–0.96)	Excellent

Rater, R; RX, X-ray; DXA, dual X-ray; Δ, difference; ICC, intraclass correlation coefficients; CI, confidence interval; classification: ICCs < 0.7 were considered non-acceptable, 0.71 < ICCs < 0.79 were acceptable, 0.80 < ICCs < 0.89 were very good and ICCs >0.90 were excellent.

[a]Interrater reliability of first measurement.

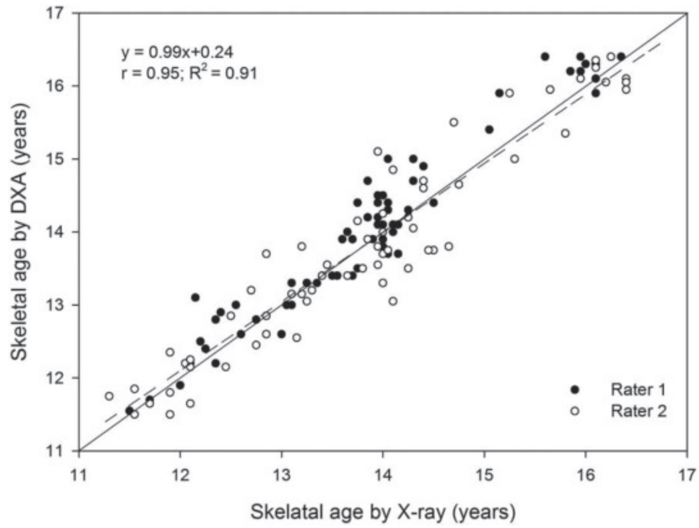

Figure 2. Bone age assessed by X-ray and dual-energy X-ray absorptiometry scan, with the line of identity (solid line), regression line (dashed line) and regression equation.

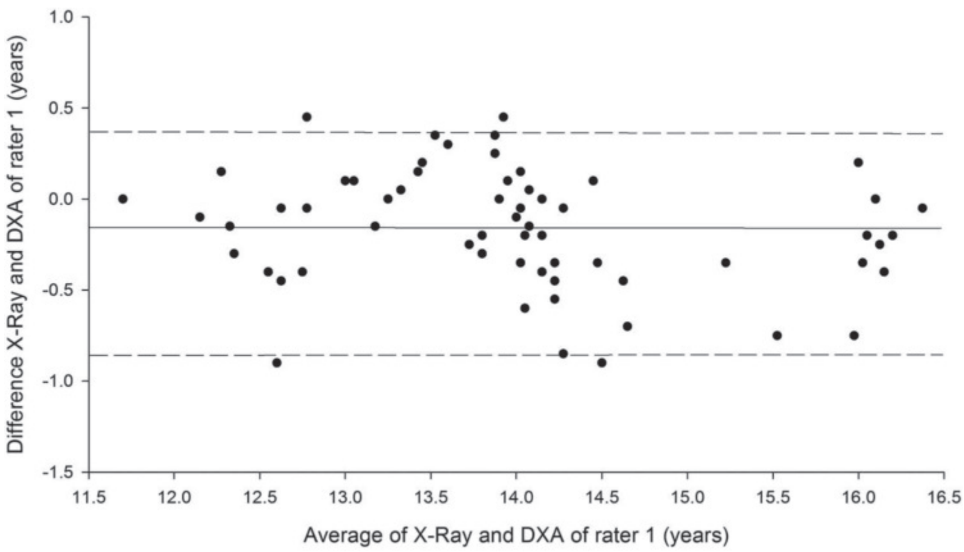

Figure 3. Bland and Altman plot of skeletal age assessments derived by X-ray and dual-energy X-ray absorptiometry of rater 1. The solid line indicates the mean difference, with 95% limits of agreement (dotted lines).

difference between R2's measurements was 0.1 years (0.4%), with a SEE of 0.5 years and an ICC of 0.98 (0.97–0.99). The 95% LoAs were ±0.9 years (6.6%). Moreover, all of the points seem to lie randomly around the line of mean difference, indicating an absence of systematic bias (Bland & Altman, 1999).

R1 classified 10 players as early, 39 as normal and 14 as late using the X-ray data and classified 14 players as early, 38 as normal and 11 as late using the DXA data. Agreement between assessments of R1 showed proportions of agreement of 0.86 (0.77–0.94) and κ = 0.74, representing good agreement between assessments analysed by X-ray and DXA. R2 classified 13 players as early, 30 as normal and 20 as late using the data of X-Ray and classified 14 players as early, 31 as normal and 18 as late using the data of DXA.

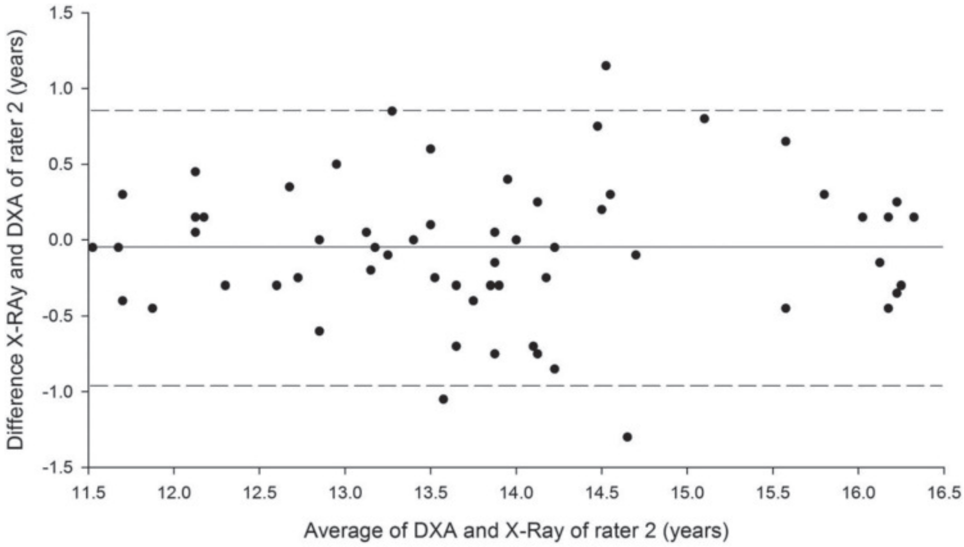

Figure 4. Bland and Altman plot of skeletal age assessments derived by X-ray and dual-energy X-ray absorptiometry of rater 2. The solid line indicates the mean difference, with 95% limits of agreement (dotted lines).

Concordance between assessments of R2 showed proportions of agreement of 0.86 (0.77–0.94) and κ = 0.77, representing good agreement between assessments analysed by X-ray and DXA as well.

Discussion

In this study, we observed excellent intra- and interobserver reliabilities for both X-ray and DXA assessments. The Bland and Altman plots visualized very high agreement between both methods. The mean difference between the methods did not deviate more than 5% from the mean of both methods, which was defined as the maximum acceptable difference prior to the study. Taken together, the results of our study suggest that DXA offered a replicable method for assessing SA and maturity in youth national soccer players.

Intrarater and interrater reliability

Only one study has evaluated intrarater and interrater reliability for bone age assessments using DXA (Heppe et al., 2012). In this study, excellent intrarater reliabilities for DXA assessments were reported (ICCs of 0.99 and 0.98) and were comparable to the results of our study (ICC of 0.97 and 0.98). Heppe et al. (2012) showed excellent interrater reliabilities as well, reporting ICCs of 0.99. In accordance with these results, our study showed excellent interrater reliabilities for X-ray and DXA assessments at both t_0 and t_1. The ICCs of 0.93 and 0.95 in our study were slightly lower, but excellent as well. Several studies have been published on intrarater and interrater variances of SA using X-rays (King et al., 1994; van Rijn, Lequin, & Thodberg, 2009). The results of these studies showed an average intrarater variation of 0.7 years, and an average interrater variation of 0.3 years (CI −0.9 to +1.5 years) using X-ray as the assessment method. Recent studies have reported a standard error of 0.5 years among the readings of a group of five paediatric endocrinologists and a standard error of 0.6 years among seven radiologists (Thodberg & Sävendahl, 2010). Compared to the results, the present study showed lower intrarater variations (SEEs of 0.3 years and 0.4 years) and similar interrater variations (SEEs of 0.4 years and 0.5 years). However, in previous studies, different study designs were used, the experience of the raters varied and the calculations of intrarater and interrater reliability differed. Therefore, it is difficult to compare the studies and draw conclusions from the results.

Agreement

To the best of our knowledge, only one reliable study compared SA assessment performed by X-ray and DXA (Heppe et al., 2012), and its intrarater and interrater reliabilities for DXA and X-ray observations were similar to our study. The mean difference between X-ray and DXA was 0.1 years, 95% LoA (−0.9 to 1.1) and their results were close to the results of our study. Both our study and the study of Heppe et al. (2012) suggested excellent agreement between X-ray and DXA assessments. Moreover, the DXA method has been validated for other measures like bone densitometric measurements in all age groups and the diagnosis of rheumatoid arthritis using hand scans (Fouque-Aubert, Chapurlat, Miossec, & Delmas, 2010; Gordon et al., 2008). It thus has been proposed that DXA seems to be an alternative for the assessment of SA in paediatric hospital-based patients.

The grouping in maturity categories (e.g. late, normal and early) is an important aspect for coaches to apply the results of maturity assessments in selection and training procedures in a practicable way (Malina et al., 2004; Sherar et al., 2010). Nevertheless, this grouping leads to a loss of information. Even small errors in DXA assessments which might occur due to the worse definition of DXA scans compared to X-ray could lead to small misinterpretations of SA and a different final categorization. Therefore, there might be a tendency to overestimate SA with DXA, because very thin gaps that can be seen on the X-ray film, but not clear on the DXA could be interpreted as a beginning of epiphyseal fusion. It has also to be mentioned that SA assessments in general are associated with practical and ethical problems (radiation exposure to healthy children and adolescents), high costs (material, transport and medical staff), radiation exposure and specific expertise for evaluation (Sherar et al., 2010). Therefore, SA assessments in sport can only be performed with a limited number of high-level players. However, in soccer practice, SA assessments are already used in football institutes and academies to classify the maturity status of players compared to their CA (Carling, le Gall, Reilly, & Williams, 2008; Malina et al., 2004).

Limitations and strength of the study

In this study, male participants of a highly selective elite sport setting were examined. Additionally, the sample size of 63 players is quite small for a validation study. Therefore, the results cannot be transferred to basic populations and need further confirmation specifically for females. Furthermore, DXA devices are expensive in procurement and therefore not easily available for common soccer academies. However, a strength of our study is that the results are based on healthy high-level soccer players. The participants were in the age range showing the highest variations of maturity and where the consideration of maturity characteristics in the selection process is very relevant and important (Vaeyens et al., 2008). We expect our results to be valid for other populations in elite sports settings; however, this topic needs further study. Additionally, with the use of modern DXA scans, it might be possible to detect an overlap of the palmar or dorsal surfaces of epiphysis. Therefore, future studies may include information of agreement bone per bone. Besides the advantages of the DXA technique, there is the disadvantage that the scanning procedure is more time consuming. The DXA scan lasts approximately 60 s (depending on the size of the wrist-hand), which increases the probability of movement artefacts. By contrast, an X-ray examination takes less than 1 s. Nonetheless, in our study, no movement artefacts occurred and maturity classifications showed good agreement with classifications made with X-ray.

Conclusion

Results using the DXA method are similar in accuracy to those obtained by X-rays. Therefore, DXA seems to be an acceptable alternative method to X-ray for assessing SA and classifying maturity in children and youth high-level athletes. A disadvantage of the use of the DXA technique is a longer duration of the scanning procedure and high costs. The major advantages of the DXA method compared with the classical X-ray method are a 10-fold lower exposure to radiation and lower qualification requirements for the person who performs the scan. In sports, the implementation of maturity classifications could hold significant implications for performance assessment, evaluation and selection during athlete development.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Assessment of skeletal age on the basis of DXA-derived hand scans in elite youth soccer

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ABSTRACT
Physical performance is highly dependent on maturity. Therefore, consideration of maturity is recommended in the talent identification process. To date, skeletal age (SA) is assessed using X-ray scans. However, X-rays are associated with a 10-fold higher radiation compared to dual-energy X-ray absorptiometry (DXA). The aim of the study was to validate SA assessments in male soccer players with the DXA technique. Paired X-ray and DXA scans of the left hand of 63 Swiss U-15 national soccer players were performed. SA assessments were performed twice by two blinded raters using Tanner and Whitehouse' reference technique. Intrarater and interrater reliability as well as agreement between both techniques were tested. Intrarater and interrater reliabilities were excellent. Bland-Altman plots showed that SA assessments between X-ray and DXA differed by −0.2 years and 95% limits of agreement were ±0.6 years. Therefore, DXA offered a replicable method for assessing SA and maturity in youth soccer players.

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Bone age; maturity classification; talent identification; young athletes

Introduction

In youth sports, grouping by chronological age (CA) is the customary procedure for separating young athletes into age-related training and competition groups. However, individuals in the same age category can vary by as much as 4 years in biological age (Malina, Bouchard, & Bar-Or, 2004). Variations in performance like speed and endurance are highly dependent on biological age especially during the transition into and during male adolescence (Malina et al., 2004; Malina, Coelho-e-Silva, & Figueiredo, 2012). Therefore, elite youth athletes in several sports tend to be advanced in biological maturity during late childhood and adolescence for female and male athletes (Gil et al., 2014; Idrizovic, 2014; Malina, Coelho-e-Silva, & Figueiredo, 2012; Ostojic et al., 2014; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). Specifically, data in soccer suggests that a disproportionately large amount of late maturing players is excluded and average and early maturing players are favoured. As a consequence, maturation characteristics should be considered in any talent identification or development programme to provide fair selection and to invest available resources appropriately (Vaeyens et al., 2008).

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Amongst different methods, skeletal age (SA) is said to be the best indicator of biological maturity and is more meaningful than CA for the evaluation of the performance of young athletes (Malina et al., 2004; Tanner, Healy, Goldstein, & Cameron, 2001). The classical method for assessing SA is based on the comparison of actual bone characteristics and maturity indicators in hand-wrist X-rays with reference images from Greulich and Pyle (Greulich & Pyle, 1959), Tanner and Whitehouse (Tanner et al., 2001) or the Fels method (Roche, Chumlea, & Thissen, 1988). The Tanner–Whitehouse 3 method is commonly used outside of the United States and more applicable to European athletes (Gordon et al., 2008).

In modern technology, the assessment of SA by X-ray entails a contained risk. A hand-wrist radiography requires 1 µSv of radiation, which is the equivalent of less than 4 hours of natural background radiation or 10 minutes on an intercontinental flight (Mettler, Huda, Yoshizumi, & Mahesh, 2008). Nevertheless, to avoid possible detrimental effects of cumulative radiation exposure, children and adolescents should only be exposed to a minimal amount of radiation (Hall & Brenner, 2008; Radiological & America, 2012). Additionally, the International Atomic Energy Agency (IAEA) of which all European countries are members demands that the dose of radiation has to be minimised in every use of radiological devices (International Atomic Energy Agency [IAEA], 2006). Consequently, reducing the radiation dose when assessing SA is an important issue, and methods involving less radiation are generally preferable, particularly in childhood and adolescence.

Dual-energy X-ray absorptiometry (DXA) is the most commonly used bone densitometric technique for children worldwide (Gordon et al., 2008) and the use of DXA is common for body composition measurements in elite sport settings (Guppy & Wallace, 2012). Compared to X-ray, computerized axial tomography and magnetic resonance imaging, the main advantages of the DXA method are a high safety and significantly lower exposure to radiation (Coelho e Silva et al., 2013; Gordon et al., 2008). DXA-derived hand-wrist scans recently have become available and could be an approach to adjust for factors related to growth and puberty (Heppe et al., 2012; Płudowski, Lebiedowski, & Lorenc, 2004). Evaluating SA via hand-wrist radiographs using DXA produces one-tenth of the effective radiation dose (0.1 µSv) compared to X-rays (1 µSv) (Gordon et al., 2008; International Atomic Energy Agency [IAEA], 2006). In Switzerland, X-ray and DXA scans have to be supervised by a medical doctor. However, an additional advantage of the DXA technique is that every person can perform the scan who completed a 1-day qualification course. In contrast, X-ray scans can only be performed by medical staff who are qualified to perform the X-ray technique.

To the best of our knowledge, only two studies have investigated the agreement between DXA and X-ray hand-wrist imaging as methods for assessing SA (Heppe et al., 2012; Płudowski et al., 2004). The first study was performed in a paediatric population of 24 girls (age range: 5–17 years) and 26 boys (age range: 5–20 years). The results suggested that SA assessments using DXA are similar to those performed by X-ray (Płudowski et al., 2004). However, the statistical analyses employed in that study – *t*-tests and correlation coefficients – are questionable (Kottner et al., 2011). The second study of Heppe et al. (2012) showed a mean difference between the X-ray and DXA assessments of 0.11 years, with a 95% limit of agreement (LoA) (–0.85 to 1.05). The authors concluded that DXA seemed to be an alternative for the assessment of SA in paediatric hospital-based patients, and that the results should be validated in different populations. The results of Heppe et al. (2012) are not transferable to elite sport settings, because all participants in this study had various medical indications. Diseased persons significantly differ to a normal population and even more to an elite sport cohort (Malina et al., 2004; Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010), which justifies a separate analysis with a sample of youth national athletes.

To date, no study using appropriate statistical methods has investigated the agreement between DXA and X-ray hand-wrist imaging as a method for assessing SA in healthy participants. In addition, no studies have been conducted in sport settings, where the assessment of SA and the classification of maturity play a very important role (Malina, Coelho, Figueiredo, Carling, & Beunen, 2012; Tanner et al., 2001). Given the relevance of using DXA scans due to lower qualification requirements for staff members, significantly lower radiation emissions and legal requirements, this study first aimed to evaluate the reliability of SA assessments using DXA, which is an important prerequisite for validity analysis. Secondly, it sought to validate DXA as a method for assessing SA in order to classify the maturity of soccer players under 15 years of age.

Methods

Sample

Participants were recruited among all male soccer players who were invited to the national selection day of the Swiss Soccer Association. The players were selected from local clubs in 13 regional squads (n = 226). From the regional squads, 72 players were selected to participate during the national selection day. Selections on all levels were based on coaches' evaluation of players' technical skills, game intelligence, personality and speed (Tschopp, Biedert, Seiler, Hasler, & Marti, 2003). All 72 players were offered participation in the study by one of the authors, the leader of the project. Sixty-five parents and participants returned written informed consent. The participants were informed that participation was voluntary and that they could withdraw from the study at any time. After SA assessment, two of 65 players were excluded from the study because they were assessed as skeletally mature. The final cross-sectional sample included 63 (87.5%) participants, aged 14.0 ± 0.3 years. All of the participants were in good health and free of acute or known chronic diseases at the time of the study. The study was approved by the responsible research ethics committees (Kantonale Ethikkommission Bern, Switzerland, No. 022/13) and in line with the Declaration of Helsinki.

Measures

Weight, height, CA and SA were measured. Descriptive statistics of participants are shown in Table 1. Height was measured with a fixed stadiometer (Seca 217; Seca, Hamburg, Germany), and weight was measured with calibrated scales (Tanita WB-110 MA; Tanita, Tokyo, Japan). Weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively. Players wore shorts and a T-shirt, and shoes were removed. Two measurements were taken for each anthropometric variable on the same day as the

Table 1. Subject characteristics.

Characteristic	Mean (SD)	95% CI		Range	
Height	164.9 (8.4)	162.8,	167.0	150.1	−184.4
Weight	53.0 (8.7)	50.8,	55.2	37.8	−73.4
CA	14.0 (0.3)	13.9,	14.1	13.3	−14.3
Observer 1					
SA (X-ray)	13.9 (1.1)	13.5,	14.2	11.7	−16.4
SA-CA (X-ray)	0.0 (1.1)	−0.3,	0.2	−2.3	−2.6
SA (DXA)	14.0 (1.2)	13.7,	14.3	11.7	−16.4
SA-CA (DXA)	0.1 (1.1)	−0.2,	0.4	‘2.3	−2.8
Observer 2					
SA (X-ray)	13.8 (1.4)	13.5,	14.1	10.9	−16.4
SA-CA (X-ray)	−0.1 (1.4)	−0.5,	0.2	−3.1	−3.1
SA (DXA)	13.8 (1.4)	13.5,	14.1	10.8	−16.4
SA-CA (DXA)	−0.2 (1.4)	−0.6,	0.2	−3.2	−2.7

SA, skeletal age; CA, chronological age; CI, confidence interval.

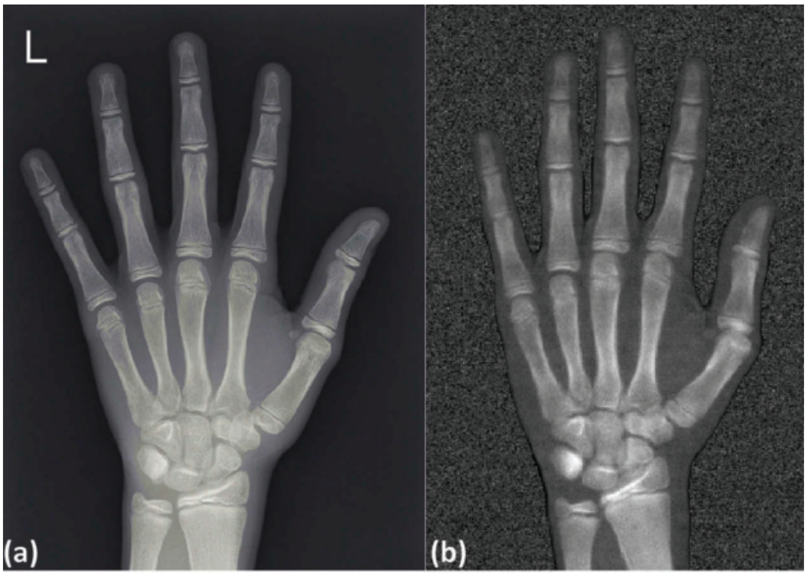

Figure 1. Hand-wrist scan of a national soccer player with chronological age of 14.2 years derived by (a) X-ray and (b) DXA.

radiograph. If the results differed by more than 4 mm for height and 0.4 kg for weight, we started the procedure again. The two measurements for each anthropometric measure were averaged. All hand-wrist X-rays and DXA scans were performed at the Swiss Olympic Medical Centre Magglingen according to hand-wrist guidelines for SA. Examples of an X-ray and DXA digital scan are given in Figure 1.

Procedure

With the participants sitting beside the X-ray device (Stadler SE 4600; Stadler, Littau, Switzerland), the left hand-wrist was placed on a double-layered phosphor cassette without any radial or ulnar deviance. In order to assess all epiphyses, the X-ray tube was focused on the metacarpus. Using this standardization, posterior–anterior radiographs of the left hand-wrist were taken with an X-ray device. A standardized modus of 42-kV tube voltage and 1.60 mA, with a radiation time of 0.78 s, was used. Subsequently, on the same day, each participant underwent a DXA scan (iDXA; General Electric Lunar, Madison, WI) of the left hand-wrist. All scans were performed by one investigator using a standardized modus of 100 kV tube voltage and 0.19 mAs. For scans of the left wrist-hand, the participants were seated parallel to the side of the scanning table. It was ensured that the hand was placed along the longitudinal line of the scan field and that the hand was flat on the device. The beam was focused on the hand-wrist starting 4 cm below the radiocarpal joint in order to obtain an image of all epiphyses, the distal radius, the wrist and all of the hand bones. All X-ray and DXA images were saved without any participant characteristics to blind the assessments. Two experienced and specialized raters (R1, R2) rated all scans in a randomized order. R1 and R2 independently assessed all of the participants' SAs by X-ray and by DXA a first time (t_0). The same procedure was performed a second time (t_1) after 4 weeks to evaluate intrarater and interrater reliability and to minimize recall bias. Skeletal age was assessed by comparing the maturity indicators on each participant's X-ray or DXA scan to the standardized reference pictures according to the TW3 radius, ulna and short bone method (Tanner et al., 2001). SA was assessed with a maximum precision of 0.1 years. X-rays and DXA scans were assessed using optimal brightness and contrast.

Statistical analysis

Intrarater and interrater reliability were analysed using the intraclass correlation coefficient (ICC) with a 95% CI. Additionally, mean SA and difference between the two measurements were reported. For the calculation of interrater reliability, both assessments (t_0 and t_1) of R1 and R2 were analysed separately. Values of less than 0.40 indicated poor reliability, values of 0.40–0.60 indicated fair reliability, values of 0.60–0.75 indicated good reliability and values greater than 0.75 indicated excellent reliability (Rosner, 2011).

To compare the two methods of assessing SA, we used the statistical plotting methods described by Bland and Altman (1999) in order to visualize the differences between the X-ray and DXA scans and their distribution. Beforehand residuals were examined for normality, linearity and homoscedasticity. All assumptions were given. We calculated the mean, the mean difference in years and in percentage, SD of the mean difference, 95% LoA and standard error of estimate (SEE) (Kundel & Polansky, 2003). The difference between the X-ray and DXA assessments was plotted against the mean of both assessments (Figures 3 and 4). In accordance with previous studies, we decided to accept the mean difference between the two techniques to deviate a maximum of 5% from the mean of both techniques and to accept LoA within a range of ±1 year (Heppe et al., 2012; Malina, Coelho, Figueiredo, Carling, et al., 2012).

The players were classified as early, on-time (average) or late maturing on the basis of the difference between SA and CA with each method. On-time was defined as an SA within 1.0 year of CA. Early maturing was defined as an SA older than CA by more than 1.0 year. Late maturing was defined as an SA younger than CA by more than 1.0 year. The classification procedure for early, on-time and late corresponded to previous studies that used SA to classify youth athletes into maturity categories (Malina, Coelho-e-Silva, & Figueiredo, 2012; Sherar et al., 2010). Kappa coefficients (κ) and proportions of agreement were calculated to estimate the agreement between classifications assessed by X-ray and DXA. κ-values >0.80 denoted excellent agreement, values >0.6 and <0.8 denoted good agreement, values >0.4 and <0.6 denoted fair agreement and values <0.4 denoted poor agreement (Kundel & Polansky, 2003). Values are expressed as mean ± SD. Statistical analysis was performed using SPSS version 21 (IBM SPSS, Chicago, IL, USA).The level of significance was set at $P < 0.05$.

Results

Intrarater and interrater reliability

Table 2 shows the intrarater reliability and the interrater reliability of assessments using X-ray and DXA. For R1, the intrarater difference between the two assessments using X-ray was −0.7% (−0.1 years) with a SEE of 0.2 years. Using DXA, the difference was +0.7% (0.1 years) with a SEE of 0.2 years. For R2, there was no intrarater difference between the two assessments for both X-ray and DXA. SEE for X-ray was 0.3 years and 0.4 years for DXA. The intrarater reliabilities of both raters were excellent.

At t_0, the interrater difference between the assessments using X-ray was −0.7% (−0.1 years) with a SEE of 0.5 years. The interrater difference between the assessments using DXA was −2.1% (−0.3 years) with a SEE of 0.4 years. At t_1, the interrater difference between the assessments using X-ray was 0.7% (−0.1 years) with a SEE of 0.5 years and an ICC of 0.90 (0.86–0.93). The interrater difference between the assessments using DXA was −2.1% (−0.3) years, with a SEE of 0.4 years and an ICC of 0.92 (0.88–0.95). The interrater reliabilities were excellent with both assessment techniques at both t_0 and t_1.

Agreement

Figure 2 shows a plot of the SA assessments by X-ray and DXA against the line of identity. Bland–Altman plots (Figures 3 and 4) demonstrated the agreement between assessment methods with the mean difference and LoAs. Differences between X-ray and DXA assessments were normally distributed ($D = 0.08$; $P > 0.05$). The mean difference between R1's measurements was −0.2 years (−1.1%), with a SEE of 0.2 years and an ICC of 0.98 (0.97–0.99). The 95% LoAs were ±0.6 (±4.4%). The mean

Table 2. Intrarater and interrater reliabilites for X-ray and DXA assessments.

Reliability	Rater	Method	Mean (SD) (years)	Δ (years)	ICC (95% CI)	Classification
Intrarater	R1	RX1 vs. 2	13.9 (1.1)	−0.1	0.98 (0.97–0.99)	Excellent
	R1	DXA1 vs. 2	14.0 (1.2)	0.1	0.97 (0.96–0.98)	Excellent
	R2	RX1 vs. 2	13.8 (1.4)	0.0	0.98 (0.97–0.99)	Excellent
	R2	DXA1 vs. 2	13.8 (1.4)	0.0	0.95 (0.93–0.97)	Excellent
Interrater[a]	R1 vs. R2	RX	13.9 (1.3)	−0.1	0.92 (0.89–0.95)	Excellent
	R1 vs. R2	DXA	13.9 (1.3)	−0.3	0.93 (0.90–0.96)	Excellent

Rater, R; RX, X-ray; DXA, dual X-ray; Δ, difference; ICC, intraclass correlation coefficients; CI, confidence interval; classification: ICCs < 0.7 were considered non-acceptable, 0.71 < ICCs < 0.79 were acceptable, 0.80 < ICCs < 0.89 were very good and ICCs >0.90 were excellent.

[a]Interrater reliability of first measurement.

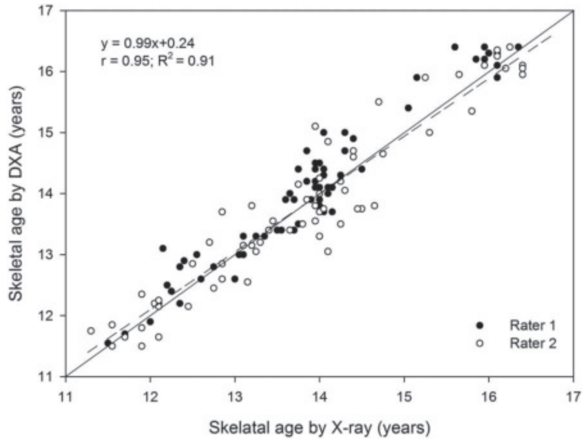

Figure 2. Bone age assessed by X-ray and dual-energy X-ray absorptiometry scan, with the line of identity (solid line), regression line (dashed line) and regression equation.

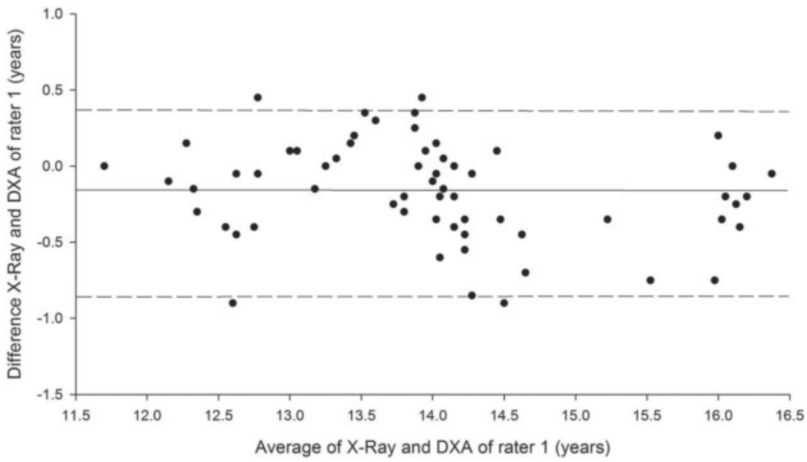

Figure 3. Bland and Altman plot of skeletal age assessments derived by X-ray and dual-energy X-ray absorptiometry of rater 1. The solid line indicates the mean difference, with 95% limits of agreement (dotted lines).

difference between R2's measurements was 0.1 years (0.4%), with a SEE of 0.5 years and an ICC of 0.98 (0.97–0.99). The 95% LoAs were ±0.9 years (6.6%). Moreover, all of the points seem to lie randomly around the line of mean difference, indicating an absence of systematic bias (Bland & Altman, 1999).

R1 classified 10 players as early, 39 as normal and 14 as late using the X-ray data and classified 14 players as early, 38 as normal and 11 as late using the DXA data. Agreement between assessments of R1 showed proportions of agreement of 0.86 (0.77–0.94) and κ = 0.74, representing good agreement between assessments analysed by X-ray and DXA. R2 classified 13 players as early, 30 as normal and 20 as late using the data of X-Ray and classified 14 players as early, 31 as normal and 18 as late using the data of DXA.

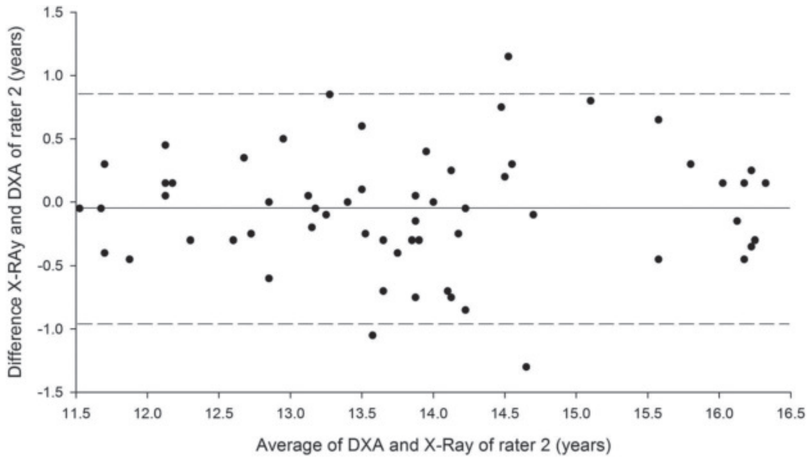

Figure 4. Bland and Altman plot of skeletal age assessments derived by X-ray and dual-energy X-ray absorptiometry of rater 2. The solid line indicates the mean difference, with 95% limits of agreement (dotted lines).

Concordance between assessments of R2 showed proportions of agreement of 0.86 (0.77–0.94) and κ = 0.77, representing good agreement between assessments analysed by X-ray and DXA as well.

Discussion

In this study, we observed excellent intra- and interobserver reliabilities for both X-ray and DXA assessments. The Bland and Altman plots visualized very high agreement between both methods. The mean difference between the methods did not deviate more than 5% from the mean of both methods, which was defined as the maximum acceptable difference prior to the study. Taken together, the results of our study suggest that DXA offered a replicable method for assessing SA and maturity in youth national soccer players.

Intrarater and interrater reliability

Only one study has evaluated intrarater and interrater reliability for bone age assessments using DXA (Heppe et al., 2012). In this study, excellent intrarater reliabilities for DXA assessments were reported (ICCs of 0.99 and 0.98) and were comparable to the results of our study (ICC of 0.97 and 0.98). Heppe et al. (2012) showed excellent interrater reliabilities as well, reporting ICCs of 0.99. In accordance with these results, our study showed excellent interrater reliabilities for X-ray and DXA assessments at both t_0 and t_1. The ICCs of 0.93 and 0.95 in our study were slightly lower, but excellent as well. Several studies have been published on intrarater and interrater variances of SA using X-rays (King et al., 1994; van Rijn, Lequin, & Thodberg, 2009). The results of these studies showed an average intrarater variation of 0.7 years, and an average interrater variation of 0.3 years (CI −0.9 to +1.5 years) using X-ray as the assessment method. Recent studies have reported a standard error of 0.5 years among the readings of a group of five paediatric endocrinologists and a standard error of 0.6 years among seven radiologists (Thodberg & Sävendahl, 2010). Compared to the results, the present study showed lower intrarater variations (SEEs of 0.3 years and 0.4 years) and similar interrater variations (SEEs of 0.4 years and 0.5 years). However, in previous studies, different study designs were used, the experience of the raters varied and the calculations of intrarater and interrater reliability differed. Therefore, it is difficult to compare the studies and draw conclusions from the results.

Agreement

To the best of our knowledge, only one reliable study compared SA assessment performed by X-ray and DXA (Heppe et al., 2012), and its intrarater and interrater reliabilities for DXA and X-ray observations were similar to our study. The mean difference between X-ray and DXA was 0.1 years, 95% LoA (−0.9 to 1.1) and their results were close to the results of our study. Both our study and the study of Heppe et al. (2012) suggested excellent agreement between X-ray and DXA assessments. Moreover, the DXA method has been validated for other measures like bone densitometric measurements in all age groups and the diagnosis of rheumatoid arthritis using hand scans (Fouque-Aubert, Chapurlat, Miossec, & Delmas, 2010; Gordon et al., 2008). It thus has been proposed that DXA seems to be an alternative for the assessment of SA in paediatric hospital-based patients.

The grouping in maturity categories (e.g. late, normal and early) is an important aspect for coaches to apply the results of maturity assessments in selection and training procedures in a practicable way (Malina et al., 2004; Sherar et al., 2010). Nevertheless, this grouping leads to a loss of information. Even small errors in DXA assessments which might occur due to the worse definition of DXA scans compared to X-ray could lead to small misinterpretations of SA and a different final categorization. Therefore, there might be a tendency to overestimate SA with DXA, because very thin gaps that can be seen on the X-ray film, but not clear on the DXA could be interpreted as a beginning of epiphyseal fusion. It has also to be mentioned that SA assessments in general are associated with practical and ethical problems (radiation exposure to healthy children and adolescents), high costs (material, transport and medical staff), radiation exposure and specific expertise for evaluation (Sherar et al., 2010). Therefore, SA assessments in sport can only be performed with a limited number of high-level players. However, in soccer practice, SA assessments are already used in football institutes and academies to classify the maturity status of players compared to their CA (Carling, le Gall, Reilly, & Williams, 2008; Malina et al., 2004).

Limitations and strength of the study

In this study, male participants of a highly selective elite sport setting were examined. Additionally, the sample size of 63 players is quite small for a validation study. Therefore, the results cannot be transferred to basic populations and need further confirmation specifically for females. Furthermore, DXA devices are expensive in procurement and therefore not easily available for common soccer academies. However, a strength of our study is that the results are based on healthy high-level soccer players. The participants were in the age range showing the highest variations of maturity and where the consideration of maturity characteristics in the selection process is very relevant and important (Vaeyens et al., 2008). We expect our results to be valid for other populations in elite sports settings; however, this topic needs further study. Additionally, with the use of modern DXA scans, it might be possible to detect an overlap of the palmar or dorsal surfaces of epiphysis. Therefore, future studies may include information of agreement bone per bone. Besides the advantages of the DXA technique, there is the disadvantage that the scanning procedure is more time consuming. The DXA scan lasts approximately 60 s (depending on the size of the wrist-hand), which increases the probability of movement artefacts. By contrast, an X-ray examination takes less than 1 s. Nonetheless, in our study, no movement artefacts occurred and maturity classifications showed good agreement with classifications made with X-ray.

Conclusion

Results using the DXA method are similar in accuracy to those obtained by X-rays. Therefore, DXA seems to be an acceptable alternative method to X-ray for assessing SA and classifying maturity in children and youth high-level athletes. A disadvantage of the use of the DXA technique is a longer duration of the scanning procedure and high costs. The major advantages of the DXA method compared with the classical X-ray method are a 10-fold lower exposure to radiation and lower qualification requirements for the person who performs the scan. In sports, the implementation of maturity classifications could hold significant implications for performance assessment, evaluation and selection during athlete development.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Coaches' eye as a valid method to assess biological maturation in youth elite soccer

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Abstract: Consideration of maturity is recommended in the talent identification and development process. Skeletal age (SA), prediction of age of peak height velocity (APHV) and an estimation of biological maturation by coaches' eye of 121 soccer players were compared. The SA of soccer players was 13.9 ± 1.1 years, and did not differ significantly from chronological age (CA). Agreement between the SA-CA classifications and APHV was 65.5%. Spearman rank-order correlation (r_s) between maturity classifications was moderate, kappa (k) was 0.25. Agreement between SA-CA classifications and coaches' eye was 73.9%. The r_s between maturity classifications was strong, k was 0.48, which was better than the widely used APHV assessment. Therefore, estimations of experienced coaches seem to be an acceptable alternative method for classifying maturity in youth athletes.

Keywords:
skeletal age, age at peak height velocity, coach estimation, maturation, young athletes

Introduction

Talent identification (TID) in soccer is a necessary process in talent development (TD) programs, but it requires a considerable understanding of the game demands as well as knowledge of human growth and maturation. Game performance depends on multiple factors, including physical, technical, tactical, mental and physiological elements (Williams & Reilly, 2000). Many of these factors, including height, speed, endurance and cognition, are highly dependent on biological age (BA) (Malina, Bouchard, & Bar-Or, 2004; Malina, Coelho e Silva, & Figueiredo, 2012). Therefore, elite youth athletes in a variety of sports such as soccer and ice hockey tend to have advanced biological maturity during late childhood and adolescence (Malina et al., 2012; Unnithan, White, Georgiou, Iga, & Drust, 2012; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). Grouping by chronological age (CA) is the customary procedure for separating young players into age-related training and competition groups. However, the biological age (BA) of individuals in the same age category can vary by as much as four years (Malina et al., 2004). In boys, this trend is mostly observed between 13 and 16 years of age when the differences in maturity status are amplified by the timing and tempo of adolescent growth spurts (Figueiredo, Goncalves, Coelho e Silva, & Malina, 2009a; Hirose, 2009). Therefore, maturity may play a crucial role in the coaches' view of an athlete's potential and the chance of a young player achieving senior elite status. Specifically, data for soccer suggests that a disproportionately large number of late maturing players are excluded, and coaches favour average and early maturing players (Figueiredo et al., 2009a). Till et al. (2014) showed that the process of favourably selecting relatively older and early-maturing athletes within competitive youth sports may be counterproductive in the long-term. The current process may exclude skilled individuals from attaining the elite level due to their delayed maturity in comparison to early maturing peers. Consequently, maturation characteristics should be considered in any TID and TD program to provide fair selection and to invest available resources appropriately (Unnithan et al., 2012; Vaeyens et al., 2008). For example, the widely-used long-term athlete development

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model recommends the identification of early, on-time and late maturation stages (Balyi & Hamilton, 2004). Therefore, the biological maturity assessment of youth athletes is an important aspect of TID in soccer as well as in other sports.

Amongst different methods, skeletal age (SA) is said to be the best indicator of BA, and could be a more meaningful way to evaluate the performance of young athletes than CA (Malina et al., 2004; Tanner, Healy, Goldstein, & Cameron, 2001). The classical method for assessing SA is based on the comparison of actual bone characteristics and maturity indicators of hand-wrist X-rays using reference images from Greulich and Pyle (Greulich & Pyle, 1959), Tanner et al. (2001) or the FELS method (Roche, Chumlea, & Thissen, 1988).

However, SA assessments are associated with practical and ethical problems (radiation exposure to healthy children and adolescents), high costs (medical staff, material) and specific expertise for evaluation (Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010). Exposure to radiation is the main problem with using conventional X-rays in TID (Hall, 2009). In modern technology, the assessment of SA by hand-wrist requires less than 1 μSv of radiation via conventional radiography (Mettler Jr, Huda, Yoshizumi, & Mahesh, 2008; Romann & Fuchslocher, 2016); 1 μSv of radiation is the equivalent of less than four hours of natural background radiation or 10 minutes on an intercontinental flight (Mettler Jr et al., 2008). Nevertheless, to avoid the possible detrimental effects of cumulative radiation exposure, children and adolescents should only be exposed to a minimal amount of radiation (Hall, 2009; Radiological Society of North America, 2017). Consequently, avoiding any radiation when assessing maturation is an important issue, and methods involving less radiation or none at all are preferable, particularly in childhood and adolescence.

Secondary sex characteristics and somatic measurements are the most common methods used to categorise maturity that do not use radiation (Mirwald, 2002; Tanner et al., 2001). The indicators considered when assessing maturity status by secondary sex characteristics are generally the development of breasts (in girls), genitals (in boys) and pubic hair (boys and girls). The rating of secondary sex characteristics as a measure of maturity status is only useful during puberty; hence, it does not cover the full spectrum of growth. The protocols are often viewed as an invasion of personal privacy. In addition, the validity of the results, financial resources and access to a physician may be factors that limit the use of this method in a practical setting (Malina, Coelho, Figueiredo, Carling, & Beunen, 2012).

A common maturity-assessment technique used in the literature is the determination of years based on peak height velocity (PHV). PHV is an indicator of somatic maturity, and it reflects the age at the maximum growth rate in stature during adolescence (age of PHV [APHV]). Mirwald et al. (2002) developed an equation using regression analysis to predict APHV, and they reported that APHV could be predicted ±1 year. Current height, weight, age, sitting height, estimated leg length (height minus sitting height) and interaction terms are used to estimate the time before or after PHV, and, in turn, to predict APHV (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). This approach has also been found to have good reproducibility and good agreement with maturity status as calculated from hand-wrist X-rays (Matsudo & Matsudo, 1994; Mirwald, 2002). However, Malina et al. (2012) have demonstrated that a relatively poor correlation exists between maturity status calculated via the FELS method and Mirwald's equation, and they suggested that Mirwald's equation was not sensitive enough to classify players into maturity groups in comparison to X-ray results.

Therefore, more practicable and valid methods are warranted. Many soccer clubs and soccer federations select their players using the subjective assessments of scouts and coaches (Reilly, Williams, Nevill, & Franks, 2000). The scout or coach-driven TID methods are based on multifactorial intuitive knowledge, which includes socially-constructed images of the perfect player. Generally judgements can be categorised as either intuitive or deliberate (Kruglanski & Gigerenzer, 2011). Deliberative judgments have been assumed to be analytical, rational, rule-based, conscious, and slow. Intuitive judgments have been assumed to be associative, unconscious, heuristic, error-prone and quick (Kruglanski & Gigerenzer, 2011). The accuracy of both deliberate and intuitive judgements depends on the ecological rationality of the rule. Accordingly, more complex rules are not necessarily more accurate than simpler rules and statistical rules are not necessarily more accurate than heuristic rules. It has been found that relying on one good reason often results in more accurate predictions compared to complex approaches (Gigerenzer & Brighton, 2009). These results put heuristics on par with standard statistical models of rational cognition. Judgements that are intuitive (subjective estimations) and simple, can be more accurate than cognitive strategies that have more information (Evans, 2008; Kruglanski & Gigerenzer, 2011).

In the talent development process, aspects of the biological maturation play a crucial role. SA and anthropometric measurements, such as APHV and coaches' eye, evaluate different but related aspects of biological maturation during male adolescence. Given the relevance of maturity assessments in TD and TID, this study aimed to evaluate the agreement between classifications based on skeletal maturity, anthropometric measurements (e.g. APHV) and categorisations by coaches' eye.

Method

Sample

Participants were recruited from all the male soccer players who were invited to the under-15 national selection day for the Swiss Soccer Association during the 2012-2013 and 2013-2014 seasons. The players were selected from local clubs representing 13 regional squads (n = 226). From the regional squads, 144 players were selected to participate during the national selection days. Selection on all levels was based on the coaches' evaluation of the players' technical skills, game intelligence, personality and speed (Tschopp, Biedert, Seiler, Hasler, & Marti, 2003). The leader of the project asked all 144 players if they would like to participate in the study. Of those, 121 participants and their parents provided written informed consent. The participants were informed that participation was voluntary and that they could withdraw from the study at any time. An SA is not assigned to individuals who are skeletally mature, and mature individuals are usually excluded from SA studies (Malina et al., 2012; Roche et al., 1988). Therefore, after the SA assessment, two players were excluded from the study because they were assessed as being skeletally mature. The final cross-sectional sample included 119 (82.6%) participants. At the time of the study, all the participants were in good health and free of acute or known chronic diseases. The study was approved by the local research ethics committee and was in line with the Declaration of Helsinki.

Measurements

Weight, height, CA and SA were measured. Descriptive statistics of the participants are shown in Table 1. Height was measured with a fixed stadiometer (Seca 217; Seca, Hamburg, Germany), and weight was measured with calibrated scales (Tanita WB-110 MA; Tanita, Tokyo, Japan). Weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively. Players wore shorts and a t-shirt, and they removed their shoes. Two measurements were taken for each anthropometric variable on the same day as the radiograph. If the results differed by more than 4 mm for height and 0.4 kg for weight, the procedure was repeated. The two findings for each anthropometric measurement were averaged. All of the hand-wrist X-rays scans were performed at the Swiss Olympic

Medical Centre Magglingen, according to hand-wrist guidelines for SA (Martin et al., 2011).

Table 1.
Subject Characteristics

Characteristic	Mean (SD)	95% CI		Range	
CA (years)	14.0 (0.3)	13.9,	14.1	13.3	- 14.3
Height (cm)	164.9 (8.4)	162.8,	167.0	150.1	- 184.4
Weight (kg)	53.0 (8.7)	50.8,	55.2	37.8	- 73.4
SA (years)	13.9 (1.1)	13.5,	14.2	11.7	- 16.4

Note: CA = chronological age; SA = skeletal age; CI = confidence interval.

Procedure

Skeletal age. With the participants sitting beside the X-ray device (Stadler SE 4600; Stadler, Littau, Switzerland), the left hand-wrist was placed on a double-layered phosphor cassette without any radial or ulnar deviance. In order to assess all epiphyses, the X-ray tube was focused on the metacarpus. Using this standardisation, posterior-anterior radiographs of the left hand-wrist were taken with an X-ray device. A standardised modus of 42 kV tube voltage and 1.60 mAs, with a radiation time of 0.78 s, was used. All the films were rated by two independent, trained raters (R1, R2), using the radius-ulna-short bone protocol of Tanner et al. (2001) (TW3). The intra-rater difference in SA was 0.01±0.02 years and the inter-rater difference was 0.1±0.05 years.

SA was assessed by comparing the maturity indicators on each participant's X-ray scan to the standardised reference pictures according to the TW3 radius, ulna and short bone (RUS) method (Tanner et al., 2001). This method uses a detailed shape analysis of 13 bones, leading to their individual classification into one of several stages. Scores are derived from each bone stage. All the single bone scores were totalled and used for the overall classification. SA was assessed with a maximum precision of 0.1 years.

Using SA, the players were classified as early, on-time (average) or late maturation on the basis of the difference between SA and CA. On-time maturation was defined as an SA within 1.0 year of CA. Early maturation was defined as an SA older than CA by more than 1.0 year. Late maturation was defined as an SA younger than CA by more than 1.0 year.

Age at peak height velocity. The APHV was calculated as the difference between the CA and the predicted time (in years) from PHV. APHV is an indicator of biological maturity representing the time of maximum growth during adolescence. Predicted age based on APHV was estimated as CA minus maturity onset, as described by Mirwald et al. (2002). In this study, the mean age at PHV for the three samples adjusted for sample sizes was 13.8 years. Standard deviation (SD) for ages at PHV in longitudinal studies was about 1.0 year (Malina & Beunen, 1996; Malina et al., 2004). Using the values, on-time maturation was defined as a predicted age at PHV within ± 1.0 years (one SD). Therefore according to previous studies, on-time maturation was defined as an APHV between 13.8 ± 1 years or between 12.8 years and 14.8 years. Late maturation was defined as an APHV > 14.8 years and early maturation was defined as an APHV < 12.8 years.

Coaches' eye. Estimations of biological maturation were conducted subjectively by all assigned six national coaches, who are responsible for the national teams (U-15 to U-21). Classification was performed according to the categories of SA-CA and APHV into late, on-time and early maturation (Malina et al., 2012; Sherar et al., 2010). The coaches were instructed to record their estimation on a rating sheet. The coaches did not receive any other instruction or explanation about estimating the players' biological maturation. All the coaches had more than five years' experience, and each had attained the highest level of sport-specific education. All the coaches conducted their estimations independently, and they had no conflict of interest (e.g. relationships with the players). The inter-rater reliability of the coaches' classifications was excellent (ICC>0.95).

Statistical analysis. The classification procedure for early, on-time and late maturation corresponded to previous studies that used SA to classify youth athletes into maturity categories (Malina, et al., 2012; Sherar et al., 2010). According to the study of Malina et al. (2012), Kappa coefficients (k), Spearman rank order correlations (r_s) and proportions of agreement were calculated to estimate the agreement between classifications. For the k values, values >0.80 denoted almost perfect agreement, values >0.6 and <0.8 denoted substantial agreement, values >0.4 and <0.6 denoted moderate agreement, values >0.2 and <0.4 denoted fair agreement, values >0 and <0.2 denoted slight agreement and values <0 denoted poor agreement (Landis & Koch, 1977). Values are expressed as mean ± SD. Statistical analysis was performed using SPSS version 21 (IBM SPSS, Chicago, IL, USA). The level of significance was set at P<0.05.

Results

The SA of the players was 13.9 ± 1.1 years, and SA did not differ significantly from CA. Using SA, 24 players were classified as early maturation, 70 as on-time maturation and 25 as late maturation. Calculations of APHV resulted in eight players with early maturation, 105 with on-time maturation and six with late maturation. Mean APHV was 13.9 ± 0.3 years. The estimation by coaches' eye resulted in 11 players with early maturation, 91 with on-time maturation and 17 with late maturation.

The cross-tabulations of maturity status classifications based on SA-CA and by coaches' eye are summarised in Table 2. The agreement between the SA-CA classifications and the estimations by coaches' eye is 73.9%. The Spearman rank-order correlation between maturity classifications is strong (0.62). The Kappa coefficient is 0.48, which indicates moderate agreement.

Table 2.
Maturity categories by skeletal age and coaches' eye

Maturity categories from SA-CA	Maturity categories by coaches' eye				Agreement (%) [96% CI]	rs	Cohen's kappa	Magnitude
	Late	On time	Early	Total				
Late	13	12	0	25				
On time	4	65	1	70	73.9 [65.4, 81.0]	0.62	0.48	moderate
Early	0	14	10	24				
Total	17	91	11	119				

On time (average) is as a skeletal age within+1.0 year of chronological age; late is a skeletal age behind chronological age by more than 1.0. year; early is a skeletal age in advance of chronological age by more than 1.0 year.

Cross-tabulations of maturity status classifications based on SA-CA and APHV are summarised in Table 3. The agreement between the SA-CA classifications and APHV is 65.5%. The Spearman rank-order correlation between maturity classifications is moderate (0.42). The Kappa coefficient is 0.25, which indicates fair agreement.

Table 3.
Maturity categories by skeletal age and age at peak height velocity

Maturity categories from SA-CA	Maturity categories by age at peak height velocity: Late	On time	Early	Total	Agreement (%) [96% CI]	rs	Cohen's kappa	Magnitude
Late	6	19	0	25				
On time	0	67	3	70	65.5 [56.6, 73.5]	0.42	0.25	fair
Early	0	19	5	24				
Total	6	105	8					

On time (average) is as a skeletal age within+1.0 year of chronological age; late is a skeletal age behind chronological age by more than 1.0. On time (average) is an age at peak height velocity within +1 standard deviation of the mean age at peak height velocity; late is a peak height velocity of more than 1 standard deviation; early is a peak height velocity of more than -1 standard deviation.

Cross-tabulations of the maturity status classifications based on coaches' eye and APHV show an agreement of 78.2% (Table 4). The Spearman rank-order correlation between the maturity classifications is moderate (0.41). The Kappa coefficient is 0.30, which indicates fair agreement.

Table 4.
Maturity categories by coaches' eye and age at peak height velocity

Maturity categories by coaches' eye	Maturity categories by age at peak height velocity: Late	On time	Early	Total	Agreement (%) [96% CI]	rs	Cohen's kappa	Magnitude
Late	5	12	0	17				
On time	1	85	5	91	78.2 [69.9, 84.7]	0.41	0.3	fair
Early	0	8	3	11				
Total	6	105	8					

On time (average) is as a skeletal age within+1.0 year of chronological age; late is a skeletal age behind chronological age by more than 1.0. On time (average) is an age at peak height velocity within +1 standard deviation of the mean age at peak height velocity; late is a peak height velocity of more than 1 standard deviation; early is a peak height velocity of more than -1 standard deviation.

Discussion

There is little doubt that maturity assessments are an important aspect of TID. In our study, the coaches' eye had moderate agreement and a strong correlation with the SA categorisation, and was even better than the widely used APHV assessment. Therefore, a coaches' eye method seems to be an acceptable alternative to X-ray and APHV for classifying maturity in youth athletes. The SA of the players was 13.9 ± 1.1 years, and SA did not differ significantly from CA. The APHV method only showed fair agreement.

Many young, talented athletes go unnoticed and often drop out of soccer early because of delayed maturation. Consequently, there is a severe loss of talented young soccer players. Given the need to consider the maturation characteristics in any TID or TD program, appropriate ways to assess the maturity of young athletes should be established. This study fulfilled these requirements by demonstrating that a simple, subjective classification by coaches' eye could be a valid method to assess the maturation of young athletes. BA, determined using either non-invasive or invasive measures, can give a coach and medical staff an indication of the player's maturity in comparison to peers in the same age group. This information can be used for talent selection and to determine critical periods for training in terms of long-term talent development.

Skeletal age

The present study determined SA using the TW3 method. The SA results were generally consistent with previous studies of Brazilian (Teixeira et al., 2015), French (Carling, Le Gall, & Malina, 2012), Japanese (Hirose, 2009), and Portuguese players (Figueiredo et al., 2009b). In mid-adolescence, the full spectrum of skeletal maturity from early through late maturation is apparent. In our study, SA was similar to CA and the majority of players were found to have average, on-time maturation. Players with early and late maturation were slightly over-represented in comparison to the general population, but this trend was not significant.

However, in our study, the distribution of BA was different from other studies investigating youth soccer players. Those studies showed that coaches are more likely to select and promote average and early maturing boys (Figueiredo et al., 2009b; Malina et al., 2004; Malina et al., 2012). A possible reason for this difference is the TID program of the Swiss Soccer Federation, which defines BA as the stage of late childhood.

Other researchers have detected a mean bone age of 14.2 years in youth soccer players in the Under-13 category, and some of the athletes in that category had a bone age of 16.4 years (Hansen, Klausen, Bangsbo, & Muller, 2010). When comparing elite athletes in the Under-14 category with contrasting maturity status (i.e. late vs. early), a difference of 3.7 years was observed in bone age. In terms of anthropometric dimensions, this is a difference of 14 cm in height and 22 kg in body mass (Reilly, Bangsbo, & Franks, 2000). Figueredo et al. (2009) analysed the BA of 11- and 12-year-old soccer players and showed mean differences of 3.5 years between early and late maturity. These results are in line with our study, which found a mean difference of 3.7 years for BA.

Classifications in maturity categories

Classifications of youth soccer players into contrasting maturity categories (early, on-time, late) on the basis of predicted APHV have already been validated against classifications based on X-rays in youth soccer players. Malina (2012) analysed the relationships among indicators of biological maturation and the agreement between classifications of maturity status of two age groups of youth soccer players. In that study, the data included SA assessed by the FELS method, stage of pubic hair, predicted APHV, and percentage of predicted adult height. The Kappa coefficients were low (0.02–0.23) and indicated poor agreement between the maturity classifications. The Spearman rank-order correlations between categories were low to moderate (0.16–0.50). Although the indicators were related, the agreement of maturity classifications between SA and the predicted APHV was poor.

In line with previous studies, our classifications for SA-CA and predicted APHV were based on the SD of approximately 1 year (Malina et al., 2004).

Age at peak height velocity

In our study, mean APHV was 13.9 ± 0.3 years, which is in line with the findings from previous studies (Figueiredo, Gonçalves, Coelho e Silva, & Malina, 2009a; Malina et al., 2012; Teixeira et al., 2015). The limited agreement between maturity classification based on APHV and SA was likely due to the reduced standard deviations for APHV compared with that in the samples from which the protocol was developed. Additionally, the APHV distributions were relatively narrow. Therefore, the sensitivity and specificity used to differentiate players by maturity status of the offset protocol has been questioned, and validation studies on Polish youth followed from 8 to 18 years indicated several limitations (Malina, Rogol, Cumming, Coelho e Silva, & Figueiredo, 2015). Maturity offset has been suggested as a categorical variable, pre- or post-PHV (Mirwald, 2002). This appears to be a useful way to average PHV in maturing boys near the time of actual PHV within a narrow range of PHV ± 1 year (Malina & Kozieł, 2014). However, its utility is limited in practice (Malina et al., 2004; Malina et al., 2006).

The classification of players into maturity groups on the basis of predicted APHV was found to be fairly related to the SA classifications. Because the majority of players (over 88%) were classified as on-time maturation, the practicability of the method to categorise youth soccer players into maturity groups is called into question (Malina & Kozieł, 2014). This reflected the reduced range of variations in APHV. The observation that the APHV protocol did not correspond, at least moderately, impacts the practical application of its use in TD programs (Malina et al., 2012).

Both maturity indicators used in the present study measured different, but related, aspects of biological maturation during male adolescence. SA reflects the maturation of the bones of the hand-wrist. In contrast, APHV is an indicator of the timing of the maximal rate of growth in height during the growth spurt.

Coaches' eye

Classifications of biological maturity by coaches' eye correlated moderately with the SA classifications. Experienced coaches seemed to estimate the maturity of young soccer players better than the widely-used APHV method. In fact, the construct of biological maturation is very complex. It consists of the skeletal system, specifically ossification of cartilaginous endochondral bones, as well as aspects of sexual maturation, specifically hormonal status. It also includes indicators of somatic maturation, specifically progress in height and the tempo and timing of growth during the growth spurt. Thus, biological maturation is a very complex system of status, tempo and timing. The advantage of this intuitive approach used by the coaches lies in its holistic character and in its practicability. The coaches' judgement focuses on the person, as a whole. Thus, it integrates a variety of critical elements that determine maturity. Although maturation is complex, the inter-rater reliability of the coaches was excellent. Even more, current research shows that intuitive judgements are valid, which supports subjective assessments of coaches (Gigerenzer & Brighton, 2009; Kruglanski & Gigerenzer, 2011).

The weakness of this appraisal appears to be its subjective nature, even though we have to be conscious that this intuitive judgement is also based on an internal frame of reference built on relevant knowledge (Buekers, Borry, & Rowe, 2015).

Limitations and strength of the study

This study examined 119 male soccer players in a highly selective sport setting and very experienced coaches. All national coaches had more than five years' experience, and each had attained the highest level of sport-specific education. Therefore, the results cannot be transferred to the general population and need further confirmation. However, one strength of our study is that the male soccer players who participated were in an age range that showed the greatest variations of maturity, and the consideration of maturity characteristics in the selection process is very important. The coaches' eye is very practical, and it uses a holistic approach for the classification of biological maturation. It may be potentially useful in affording more opportunities to players who are less mature than their peers and in developmental programs where technically skilled, yet less mature, players may be overlooked due to maturity-associated limitations in physical and functional capacities (smaller size, and less strength, power and speed). This is important in early- and mid-adolescence, when selection processes are executed (Figueiredo et al., 2009b). We expect our results to be valid for other youth elite sports; however, this topic needs further study.

In the current system with early selection processes, late maturing players may be dismissed on the basis of their physical characteristics. Therefore, modern models of TID and TD have to integrate the maturation characteristics of young athletes into the selection process (Reilly, Williams, et al., 2000; Unnithan et al., 2012; Vaeyens et al., 2008). At a young age (less than 12 years), the APHV is not valid and the measurement of SA is often ethically and financially unjustifiable. A classification and integration of biological maturity using coaches' eye could be a first step towards fairer and more efficient identification and development of young athletes. Since the aim of a federation or club is to identify and develop promising young players who can later progress to an elite team, it is crucial that talent models have the ability to distinguish between the current performance levels of players and their future potential (Vaeyens et al., 2008).

Conclusion

TD programs call for implementing biological maturity into the TID process. Thus, there is a need to classify youth into early, on-time and late maturation stages for TID and to design training and competition programs. Many soccer clubs and soccer federations already select their players based on the subjective assessments of scouts and coaches. However, these subjective assessments are often biased toward selecting players with early biological maturation, because that maturity status strongly correlates to the development of physical attributes, motor ability and some specific soccer skills. Our results show that coaches' eye is a valid method to assess biological maturation. Coaches' eye was even better than the widely-used APHV assessment. In comparison to the classical X-ray method, coaches' eye offers much quicker information gathering, lower costs and no exposure to radiation. In sports, a systematic and broad implementation of maturity classifications could have a significant impact on performance assessment, evaluation, selection and training during athlete development.

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Relative age effects in Swiss talent development – a nationwide analysis of all sports

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ABSTRACT
Relative age effects (RAE) generate consistent participation inequalities and selection biases in sports. The study aimed to investigate RAE across all sports of the national Swiss talent development programme (STDP). In this study, 18 859 youth athletes (female N = 5353; mean age: 14.8 ± 2.5 y and male N = 13 506; mean age: 14.4 ± 2.4 y) in 70 sports who participated in the 2014 competitive season were evaluated. The sample was subdivided by sex and the national level selection (NLS, N = 2464). Odds ratios (ORs) of relative age quarters (Q1-Q4) and 95% confidence intervals (CI) were calculated. In STDP, small RAE were evident for females (OR 1.35 (95%-CI 1.24, 1.47)) and males (OR 1.84 (95%-CI 1.74, 1.95)). RAE were similar in female NLS athletes (OR 1.30 (95%-CI 1.08, 1.57)) and larger in male NLS athletes (OR 2.40 (95%-CI 1.42, 1.97)) compared to athletes in the lower selection level. In STDP, RAE are evident for both sexes in several sports with popular sports showing higher RAE. RAE were larger in males than females. A higher selection level showed higher RAE only for males. In Switzerland, talent identification and development should be considered as a long-term process.

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Youth sports; talent selection; athletic development; maturation

Introduction

The phenomenon of relative age effects (RAE) is well-known in youth sports. Children and adolescents are commonly pooled into annual age groups to account for developmental differences and, thus, to allow for more equal inter-individual opportunities for being successful in a particular sport. There remains, however, a potential gap of up to 12 months in chronological age between individuals. RAE is defined as the overrepresentation of chronologically older participants within one selection year relative to their chronologically younger counterparts. This effect occurs during the early development of youth athletes (Cobley, Baker, Wattie, & McKenna, 2009; Musch & Grondin, 2001). RAE may lead to a biased view of the potential of children in a particular sport as early-born athletes may have advanced physical and cognitive abilities compared to their late-born opponents and are, therefore, more likely be identified as more talented (Cobley et al., 2009; Delorme, Boiché, & Raspaud, 2010; Gil et al., 2014; Hancock, Adler, & Côté, 2013; Wattie, Schorer, & Baker, 2015). Consequently, these children may have a higher chance of being selected for representative teams or talent centres and may receive more comprehensive future training. It has been shown in youth soccer and basketball players that those who are born late in the selection year are more likely to drop out of these sports than players who are born early in the selection year (Delorme et al., 2010; Delorme, Chalabaev, & Raspaud, 2011).

In a comprehensive meta-analytical review, Cobley et al. (2009) reported a consistent risk for RAE, which is apparent across a variety of different sports. These authors presented data on RAE in 14 different sports (ice hockey, volleyball, basketball, American football, Australian rules football, baseball, soccer, cricket, swimming, tennis, gymnastics, netball, Rugby Union and golf) for male and female athletes from 4 years of age to the senior professional level. Most studies were conducted in soccer and ice hockey. The largest RAE were found in basketball and soccer. RAE were present in all age categories and increased with age until late adolescence. In adult athletes, the RAE were lower, comparable to (pre)pubertal children. Further, RAE were apparent in all levels of play. Whereas the RAE were marginal at the lowest levels, they increased with higher representative levels. However, on the elite level, the effect size decreased to values of lower competitive levels. Meanwhile, data on RAE in other sports, such as alpine skiing (Müller, Hildebrandt, & Raschner, 2015), handball (Schorer, Cobley, Busch, Brautigam, & Baker, 2009) and athletic sprinting (Romann & Cobley, 2015) are available, confirming the presence of RAE in these sports as well.

Data on RAE in the above-mentioned meta-analysis were, however, not consistent between studies, and evidence for some sports is based on only small samples. Particularly, for female athletes, the number of available studies is limited and

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Supplemental data for this article can be accessed here

data are inconsistent. For instance, Delorme et al. (2010) found RAE in French female soccer players, particularly in the youth age categories. Interestingly, there was also an inverse RAE in dropouts who were overrepresented in the second half of the selection year and underrepresented in the first half. In contrast, Vincent and Glamser (2006) observed marginal RAE among female youth soccer players, whereas in their male counterparts the RAE was clearly larger. The authors discussed complex interactions of biological and maturational differences with socialization influences as possible reasons for these sex differences. Goldschmied (2011) reported no RAE in elite level female soccer, basketball and handball players. This report, however, was not published in a peer-reviewed scientific journal, is based on a limited number of players and contains data from three different countries and seasons. Overall, the inconsistent evidence on RAE in females warrants further research in this population (Delorme et al., 2010).

Methodological confounding through differences in the talent identification and development systems between countries or country-specific popularity of a particular sport may also affect results. Cohort studies analysing large homogeneous samples of youth athletes over a variety of different sports from a single country are rare. In most studies with large nationwide samples, only a limited number of different sports (in most instances a single sport) were analysed (Delorme et al., 2010, 2011; Romann & Fuchslocher, 2013). It has been suggested that the popularity of a particular sport, the number of active participants, the importance of physical development and the competitive level affect the existence of a RAE (Musch & Grondin, 2001). There is evidence supporting these hypotheses. For example, Delorme and Raspaud (2009) showed that no RAE is present in shooting sports, i.e. a sport in which physical capabilities are of minor relevance for sports performance. Similarly, it has been shown that in sports with weight categories, RAE are not present (Albuquerque et al., 2012; Delorme, 2014). Weight categories may counterbalance maturational and physical differences between young athletes within age categories and, thus, may prevent the occurrence of RAE. Altogether, important questions remain, for instance, whether RAE are indeed consistent through all sports or whether there are inverse RAE in some sports as late-born talented age-groupers might tend to change to specific sports with fewer competitive demands and less rivalry. The analysis of RAE within a national talent development programme including all selected youth athletes of all organised sports, may facilitate to answer such questions within a homogenous talent development context.

The aim of the study was to investigate the RAE in all organized sports based on a countrywide Swiss database where youth athletes (7 to 20 years of age), who were selected into a nationwide talent programme, were registered. It was hypothesized that overall RAE are apparent in sports with high rates of participation and high selection pressure (e.g. soccer, alpine skiing), whereas sports with less public attention and fewer participants (e.g. fencing, curling) do not necessarily show RAE or even inverse RAE. As Olympic sports are usually more popular, include more participants and show a high competitive level already in young athletes, RAE should be more pronounced in Olympic as compared to Non-Olympic sports. Furthermore, it was expected that there are more pronounced RAE in male as compared to female youth athletes and that RAE are less pronounced in sports with weight categories.

Methods

Participants

The Swiss system of talent identification, selection and development is based on three levels of performance (Figure 1) (Romann & Fuchslocher, 2013). The first level is a nationwide extracurricular programme called “Jugend und Sport” (J + S), which is offered to all young children and adolescents aged 5 to 20 years. The second level is the national Swiss talent development programme (STDP) within J + S in 70 different sports starting at the age of 7 years. All Swiss youth athletes in the STDP (N = 18 859; female N = 5353; age: 14.8 ± 2.5 y and male N = 13 506; age: 14.4 ± 2.4 y) who participated in the 2014 competitive season were included in the present analysis. Athletes in STDP are selected by the national talent selection instrument (PISTE), which includes six major assessment criteria (competition performance, performance tests, performance development, psychological factors, athlete’s biography and biological development) and a number of sub-components (e.g. resilience, anthropometry, achievement motivation) (Fuchslocher, Romann, & Gulbin, 2013). Licensed coaches perform the practices in this programme, and the athletes are expected to train more than 400 hours per year. J + S and Swiss Olympic jointly established this cut-off criterion. The third level is the subgroup of the national level selection (NLS). In the PISTE process, athletes with the potential to successfully perform in national and international competitions are selected in the NLS.

Procedures and data analysis

Anonymised information on participant’s age, sex, date of birth and sport disciplines was retrieved from the database of J + S (Swiss Federal Office of Sport, 2015). The study was approved by the institutional ethical review board of the Swiss Federal Institute of Sport.

In Switzerland, the cut-off date for all sports is January 1st. The athletes were categorized into four relative age quarters (Q) according to their birth month independently of birth year (i.e., Q1 = January to March; Q2 = April to June; Q3 = July to September; and Q4 = October to December). The observed birth-date distributions were calculated for every relative age quarter. The expected birthdate distributions were obtained from the actual corresponding distributions (1994–2009) as the number of live births registered with the Swiss Federal Office of Statistics. The relative age quarters of the Swiss population were as follows: Q1 = 24.5%; Q2 = 25.2%; Q3 = 26.1%; and Q4 = 24.2%. Sports were categorized into Olympic and Non-Olympic sports and for clarity, into large (25 largest sports according to the number of involved athletes for each sex separately; sports with more than 43 selected athletes for females and more than 74 selected athletes for males on the STDP level) and small sports (lower number of athletes in STDP). The reason for this categorisation is a higher participation, more funding and more scientific support for Olympic sports (Swiss Olympic Association, 2017). Data of the latter are presented in the supplementary files only.

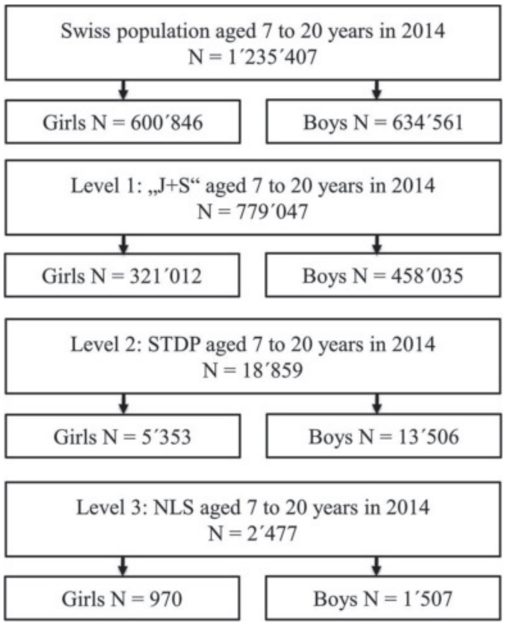

Figure 1. Overview of the different levels of selection in the Swiss organized sport system (J + S), the Swiss talent development programme (STDP) and the national level selection (NLS).

Based on these data, odds ratios (OR) with 95% confidence intervals (95% CI) were calculated between Q1/Q4 as commonly used in RAE studies (Cobley et al., 2009). A relevant RAE was assumed if the confidence interval of the OR did not include 1. The OR for the Q1 vs. Q4 comparison was interpreted as follows: OR < 1.22, 1.22 ≤ OR < 1.86, 1.86 ≤ OR < 3.00, and OR ≥ 3.00, indicating negligible, small, medium and large effects, respectively (Olivier & Bell, 2013). If the OR was < 1 and the confidence interval did not include 1, this finding was interpreted as an inverse RAE. As population-based data were analysed, inferential statistics were not applied (Gibbs, Shafer, & Dufur, 2012).

Results

In total, 18 859 youth athletes (5353, 28% girls) between 7 and 20 years of age were included in the STDP in the year 2014 (Figure 1). Thirteen percent (N = 2477) of these athletes (female, N = 970; male, N = 1507) were included in the subgroup of NLS.

Tables 1 and 2 show the relative age quarter distribution of female and male youth athletes together with the odds ratios for athletes born in the first quarter vs. last quarter of the selection year for the 25 sports with the largest number of participants in Switzerland. Detailed data for all sports included in the STDP are shown in the appendices in the online supplementary material (Tables SI and SII).

In female athletes in the STDP (Table 1), medium RAE in track and field and synchronized swimming were observed. Small RAE were present in tennis, volleyball, soccer and alpine skiing. No relevant RAE were found in the NLS in female athletes.

In male athletes in the STDP (Table 2), track and field, soccer, shooting, basketball, ice hockey, field hockey and volleyball showed medium RAE. Small RAE were present in cross-country skiing, alpine skiing, tennis, swimming, handball and floorball. In athletes in the NLS, large RAE were found in tennis, rowing, soccer, alpine skiing and ice hockey and medium effects in basketball and handball.

When comparing small sports with the 25 biggest sports for male youth athletes, on average medium RAE were found in the 25 biggest sports for male athletes of the STDP and the NLS, small RAE in small sports of the STDP and inverse RAE in small sports in the NLS. The only single small sport with large RAE was trampoline (OR = 9.92 (95%-CI 1.27, 77.50)). In female youth athletes, no relevant RAE was present in small sports (see online supplementary Tables SI and SII).

The ORs for selected athletes born in the first quarter vs. the last quarter of the selection year are categorised for the STDP and the NLS for Olympic and Non-Olympic sports separately in Figure 2. Whereas there is medium RAE for Olympic sports in male youth athletes with larger RAE in the NLS, female sports and Non-Olympic sports merely showed small to negligible RAE.

As expected, no relevant RAE were found in sports with weight categories (judo, karate, wrestling, boxing; female, OR = 1.42 (95%-CI 0.87, 2.30); male, OR = 0.85 (95%-CI 0.64, 1.12)) in athletes in the STDP. In contrast, athletes in the NLS showed medium RAE in these sports (females, OR = 4.46 (95%-CI 0.96, 20.66); males, OR = 1.75 (95%-CI 0.84, 3.17)).

Discussion

In this study, data on RAE are presented in a population-based approach comprised of all youth athletes who were registered in the Swiss talent development programme (STDP) in the year 2014. A large variability in RAE was found across different types of sports and between girls and boys. The main findings are (a) that in female athletes a small and in male athletes medium overall RAE were present, (b) that in male athletes the RAE were considerably larger in Olympic as compared to Non-Olympic sports and (c) that in male athletes the RAE were larger in athletes in the NLS as compared to the STDP. Small sports showed negligible to small RAE. In sports with weight categories, medium RAE were only present in the NLS athletes of both sexes.

Key findings

To the best of our knowledge, this is the first study analysing a complete sample of a nationwide talent development programme including all organized sports. Medium RAE were found over all 68 male sports in the STDP sample. The effect was clearly larger in the higher selection levels (NLS). This finding is supported by the literature, showing an increasing risk for RAE with higher levels of competition (Cobley et al., 2009). Several factors may increase the risk of RAE in a particular sport. For instance, RAE might be affected by the sport's popularity, the amount/rate of participation, the level of competition, higher selection pressure, early specialization and the expectations of coaches who are involved in the selection process (Cobley et al., 2009; Hancock et al., 2013; Wattie et al., 2015). Also, differences between late- and early-born athletes in cognitive, social, physical and maturational development might result in RAE (Musch & Grondin, 2001). For instance, Reed,

Table 1. Nationwide data of relative age effects in female youth athletes in the Swiss talent development programme (STDP) and in the national level selection (NLS) in the year 2014 for the 25 largest sports.

	STDP						NLS					
Sport	N	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	OR Q1 vs. Q4 (95% CI)	N	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	OR Q1 vs. Q4 (95% CI)
Soccer	1042	27.6	26.2	27.7	18.4	1.49 (1.23, 1.79)	121	20.7	29.8	36.4	13.2	1.55 (0.83, 2.90)
Volleyball	557	29.3	27.5	24.2	19.0	1.53 (1.19, 1.95)	45	33.3	35.6	15.6	15.6	2.13 (0.87, 5.21)
Alpine skiing	412	31.6	24.5	22.3	21.6	1.45 (1.10, 1.90)	61	37.7	23.0	19.7	19.7	1.90 (0.95, 3.82)
Swimming	375	25.3	25.6	26.1	22.9	1.10 (0.82, 1.47)	12	25.0	25.0	25.0	25.0	0.99 (0.20, 4.91)
Handball	277	25.6	33.9	20.6	19.9	1.28 (0.90, 1.82)	42	26.2	38.1	16.7	19.0	1.36 (0.55, 3.39)
Gymnastics artistic	240	28.3	23.3	27.5	20.8	1.35 (0.93, 1.95)	58	17.2	32.8	20.7	29.3	0.58 (0.27, 1.27)
Tennis	201	29.9	26.9	23.9	19.4	1.53 (1.02, 2.29)	34	29.4	17.6	26.5	26.5	1.10 (0.45, 2.71)
Athletics (track and field)	183	31.7	29.0	23.5	15.8	1.98 (1.27, 3.10)	29	27.6	37.9	17.2	17.2	1.59 (0.52, 4.85)
Basketball	174	25.3	26.4	26.4	21.8	1.15 (0.74, 1.78)	47	21.3	25.5	36.2	17.0	1.24 (0.49, 3.14)
Equestrian jumping	163	26.4	28.2	20.2	25.2	1.04 (0.68, 1.60)	38	28.9	21.1	21.1	28.9	0.99 (0.43, 2.29)
Figure skating	148	21.6	23.0	33.8	21.6	0.99 (0.61, 1.62)	21	33.3	14.3	38.1	14.3	2.31 (0.60, 8.95)
Cross-country skiing	116	26.7	31.0	19.0	23.3	1.14 (0.68, 1.91)	15	33.3	26.7	0.0	40.0	0.83 (0.25, 2.71)
Orienteering (running)	111	21.6	25.2	27.0	26.1	0.82 (0.48, 1.41)	11	18.2	27.3	36.4	18.2	0.99 (0.14, 7.04)
Synchronized schwimming	104	27.9	29.8	27.9	14.4	1.92 (1.03, 3.58)	42	26	28.6	33.3	11.9	2.18 (0.76, 6.28)
Judo	84	28.6	25.0	25.0	21.4	1.32 (0.72, 2.44)	13	23.1	46.2	30.8	0.0	
Sports climbing	81	35.8	17.3	21.0	25.9	1.37 (0.78, 2.41)	13	23.1	15.4	30.8	30.8	0.74 (0.17, 3.32)
Rhythmic gymnastics	73	28.8	23.3	30.1	17.8	1.60 (0.80, 3.21)	33	33.3	30.3	21.2	15.2	2.18 (0.76, 6.28)
Shooting	71	36.6	23.9	18.3	21.1	1.72 (0.91, 3.25)	9	44.4	33.3	11.1	11.1	3.97 (0.44, 35.5)
Ice hockey	67	26.9	29.9	17.9	25.4	1.05 (0.54, 2.04)	26	26.9	23.1	23.1	26.9	0.99 (0.35, 2.83)
Badminton	65	24.6	40.0	21.5	13.8	1.76 (0.78, 3.99)	18	22.2	38.9	22.2	16.7	1.32 (0.30, 5.91)
Rowing	57	29.8	29.8	24.6	15.8	1.87 (0.83, 4.21)	13	7.7	30.8	38.5	23.1	0.33 (0.03, 3.18)
Karate	53	26.0	21.0	36.0	17.0	1.54 (0.67, 3.57)	17	29.4	0.0	58.8	11.8	2.48 (0.48, 12.8)
Synchronized skating	50	30.0	26.0	24.0	20.0	1.49 (0.67, 3.31)						
Snowboarding	49	26.5	22.4	26.5	24.5	1.07 (0.49, 2.36)	17	29.4	11.8	17.6	41.2	0.71 (0.22, 2.23)
Cycling mountainbike	43	34.9	25.6	23.3	16.3	2.13 (0.87, 5.22)	11	36.4	9.1	27.3	27.3	1.32 (0.30, 5.91)
Total	**4796**	**28.0**	**26.7**	**25.1**	**20.2**	**1.38 (1.26, 1.51)**	**746**	**26.5**	**27.3**	**26.4**	**19.7**	**1.34 (1.08, 1.65)**

Notes: Q1 to Q4 = Quartile 1 to 4; OR = Odds ratio; 95% CI = 95% Confidence Interval.

Parry, and Sandercock (2016) suggested that social agents may contribute to RAE in English school sports. A recent study of German youth national football teams found RAE, but there were no relevant differences in anthropometric and performance characteristics between players of different relative age quarters (Skorski, Skorski, Faude, Hammes, & Meyer, 2016). Thus, physical or maturational differences might be of minor relevance for RAE on the highest performance level in an already highly selected population. An interesting finding is that male athletes in some NLS in sports with low participation rates showed inverse (not significant) RAE, i.e., a higher proportion of athletes was born in the last quarter of the year as compared to the first quarter of the year. It might be speculated that talented athletes, who were born late in the year, move from sports with high participation rates to those with lower participation rates in order to have the possibility to compete on a high performance level (Delorme, 2014).

In contrast to male sports, there were merely small RAE over all 63 female sports and no relevant difference between the STDP and the NLS. Previous data also revealed differences in RAE between girls and boys. For instance, Cobley et al. (2009) summarised the results of 38 studies published between 1984 and 2007 and found a larger OR (Q1 vs. Q4) of 1.65 (95%-CI 1.54, 1.77) in male athletes as compared to female athletes (OR 1.21 (95%-CI 1.10, 1.33)). Similarly, Raschner, Müller, and Hildebrandt (2012) observed a difference between males (OR 3.32) and females (OR 1.89) in more than 1000 athletes participating in the Youth Olympic Games 2012. Recently, Reed et al. (2016) reported data from more than 10 000 children participating at the London Youth Games and also found lower RAE in many sports for girls as compared to boys. Thus, these results are in line with the current evidence. Females generally mature earlier than their male peers and after peak height velocity differences in athletic performance are reduced or disappear (Vincent & Glamser, 2006). A possible additional explanation might be that the number of male athletes was 2.5 times the number of female athletes in the STDP. Further, the proportion of NLS athletes was about 11% boys and 18% girls. This reflects a larger pool for selection and a higher selection pressure in male athletes and may explain the difference in RAE between boys and girls. A further explanation for the smaller RAE in female youth athletes might be that changes in body shape, which are associated with early maturation (e.g. greater body mass per stature, shorter legs, wider hips, greater body fat) are disadvantageous for performance (Vincent & Glamser, 2006).

This study reveals that Non-Olympic sports showed a lower risk for RAE than Olympic sports. It could be speculated that this is due to the greater attractiveness of Olympic sports as a result of their greater media presence and higher funding, whereas Non-Olympic sports are less popular and, hence, attract fewer young people (Fuchslocher et al., 2013; Swiss Olympic Association, 2017). A greater attractiveness might lead to larger pools of athletes in Olympic sports, which increases selection pressure (Musch & Grondin, 2001). This view is strengthened by the fact that only about 10% of the sample was involved in Non-Olympic sports, and the remaining athletes performed in Olympic sports. Interestingly, 12.4% of the Olympic sports athletes were selected to the NLS, whereas 21.6% of Non-Olympic athletes achieved the NLS, confirming the higher selection pressure in Olympic sports. Further, a higher professionalism in Olympic sports in general, as well as their talent selection instruments might be another underlying reason for an increased risk of RAE (Fuchslocher et al., 2013).

Table 2. Nationwide data of relative age effects in male youth athletes in the Swiss talent development programme (STDP) and in the national level selection (NLS) in the year 2014 for the 25 largest sports.

	STDP						NLS					
Sport	N	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	OR Q1 vs. Q4 (95% CI)	N	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	OR Q1 vs. Q4 (95% CI)
Soccer	6010	35.9	27.8	20.9	15.3	2.33 (2.13, 2.54)	217	48.8	23.0	17.5	10.6	4.57 (2.91, 7.18)
Ice hockey	1501	33.3	26.9	23.3	16.5	2.01 (1.71, 2.35)	226	38.9	28.8	23.0	9.3	4.16 (2.58, 6.69)
Handball	601	29.8	25.6	24.5	20.1	1.47 (1.16, 1.85)	66	36.4	22.7	24.2	16.7	2.16 (1.06, 4.42)
Alpine skiing	580	30.7	27.4	24.3	17.6	1.73 (1.35, 2.22)	74	40.5	27.0	23.0	9.5	4.25 (1.87, 9.68)
Tennis	432	32.4	24.5	22.9	20.1	1.60 (1.22, 2.09)	39	53.8	23.1	17.9	5.1	10.41 (2.44, 44.4)
Gymnastics artistic	339	25.1	27.1	26.0	21.8	1.14 (0.83, 1.56)	67	23.9	35.8	19.4	20.9	1.13 (0.55, 2.32)
Swimming	335	30.1	25.7	23.9	20.3	1.47 (1.08, 2.01)	21	28.6	14.3	14.3	42.9	0.66 (0.24, 1.86)
Floorball	299	28.4	25.4	26.4	19.7	1.43 (1.02, 2.00)	24	29.2	33.3	25.0	12.5	2.31 (0.60, 8.95)
Basketball	273	31.9	28.9	23.8	15.4	2.05 (1.42, 2.98)	60	38.3	33.3	13.3	15.0	2.53 (1.17, 5.48)
Judo	250	20.4	24.4	29.6	25.6	0.79 (0.55, 1.14)	23	30.4	30.4	26.1	13.0	2.31 (0.60, 8.95)
Volleyball	223	29.6	30.0	24.7	15.7	1.87 (1.24, 2.82)	34	32.4	32.4	17.6	17.6	1.82 (0.67, 4.92)
Athletics (track and field)	179	35.8	25.7	24.0	14.5	2.44 (1.54, 3.86)	34	26.5	35.3	23.5	14.7	1.79 (0.60, 5.33)
Water polo	174	31.0	23.0	20.7	25.3	1.22 (0.82, 1.82)	72	33.3	26.4	18.1	22.2	1.49 (0.79, 2.80)
Orienteering (running)	164	22.0	25.0	25.6	27.4	0.79 (0.51, 1.23)	12	0.0	16.7	41.7	41.7	
Snowboarding	163	27.0	20.2	25.8	27.0	0.99 (0.65, 1.51)	20	35.0	15.0	40.0	10.0	3.47 (0.72, 16.71)
Badminton	162	25.9	25.9	30.9	17.3	1.49 (0.92, 2.40)	26	23.1	23.1	46.2	7.7	2.98 (0.60, 14.74)
Cross-country skiing	160	28.8	31.9	23.1	16.3	1.75 (1.08, 2.84)	22	36.4	27.3	22.7	13.6	2.64 (0.70, 9.97)
Cycling mountainbike	109	27.5	29.4	25.7	17.4	1.57 (0.88, 2.79)	29	37.9	20.7	20.7	20.7	1.82 (0.67, 4.92)
Sports climbing	106	26.4	23.6	34.0	16.0	1.63 (0.89, 2.99)	11	27.3	27.3	45.5	0.0	
Shooting	97	30.9	27.8	27.8	13.4	2.29 (1.19, 4.39)	8	12.5	37.5	50.0	0.0	
Field hockey	95	28.4	26.3	30.5	14.7	1.91 (1.00, 3.65)	49	28.6	24.5	22.4	24.5	1.16 (0.54, 2.50)
Karate	87	21.8	26.4	16.1	35.6	0.61 (0.34, 1.08)	22	31.8	27.3	13.6	27.3	1.16 (0.39, 3.44)
Table tennis	86	22.1	36.0	20.9	20.9	1.05 (0.55, 2.00)	22	22.7	36.4	13.6	27.3	0.83 (0.25, 2.71)
Rowing	85	27.1	27.1	28.2	17.6	1.52 (0.79, 2.92)	24	45.8	25.0	20.8	8.3	5.46 (1.21, 24.6)
Ski jumping	74	33.8	13.5	24.3	28.4	1.18 (0.66, 2.11)	10	20.0	10.0	30.0	40.0	0.50 (0.09, 2.71)
Total	**12,584**	**32.7**	**27.1**	**22.9**	**17.3**	**1.87 (1.76, 2.00)**	**1212**	**36.9**	**26.8**	**21.7**	**14.6**	**2.50 (2.10, 2.98)**

Notes: Q1 to Q4 = Quartile 1 to 4; OR = Odds ratio; 95% CI = 95% Confidence Interval.

In line with existing evidence (Albuquerque et al., 2012; Delorme, 2014), no relevant RAE were found in sports with weight categories for male athletes in the STDP. Similar evidence has already been revealed in combat sports (Delorme, 2014). This phenomenon might be explained by a "strategic adaptation", which is a voluntary shift of children to another sports where their physical capacities will be less determining for performance. Albuquerque et al. (2012) also did not find RAE within Olympic taekwondo athletes over 12 years of age. He assumed that RAE are reduced or diminished in taekwondo due to its competitive categories (weight categories and belt level), which are determined by the level of technical skills. Thus, the younger athletes are less disadvantaged because of lower physical capacities. This system of categorization may act as a key against drop out of younger athletes.

Methodological considerations

The obvious strength of the present study is that it analysed a complete countrywide data pool comprised of all selected youth athletes in Switzerland in 2014. Therefore, comparisons between sports are not affected by possible differences between countries in, for instance, the talent identification, selection and development systems or the popularity of particular sports. However, Switzerland is a small country with small samples available for analyses in several sports. Thus, the results in small sports should be interpreted with care and the generalizability to other countries is limited. Swiss sports federations are aware of the problems associated with RAE, and coaches are educated in this regard. Additionally the current approach to counter RAE on the national level, which was introduced in 2008, did not reduce the effect. In this approach, the RAE phenomenon was educated to coaches and the federations had to integrate bonus points for RAE disadvantaged athletes in the PISTE-selection process (Fuchslocher et al., 2013). In international professional football, it has been shown that awareness of the problem and 10 years of research did not solve the problem as well, indicating that RAE is a robust phenomenon and cannot easily be changed (Helsen et al., 2012).

Within the present investigation we were not able to investigate possible causal factors of the RAE (e.g., biological maturity status or physical performance). Additionally, the evolution of RAE in different age categories have not been analysed. Therefore, future research should focus on the underlying mechanisms behind the RAE and investigate differences of RAE between age categories and specific types of sports.

Conclusions and practical implications

RAE are present in several sports in the talent development system of Switzerland, particularly in male youth athletes in Olympic sports on the highest selection level. This implies that talent and resources are being wasted, which is especially problematic for a small country like Switzerland. The present data support the detection of high-risk sports or groups of sports and, thus, a tailored implementation of preventive measures. Such measures,

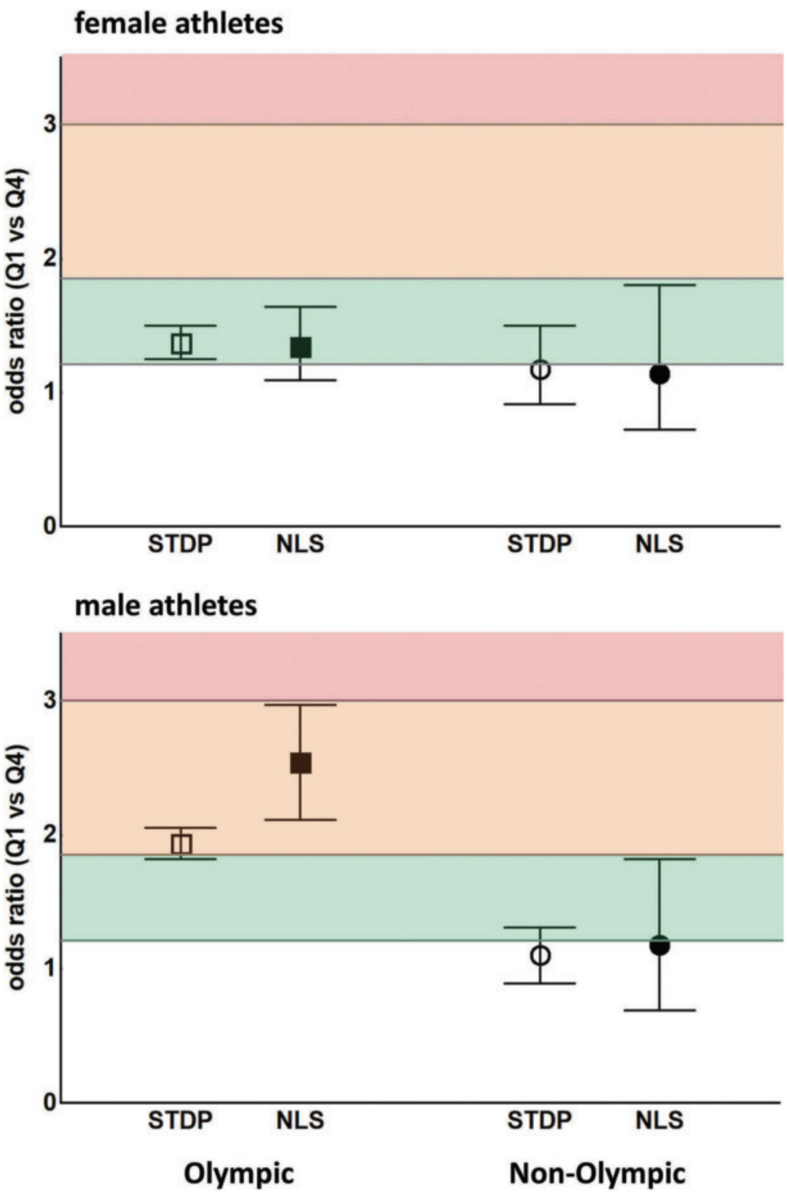

Figure 2. Relative age effects (RAE) in the Swiss talent development programme (STDP; regional to national level; open squares and circles) and the national level selection (NLS; national to international level; filled squares and circles; squares indicate Olympic sports, circles non-Olympic sports). Odds ratios (OR) for the frequency of athletes born in the first quarter of the year relative to athletes born in the last quarter of the year (females, upper panel; males, lower panel; the coloured bars indicate a large (red), medium (orange) and small (green) RAE).

which have been already described and discussed in literature, might include (a) improving coach education in sports at high risk of RAE, (b) building categories by biological age, weight or height (Musch & Grondin), (c) quotas of same RAE quarters, (d) rotating cut-off dates (Cobley et al., 2009) and (e) RAE correction factors in centimetre-gram-second sports (Romann & Cobley, 2015). As every selection increases RAE, selection as late as possible, at best after age at peak height velocity, may also contribute to reducing RAE. In Switzerland, talent identification, selection and development should be considered as a long-term process. Moreover, reducing RAE in the Swiss sport system would make long-term athlete development more legitimate and effective.

Disclosure statement

No potential conflict of interest was reported by the authors.

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SYSTEMATIC REVIEW

Relative Age Effects Across and Within Female Sport Contexts: A Systematic Review and Meta-Analysis

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Abstract

Background Subtle differences in chronological age within sport (bi-) annual-age groupings can contribute to immediate participation and long-term attainment discrepancies; known as the relative age effect. Voluminous studies have examined relative age effects in male sport; however, their prevalence and context-specific magnitude in female sport remain undetermined.

Objective The objective of this study was to determine the prevalence and magnitude of relative age effects in female sport via examination of published data spanning 1984–2016.

Methods Registered with PROSPERO (No. 42016053497) and using Preferred Reporting Items for Systematic Reviews and Meta-analysis systematic search guidelines, 57 studies were identified, containing 308 independent samples across 25 sports. Distribution data were synthesised using odds ratio meta-analyses, applying an invariance random-effects model. Follow-up subgroup category analyses examined whether relative age effect magnitudes were moderated by age group, competition level, sport type, sport context and study quality.

Results When comparing the relatively oldest (quartile 1) vs. youngest (quartile 4) individuals across all female sport contexts, the overall pooled estimate identified a significant but small relative age effect (odds ratio = 1.25; 95% confidence interval 1.21–1.30; $p = 0.01$; odds ratio adjusted = 1.21). Subgroup analyses revealed the relative age effect magnitude was higher in pre-adolescent ($\leq$ 11 years) and adolescent (12–14 years) age groups and at higher competition levels. Relative age effect magnitudes were higher in team-based and individual sport contexts associated with high physiological demands.

Conclusion The findings highlight relative age effects are prevalent across the female sport contexts examined. Relative age effect magnitude is moderated by interactions between developmental stages, competition level and sport context demands. Modifications to sport policy, organisational and athlete development system structure, as well as practitioner intervention are recommended to prevent relative age effect-related participation and longer term attainment inequalities.

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Key Points

Relative age effects have a small but consistent influence on female sport.

Relative age effect magnitudes are moderated (i.e. increased or reduced) by the factors of participant age, competition level, sport type and sport context under examination.

Modifications to the organisational structure of sport and athlete development systems are recommended to prevent relative age effect-related inequalities.

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1 Introduction

Whether considered from an athlete development or public health perspective, the dynamic factors influencing sport participation and achievement are of key interest to researchers, policy makers, sport organisations and their practitioners. In terms of athlete development, Baker and Horton [1] highlight how the path to expertise is a complex process, reflecting an interplay of direct (e.g. genetic makeup; quantity and quality of training) and indirect factors (e.g. coaching knowledge and expertise; social-cultural milieu [2]). In this process, one indirect factor, relative age, has emerged as a consistent influence on both immediate sport participation and longer term attainment [3–5].

With the goal of grouping children and adolescents according to similar developmental stages, 1- or 2-year chronological age groupings are common in youth sport. However, variations in age remain, leading to participation and attainment (dis)advantages. Relative age effects (RAEs) [6–8] refer to those (dis)advantages and outcomes that fundamentally result from an interaction between one's birthdate and the dates used to logistically organise participants [9]. Sporting RAEs in junior and youth athlete participants are commonly reflected by an over-representation of the relatively older individual. The relatively older individual is advantaged in terms of athletic selection and achievement [10], but may also be at a greater risk of injury owing to the increased sport exposure associated with higher competitive levels, such as an increased number of games/matches and training time [11]. While RAEs and selection biases can lag into adult sports, recent evidence suggests that in the long term the relatively older individual is less likely, in proportion to those selected in athlete development programmes, to go on to attain elite sporting echelons [4, 12, 13]. Thus, both perceived advantages and disadvantages of RAEs are undesirable for athlete development [14].

1.1 Brief Background on Relative Age Effects

Relative age effects were initially recognised in the education system [15–17] and only identified in sport some several decades later. Grondin et al. [18] first reported an unequal distribution of birthdates among Canadian ice hockey players. Across various skill levels, those born in the first quartile[1] of a same-age group were over-represented relative to those born in the last quartile. At a similar time, Barnsley and Thompson [19] observed comparable relative age inequalities in 'top tier' minor hockey teams (i.e. 11 years and older), Canadian elite developmental and National Hockey League [6] players. Since these early studies, RAEs have been identified across a variety of team sport and cultural contexts including North American and European ice hockey [20–22] as well as soccer [23, 24] and rugby worldwide [10, 25, 26]. RAEs are also documented in individual sports such as swimming [27, 28], tennis [27, 29, 30] and alpine skiing [31, 32]. That said, RAEs are not ubiquitous as the effect has not been consistently observed in adult senior professional sport [33, 34] and is absent in sports dependent on technique or skill rather than physical attributes *per se* (e.g. golf [35]; shooting sports [36]).

In a prior meta-analysis of research evidence (spanning studies published from 1984 to 2008), the relative age distribution of 130,108 (predominantly male) sport participants from 253 independent samples contained within 38 studies from 16 countries and 14 sports were examined [37]. Consistent overall RAEs were identified with a small-to-moderate effect size [quartile 1 ($Q1$) vs. quartile 4 ($Q4$) odds ratio (OR)[2] = 1.65, 95% confidence interval (CI) 1.54–1.77]. Further, subgroup analyses revealed that age, competition level and sport context moderated RAE magnitude. Specifically, RAE risk increased with age from child (> 11 years; OR estimate = 1.22) to adolescent (15–18 years; OR = 2.36) age categories, before declining at senior levels ($\geq$ 19 years OR = 1.44). RAEs increased from recreational (OR = 1.12) to pre-elite (OR = 2.77) competition levels; though with a lower risk in adult elite contexts (OR = 1.42). Five team sports exhibited consistent $Q1$ vs. $Q4$ over-representations with the highest magnitudes associated with basketball (OR = 2.66), soccer (OR = 2.01) and ice hockey (OR = 1.62). Findings from this review subsequently contributed to the focus and emphasis of onward RAE studies, including recommendations for examining female sport contexts.

1.2 Explanations for Relative Age Effects

In their narrative review, Musch and Grondin [7] proposed that the underlying causes of RAEs were potentially multifactorial, referring to a combination of physical, cognitive, emotional, motivational and social factors. Whilst acknowledging this possibility, the most common data-

[1] The first quartile corresponds to the first 3 months following the sport-designated cut-off date used to group participants by age. For instance, the first quartile in a system using 1 August as a cut-off would correspond to August, September and October.

[2] An odds ratio (OR) represents the odds, or likelihood, that an event will occur in one group compared to another. In this instance, the OR represents the odds that an athlete will be born in the first quartile (i.e. following a sport cut-off date) compared to the fourth quartile. An OR of one (1.00) would indicate that the outcome under investigation is equal in both groups, while an OR of two (2.00) would indicate the event is twice as likely to be observed in one compared to the other.

driven explanations have been associated with two interacting processes, notably maturation and selection (i.e. the 'maturation-selection' hypothesis) [9, 24, 37, 38]. The hypothesis suggests that greater chronological age is accompanied by favourable anthropometric (e.g. stature) and physical (e.g. muscular strength) characteristics, which may provide sporting performance advantages (e.g. soccer) [24]. While recognising that maturational processes can deviate substantially between individuals, it is conceivable that a relatively older individual may experience puberty-associated transformations (e.g. generally 12–14 years of age in girls and 13–15 years of age in boys [37, 39–42]) prior to relatively younger peers. From this point and until maturation termination, the anthropometric and physical variations between similar age peers may be exacerbated further. During this time, the relatively older and/or early maturing individual may appear more talented as a result of anthropometric/physical advances rather than skill level, and be selected for representative levels of sport. With selection, additional benefits may occur such as access to higher quality training and coaching expertise [38]; which translate into further advantages in terms of sport-specific skills and experience. For the relatively younger and later maturing individual, overcoming the physical and performance advantages may be extremely challenging in sports system structures incorporating stable and fixed (bi-) annual age grouping policies and accompanying selection and competition calendars [43, 44].

As a result of maturation-selection processes, RAEs are highlighted as discriminating against the relatively younger and later maturing individual [45], and are implicated in eliminating athletic potential before having the (equitable) opportunity to develop sport expertise [37, 39]. In fact, it has been proposed that the relatively younger individual is more likely to encounter negative sport experiences and terminate sport participation earlier [46]; particularly at stages when selection and representative tiers of participation are introduced in athlete development systems [14]. Those discrepancies are not surprising when social-cultural values emphasise elitism, which may continue to drive selection and talent identification processes despite negative outcomes (e.g. injury and burnout [47, 48]) and the low predictability of success even at the pre-elite level [49, 50].

Though with a lesser volume of supporting evidence, psychological [51] and socio-cultural explanations [7] have also been highlighted [22, 52, 53]. For instance, the 'depth of competition' hypothesis describes how the ratio of players available for playing rosters and positions could influence an individual's likelihood of participating or being selected for team membership. If a significant imbalance is present (i.e. a high number of athletes are competing for a small number of playing opportunities), the level of competition experienced by players striving to obtain a position is inflated, potentially magnifying the influence of relative age within a cohort. Therefore, the interest (or popularity) and availability (resource) imbalance in a sport system could account for RAE magnification [7, 52, 54, 55]. Parental influence may also attenuate trends at the time of initial sport involvement [9]. Some evidence suggests parents may be hesitant to register a later-born (potentially physically smaller) child in the early years of participation, as reflected in lower registration numbers of relatively younger participants [20, 56]. Selection processes are also notably absent at these early levels, and emphasis is placed on participation and beginner skill development. Thus, the contributing mechanisms outlined in the 'maturation-selection' hypothesis should be negligible.

1.3 Rationale for a Meta-Analysis

It has frequently been reported that RAE magnitudes are greater in male than female samples [39], even when participation numbers are equal [52]. This may be a reasonable conclusion when the breadth of sport differences between the sexes is considered (e.g. media attention, sport-specific funding, cultural acceptance of athletes, level of physicality), in addition to the proposed influences from maturation. Yet in Cobley et al.'s meta-analysis [37], findings suggested little evidence of overall sex difference in pooled OR estimates; though only 2% of participants (24 samples) had been tested for RAEs in female sport in 2008. What therefore remains unknown is whether RAEs are prevalent across and within female sport contexts; the magnitude of their effect; contexts associated with higher and lower RAE risks; and akin to male sport contexts, whether developmental time points are associated with higher RAE effect sizes. There has been a surge in female samples in the published literature and a review of female RAE studies is therefore timely and necessary to answer these questions.

1.4 Study Objective

The purpose of this systematic review and meta-analysis was to determine RAE prevalence and magnitudes across and within female sport participation. To achieve the objective, the published literature (1984–2016) examining relative age (quartile) distributions in female sports was synthesised using OR analyses. To identify moderators of RAE magnitude, identified samples were analysed in subgroups according to age, competition level, sport type and sport context categories. Based on existing literature, it was hypothesised that RAEs were prevalent across female sport; and, that the highest RAE risks in female sport contexts would be observed immediately prior to and during adolescence (i.e. 12–14 years of age) in comparison to early childhood and post-maturation/adult samples. RAEs were also expected to increase with selection across representative (competitive) tiers of sport participation. RAE magnitudes were expected to then progressively minimise following maturation (i.e. beyond 15 years of age) and remain low in recreational sport. At higher competition levels, it was expected that RAEs would persist through pre-elite levels though reducing with age and entry into professional contexts.

2 Methods

Procedural steps employed in completing the systematic and meta-analytical review adhered to both the Preferred Reporting Items for Systematic Reviews and Meta-analysis guidelines [57] and PROSPERO guidelines (Registration No. 42016053497).

2.1 Inclusion and Exclusion Criteria

Inclusion criteria stipulated that only peer-reviewed studies examining RAEs in female sport contexts would be included. Studies could be in any language and assess any age range, level or form of participation (e.g. elite or recreational). Studies examining associated topics (e.g. maturation or sport dropout) were included if they explicitly reported relative age distributions or reported RAE trends. Studies were excluded if they: (1) exclusively examined male athletes or sex was not identified; (2) failed to report relative age distribution on their participants; (3) examined RAEs in school sport or physical education; (4) examined other outcomes (e.g. fitness, fundamental movement skills, physical activity); (5) examined RAE interventions or solutions; (6) included older (Master) athletes where participation distributions were confounded by ageing processes; (7) examined other developmental or behavioural outcomes (e.g. leadership, anxiety); and (8) examined cognitive performance (e.g. chess).

2.2 Systematic Search

Published RAE studies were identified via systematic searching of electronic databases, scanning the reference lists of identified papers and existing meta-analyses [37, 58], and reviewing e-mail alerts from research databases. Six electronic databases were searched: CINAHL, MEDLINE via OVID, Scopus, Sports Discus, Web of Science and PsycINFO (APAPsycNET) with no restriction on publication date. Search terms were categorised into three groups: (1) Relative age (relative age OR relative age effect* OR age effect* OR birthdate/birth date effect* OR season of birth OR RAE OR age position); AND (2) Female (e.g., female* OR girl* OR wom?n;); AND (3) Sport (sports/sport* OR game* OR league*). Results were then limited to (1) humans, and (2) female. The search process was completed between January and March 2017. Following the search, the first author (KS) removed duplicates and screened titles/abstracts. If there was uncertainty as to whether inclusion criteria were met, study eligibility was determined by KS and SC. The majority of these studies were published in English, though two were found in Spanish and one each in Chinese and French respectively. The Spanish papers were translated using Google Translate. The Chinese study was reviewed by a native speaker, while the French study was reviewed by a bilingual Canadian. Refer to Fig. 1 for a summary of study screening and selection.

2.3 Data Extraction

The systematic search yielded 57 studies spanning 1984–2016 and specific information was then extracted, including: author(s), year of publication, location, sample characteristics (e.g. age, nationality, number of participants), sport setting (e.g. type of sport, level of competition), competition year, method of grouping athletes, relative age distributions (e.g. quartiles) and the distributions used for comparison purposes (e.g. 25% per quartile, population birth rates). Corresponding authors were contacted when any information was not provided or where further clarity was needed (e.g. age or competition level).[3] In total, 22 authors were contacted. Nine provided the requested information; seven were unable to provide the required information (e.g. data no longer accessible); four failed to respond, and two could not be located. Data from 44 of the 57 studies were used where possible in overall meta- and subgroup analyses. In cases where participant numbers were not reported, but presented in tables or figures, estimates were extracted.[4] Samples that could not be used owing to missing information were still assessed for methodological quality and reported in review summary tables.

[3] Identification of sample age and/or an age-group breakdown were the most common sources of missing information.

[4] Participant numbers were estimated from tables (i.e. overall sample numbers and percentage of participants per quartile were provided, but raw numbers per quartile were not available) by calculating an estimation of the number per quartile using the available values and rounding to the nearest whole number if required. Participant numbers were estimated from figures (i.e. presented in a graph but raw numbers per quartile not provided) by extrapolating from the graph using a ruler and rounding to the nearest whole number if required. Estimated samples within studies are coded and highlighted in Table 3.

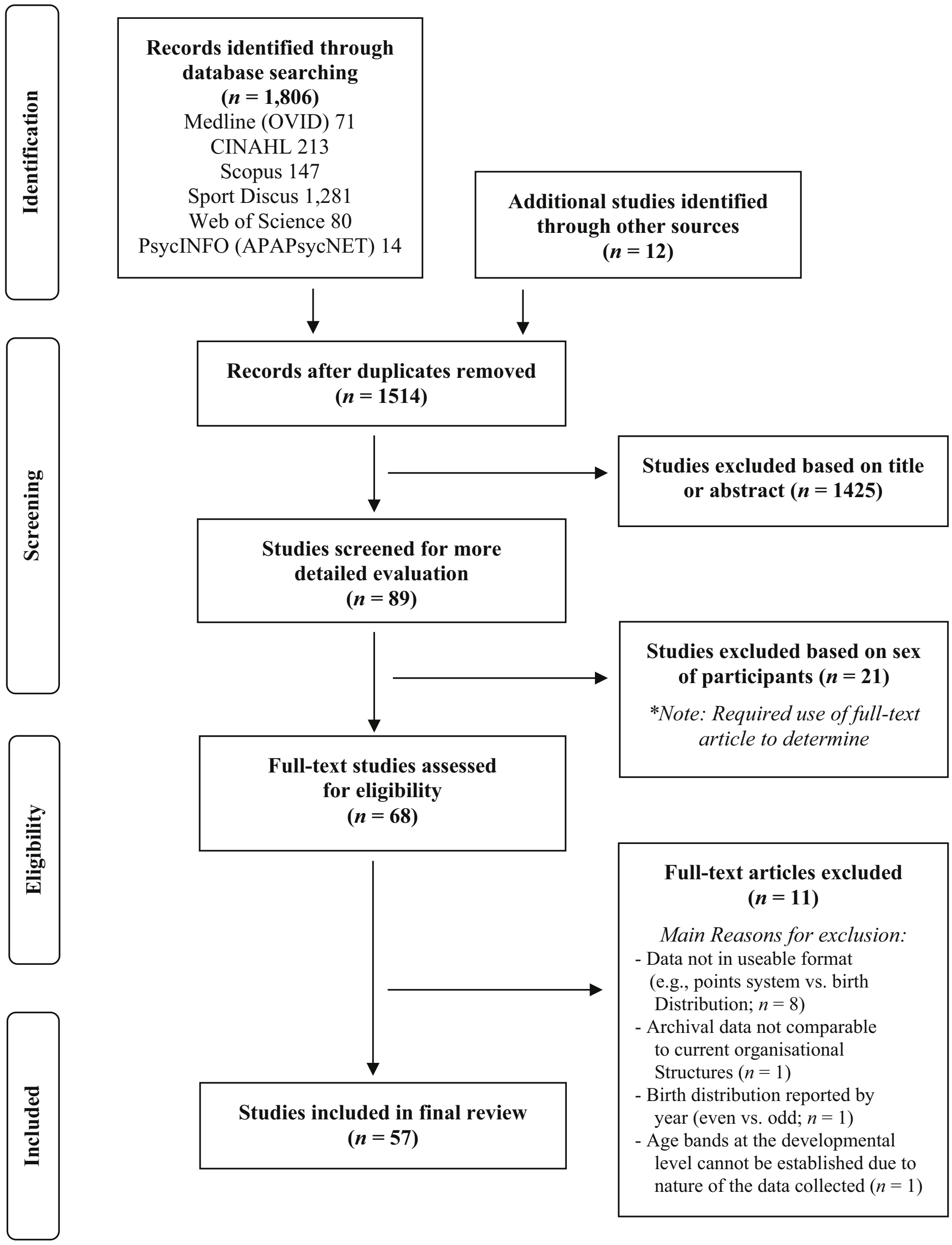

Fig. 1 Flow diagram for screening and selection of studies according to preferred reporting items for systematic reviews and meta-analysis [57]

2.4 Study Quality Assessment

An adapted version of the Strengthening the Reporting of Observational Studies in Epidemiology checklist [59] determined the quality of study reporting. The checklist included 14 items grouped into five categories: Abstract, Introduction, Methods, Results and Discussion. A score of '0' for "absent or insufficient information provided" or '1' "item is explicitly described" was assigned to items. An overall score of 5–9 was considered 'lower quality;' 10–11 'medium quality;' and 12–14 'high quality' [60]. Two independent reviewers (KT and MR) completed study quality assessment. Rating disagreements were resolved by KS and inter-rater reliability calculated.

2.5 Meta-Analyses: Data Inclusion and Exclusion

Data identified from the systematic search were included in meta-analyses. Inclusion criteria specified that with the exception of elite national levels, samples had to have examined ≥ 50 participants in a given age category or competition level to help avoid artificially inflating RAE estimates. Where samples of < 50 participants were apparent, but multiple independent samples in the sport context were reported (e.g. age categories, under 14, 15 and 16), these were collapsed in alignment with sport-designated age categories. Data from two studies were modified this way [25, 61]. Sport contexts where a participant may have been present in several samples, owing to multiple event entries (e.g. breaststroke and freestyle in swimming) were included as this was reflective of the organisational structures employed in the respective sport. However, studies that examined RAEs in multi-sport samples and a broader overall athlete population (e.g. Youth Olympic Games) were excluded because of inherent variability and a small sample size. Further, to keep the analysis relevant to modern participant trends, samples derived from archival data prior to 1981 were excluded. This competition year coincided with the first documented evidence of RAEs in sport [18], and corresponded to birthdates from the early 1960s onward. When applied, criteria yielded 308 independent samples from 44 studies. Retained samples examined 25 different sport contexts in at least 17 countries.[5] A range of junior-adult ages and a variety of competition levels (i.e. local community recreational to adult elite professional) were included.

2.6 Meta-Analyses

All data extracted were analysed using Comprehensive Meta-Analysis software (2005; Biostat, Inc., Englewood, New Jersey (USA)). An OR estimate, along with log OR and standard error, were calculated for each independent sample. For each sample, the relative age distributions observed (i.e. n $Q1$ vs. n $Q4$ participants) were compared relative to an expected frequency assuming equal distributions (e.g. $N = 100$, expected quartile count = 100/4 = 25). When comparing relative age quartiles in analyses, $Q4$ (i.e. relatively youngest) acted as the reference. Overall summary estimates were calculated using an invariance random-effects model [62], with the assumption that samples across studies were drawn from divergent populations across different sport contexts. Thus, an exact effect size was not expected to exist across samples.

Pooled OR estimates along with accompanying 95% CIs indicated whether overall effects existed in a given analysis. Accompanying Z- and p-values tested the null hypothesis that OR estimates between relatively older and younger distributions (i.e. $Q1$–$Q3$ vs. $Q4$ comparisons) were not statistically different. The Cochran Q statistic[6] [63] (with df and p) tested whether all studies shared a common effect size. I^2 identified the proportion of observed variance reflecting differences in true effect sizes as opposed to sampling errors. Moderate (> 50%) to high (> 75%) values were used to indicate values in subgroup analyses and to account for potential heterogeneity sources. T^2 provided the estimate of between-study variance in true effects, and T estimated the between-study standard deviation in true effects. When heterogeneity was detected, sources were explored using sub-stratification analysis with specific application to $Q1$ vs. $Q4$ data.

To determine the presence of publication bias, funnel plot asymmetry[7] was assessed with Log OR estimates plotted against a corresponding standard error. The Egger test [64] confirmed asymmetry. As a result, Duval and Tweedie's 'trim and fill' procedure[8] [65] was applied to determine whether estimates required adjustment based on missing studies. Asymmetry assessments and adjustments for all comparisons (i.e. $Q1$–$Q3$ vs. $Q4$) are reported.

2.7 Sub-Stratification (Subgroup) Analyses

To determine whether age moderated $Q1$ vs. $Q4$ pooled OR estimates, samples were categorised as pre-adolescent (≤ 11 years), adolescent (12–14 years [37, 39–42]), post-adolescent (15–19 years) and adult (> 19 years[9]). Samples where ages spanned across categories were excluded from the analysis. To determine whether the competition level moderated OR estimates, all samples were categorised based on an adaptation from Cobley et al. [37]: recreational (i.e. typified by an absence of selection or official competition), competitive (i.e. local community level with structured competition), representative (i.e. regional or

5 Seventeen different countries were named in the literature. However, the total number represented may be larger as some studies reported "international" samples or participants from "across Europe".

6 The Cochran Q test [63] assesses true heterogeneity in a meta-analysis. In essence, Q is a measure of dispersion of all effect sizes (individual studies) about the mean effect size (overall pooled effect) on a standardised scale.

7 A funnel plot is a scatter plot of treatment effect (e.g. odds ratio) set against a measure of study size (e.g. standard error). It provides an initial visual aid to detect bias or systematic heterogeneity. In the absence of heterogeneity, 95% of the studies should lie within the funnel defined by the two diagonal lines. Publication bias is suggested when there is asymmetry in the plot.

8 'Trim and fill' uses an iterative procedure to remove the most extreme (small) studies from the positive side of the funnel plot, re-computing the effect size at each iteration until the funnel plot is symmetric about the (new) effect size. In theory, this yields an unbiased estimate of the effect size. While trimming yields the adjusted effect size, it also reduces the variance of the effects, yielding a (too) narrow confidence interval. Therefore, the algorithm then adds the original studies back into the analysis and imputes a mirror image for each [65].

9 The 90th percentile female individual attains adult stature at 20 years of age when a criterion of four successive 6-month increments < 0.5 cm is used [66].

provincial representative levels based on selection) and elite (i.e. competition at an international level or a career athlete). Elite was further subdivided into adolescent, post-adolescent, adult and combination categories following age divisions outlined above. If competition level was unclear, data were added to a 'not codable' subgroup for analysis. To determine if the type of sport context moderated OR estimates, samples were categorised into team and individual types.

Consistent with prior work [67], team sports were those often played with multiple team members (i.e. more than one participant per team), while individual sports were those involving a single participant in a given event or in direct competition against another. Individual sports were further subdivided into those deemed physically demanding (i.e. predominantly determined by strength or endurance for example [68, 69]); technique- or skill-based sports, typically identified by the judging of movement criteria [68, 69]; and contexts using weight classifications or categories [70]. To determine whether particular sport contexts moderated RAEs, data related to each sport context (e.g. volleyball, swimming) were combined and pooled estimates generated. Finally, to determine if study quality moderated pooled estimates, samples were categorised into three groups (i.e. lower quality, scores 5–9 = 13 studies; medium, scores 10–11 = 23 studies; and, higher, scores 12–14 = 21 studies) based on a tertile division of the overall scores obtained on the study quality assessment criteria, as outlined in Sect. 2.4.

3 Results

3.1 Studies Systematically Identified

Figure 1 summarises the systematic search and study selection process. Initial database searches identified 1806 studies with 12 studies identified through other sources. Following title and abstract screening, 89 full-text articles were selected for further review. Twenty-one of these were removed as they examined male sport contexts (not reported in abstracts); while 11 were removed as they did not report relative age (quartile) comparisons in a useable format (see Fig. 1). Overall, 57 studies met inclusion and reporting criteria.[10]

3.2 Study Quality

Table 1 summarises study quality ratings assessments. Twenty-one of 57 (36.8%) were considered 'higher quality' according to the RAE-modified Strengthening the Reporting of Observational Studies in Epidemiology checklist [59]. Twenty-three (40.4%) were deemed 'medium quality.' Thirteen studies (22.8%) were considered 'lower quality;' owing to limited reporting of methodological and analysis details. Criteria commonly absent in reporting were related to the handling of missing data and/or duplicate entries for an individual athlete (i.e. when multiple competition years were assessed from the same sport context and an athlete may have been represented on multiple rosters); an absence of post hoc comparisons between quartiles; reporting of effect size; and, not identifying study limitations/biases. The inter-rater correlation between KS and independent reviewers was 0.92 and 0.88, respectively.

3.3 Summary of Sample Distributions

With consideration of the annual cut-off dates employed in each respective sport context (e.g. 1 August, 1 January), the descriptive relative age distributions for the total sample of 646,383 female sport participants (former or present) in 308 independent samples identified an uneven distribution (i.e. $Q1 = 25.97\%$; $Q2 = 26.32\%$; $Q3 = 25.13\%$; $Q4 = 22.58\%$). Table 2 provides a summary of unadjusted OR estimates for each independent sample within each study.

Table 3 summarises the distribution of total sample numbers according to subgroup categories. Samples were fairly evenly distributed across age categories, with adult (> 19 years; 5.58%) and post-adolescence (15–19 years; 30.53%) containing the lowest and highest numbers respectively; with 13% approximately not readily age categorised (i.e. sample age crossed the designated age groupings for subgroup analyses). In terms of competition level, 57.12% contained recreational level participants, with considerably smaller competitive (7.32%), representative (1.87%), elite adolescent (12–14 years; 0.08%), elite post-adolescent (15–19 years; 0.83%), elite adult (> 19 years; 0.34%) and elite combination (i.e. not codable by age; 2.43%) involvement. Thirty percent of sample numbers could not be clearly coded into a competition-level category, mainly owing to limited contextual information provided in study reporting. For sport type, samples were evenly distributed (154) between team and individual sport contexts. Within the individual subcategories, more samples (28.57%) and participant numbers (51.42%) were engaged in physically demanding contexts. Meanwhile, technique/skill-based and weight-categorised contexts contained 3.93% and 0.37% of total participants, respectively. The sport contexts with the largest sample sizes represented (in order) were: alpine skiing (31.2% of athletes), basketball (16.9%), ice hockey (12.4%), soccer (11.5%), tennis (9.63%), and track and field (9.56%).

[10] Fifty-seven studies met inclusion criteria for the systematic review; 44 had useable data that could be included in the overall meta- and subgroup analyses.

Table 1 Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [59]

	#1	#2	#3	#4	#5a,b,c	#6	#7a,b	#8	#9	#10a,b	#11	#12	#13	#14	Score/14
Albuquerque et al. [100]	0	1	1	0	(0,1,1) 0	1	(1,0) 0	1	1	(0,0) 0	1	0	0	1	7
Albuquerque et al. [101]	1	1	1	1	(0,1,1) 0	1	(1,0) 0	1	1	(0,0) 0	1	1	0	1	10
Albuquerque et al. [70]	0	1	0	1	(0,1,1) 0	1	(1,0) 0	1	1	(0,1) 0	1	1	0	1	8
Arrieta et al. [80]	0	0	1	1	(0,1,1) 0	1	(1,0) 0	1	1	(0,0) 0	1	0	0	1	7
Baker et al. [52]	1	1	1	1	(1,1,0) 0	1	(1,0) 0	1	1	(0,1) 0	1	1	1	1	11
Baker et al. [78]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(0,1) 0	1	1	1	1	12
Bidaurrazaga-Letona et al. [102]	1	1	1	0	(1,1,1) 1	1	(1,1) 1	1	1	(0,0) 0	1	0	1	1	11
Brazo-Sayavera et al. [103]	1	1	1	1	(1,1,1) 1	0	(1,0) 0	1	1	(1,1) 1	1	0	1	0	10
Chittle et al. [104]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,1) 1	1	0	1	1	13
Costa et al. [28]	1	1	1	1	(1,1,1) 1	0	(1,0) 0	1	1	(0,0) 0	1	1	1	1	11
Delorme and Raspaud [36]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,0) 0	0	0	1	1	11
Delorme and Raspaud [105]	0	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,0) 0	0	0	1	1	10
Delorme et al. [34]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,0) 0	0	0	1	1	11
Delorme et al. [56]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(0,0) 0	1	0	1	1	11
Delorme [106]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,0) 0	1	1	1	1	13
Dixon et al. [107]	0	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(1,1) 1	1	1	1	1	12
Edgar and O'Donoghue [29]	1	1	1	1	(0,1,1) 0	1	(1,0) 0	1	1	(0,0) 0	1	1	1	1	11
Fukuda [108]	1	1	1	1	(0,1,1) 0	0	(1,1) 1	1	1	(0,1) 0	1	1	1	1	11
Giacomini [30]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(0,0) 0	1	1	0	0	10
Gorski et al. [109]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(1,1) 1	1	1	1	1	13
Grondin et al. [18]	1	1	1	1	(1,1,1) 1	1	(0,0) 0	0	1	(1,0) 0	1	1	1	1	11
Hancock et al. [84]	1	1	1	1	(1,1,1) 1	0	(1,0) 0	1	1	(0,1) 0	1	0	1	1	10
Hancock et al. [110]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,1) 1	1	1	1	1	14
Helsen et al. [23]	1	1	1	1	(1,1,0) 0	1	(1,0) 0	1	1	(0,0) 0	0	0	1	1	9
Lemez et al. [25]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,1) 1	1	1	1	1	14
Lidor et al. [111]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(0,1) 0	1	0	1	1	11
Liu and Liu [112]	1	0	1	0	(0,0,0) 0	0	(0,0) 0	0	0	(0,0) 0	1	1	1	0	5
Muller et al. [32]	0	1	1	1	(0,1,1) 0	1	(1,0) 0	0	1	(1,0) 0	1	1	0	1	8
Muller et al. [82]	1	1	1	1	(0,1,1) 0	1	(1,0) 0	1	1	(0,1) 0	1	1	1	0	10
Muller et al. [69]	0	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,1) 1	1	1	1	1	13
Nagy et al. [113]	0	1	0	0	(1,0,1) 0	0	(0,0) 0	1	1	(0,0) 0	1	0	1	1	6
Nakata and Sakamoto [33]	0	1	0	1	(0,1,0) 0	1	(0,1) 0	1	1	(0,1) 0	1	0	0	0	6
O'Donoghue [114]	1	1	1	1	(0,1,1) 0	0	(1,0) 0	1	1	(0,1) 0	1	0	1	1	9
Okazaki et al. [81]	0	1	1	1	(1,1,1) 1	0	(1,0) 0	1	1	(0,0) 0	0	0	1	1	8
Raschner et al. [68]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,0) 0	1	1	1	1	13
Romann and Fuchslocher [115]	1	1	1	1	(1,1,0) 0	1	(1,0) 0	1	1	(1,1) 1	1	0	1	1	11
Romann and Fuchslocher [116]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(1,1) 1	1	1	1	1	13
Romann and Fuchslocher [61]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(1,1) 1	1	0	1	1	12
Romann and Fuchslocher [31]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(1,1) 1	1	0	1	1	12
Saavedra-García et al. [79]	1	1	1	1	(1,0,1) 0	0	(1,0) 0	1	1	(1,1) 1	1	0	1	1	10
Saavedra-García et al. [117]	0	1	1	0	(1,0,1) 0	1	(1,0) 0	1	1	(0,1) 0	1	0	1	1	8
Saavedra-García et al. [118]	0	1	1	1	(0,1,1) 0	1	(1,0) 0	1	1	(1,1) 1	1	0	0	0	8
Schorer et al. [55]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,1) 0	1	0	1	1	12
Schorer et al. [119]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,1) 0	1	1	1	1	13
Schorer et al. [120]	0	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,1) 0	1	1	1	1	12
Schorer et al. [121]	0	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,1) 0	1	1	1	1	12
Schorer et al. [53]	1	1	1	1	(0,1,1) 0	1	(1,0) 0	1	1	(0,1) 0	1	1	1	1	11
Sedano et al. [122]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(1,1) 1	1	0	0	1	11

Table 1 continued

	#1	#2	#3	#4	#5a,b,c	#6	#7a,b	#8	#9	#10a,b	#11	#12	#13	#14	Score/14
Smith and Weir [20]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,1) 1	1	1	1	1	14
Stenling and Holmstrom [21]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,1) 1	1	1	1	1	14
Till et al. [10]	1	1	1	1	(1,1,1) 1	1	(1,0) 0	1	1	(1,1) 1	1	1	1	1	13
van den Honert [123]	0	1	0	0	(1,1,0) 0	1	(1,0) 0	1	1	(0,1) 0	1	0	1	0	6
Vincent and Glamser [124]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,0) 0	0	0	1	1	11
Wattie et al. [22]	1	1	1	1	(0,1,1) 0	1	(1,1) 1	1	1	(0,0) 0	1	0	1	0	10
Wattie et al. [98]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(1,1) 1	1	1	1	1	14
Weir et al. [85]	1	1	1	1	(1,1,1) 1	1	(1,1) 1	1	1	(0,1) 0	1	0	1	1	12
Werneck et al. [125]	1	1	1	1	(1,0,1) 0	1	(0,0) 0	1	1	(0,0) 0	1	1	0	1	10

0 = Item criterion is absent or insufficiently information is provided; 1 = item criterion is explicitly described and met

#1. In the abstract, an informative and balanced summary of what was done and what was found is provided. #2. Explain the scientific background and rationale for the investigation being reported. #3. State clear, specific objectives and/or any pre-specified hypotheses. #4. Describe the setting, locations, and relevant dates for data collection. This must include information on sport context, type, level of competition, and competition year(s) for data collected to be scored as a '1'. #5a. Give characteristics of study participants (must include: age, sex, skill level, overall number and nationality). #5b. Describe the procedure for selecting and grouping athletes in the context under examination (e.g. by birthdate or weight) and how participants were categorised for study purposes (e.g., application of a cut-off date to determine birth quartile). #5c. Describe the source and procedure for obtaining the sample (e.g., obtained from an online roster, provided by a sport governing body). #6. Explain and report the reference baseline distribution (e.g. equal distribution vs. population birth rate). #7a. Clearly describe all statistical methods, including specific analytical methods used to examine subgroups. #7b. Explain how duplicates (if applicable) and missing data were addressed or incomplete data were handled. #8. Report the number or percentage of participants found in each quartile/semester (and subcategory if applicable). #9. Provide statistical estimate(s) and precision (e.g. 95% confidence interval) for each sample or subgroup group examined. #10a. Post-hoc comparisons between quartiles (e.g. Q1 vs. Q4) are provided when appropriate (i.e., overall test is significant). #10b. A measure of effect size is provided (e.g. Cramer's V, phi coefficient, Cohen's w). #11. A summary of key results with reference to study objectives is provided. #12. Discusses limitations of the study, taking into account sources of potential bias, confounding factors or imprecision. #13. A cautious overall interpretation of results considering objectives and relevant evidence. #14. Discusses the generalizability of the study results to similar or other contexts. Total/14

3.4 Meta-Analyses

Based on 44 studies containing 308 independent samples, overall pooled data comparing participation distributions of the relatively oldest ($Q1$) with the relatively youngest ($Q4$) identified a significant, but small, OR estimate = 1.25 (95% CI 1.21–1.30; $Z = 13.74$, $p = 0.0001$). This suggested that the relatively older were 25% more likely to be represented. The Q statistic of 2135.50 ($df = 307$, $p = 0.01$) highlighted the true effect size was not similar across samples. The I^2 was 85.62, indicating approximately 85% of variance in the observed effects was due to true effects, while T^2 and T were 0.04 and 0.21 (in log units), respectively. A similar RAE magnitude was identified for $Q2$ vs. $Q4$ (i.e. OR = 1.24; 95% CI 1.21–1.27, $Z = 15.75$, $p < 0.01$) before reducing for $Q3$ vs. $Q4$ (OR = 1.13; 95% CI 1.11–1.15, $Z = 14.18$, $p < 0.01$), respectively. Akin to the $Q1$ vs. $Q4$ findings, heterogeneity was apparent ($Q2$ vs. $Q4$ $Q = 1335.29$, $df = 307$, $p < 0.01$, $I^2 = 77.02$; $Q3$ vs. Q4 $Q = 513.2$, $df = 307$, $p < 0.01$, $I^2 = 40.24$). Descriptive $Q2$ total participation numbers were marginally higher than $Q1$; thus, a $Q1$ vs. $Q2$ comparison was also conducted. No overall pooled OR differences were identified 0.99 (95% CI 0.97–1.01; $Z = -1.21$, $p = 0.23$). As evidence for heterogeneity was consistent, follow-up subgroup stratification analyses examined their potential sources using $Q1$ vs. $Q4$ data.

The asymmetry of funnel plots suggested publication bias was apparent. Inspection of Fig. 2 revealed that estimates with larger samples and more precise comparative estimates between $Q1$ and $Q4$ frequencies were distributed about the overall estimate. Further, there was a comparative absence to the 'left' of the pooled estimate in terms of less precise studies with more conservative estimates for $Q1$ vs. $Q4$ proportions. Asymmetry potentially may also have occurred as smaller powered published samples may have inflated pooled effect size estimates, resulting in a slight overestimation of the actual trend. Studies containing the largest samples were clustered symmetrically around overall effect size estimates. The Egger test for $Q1$ vs. $Q4$ confirmed asymmetry (intercept = 0.91, standard error = 0.20, $p < 0.01$). Duval and Tweedie's ''trim and fill'' procedure provided an adjusted pooled estimate of 1.21 (95% CI 1.15–1.25; $n = 39$ imputed samples). Nonetheless, the adjusted estimate remained significant and close to the original. Similar results were evident for $Q2$ vs. $Q4$ (adjusted OR = 1.19, 95% CI 1.16–1.22; $n = 34$) and $Q3$ vs. $Q4$ (adjusted OR = 1.11, 95% CI 1.09–1.13; $n = 38$). The

Table 2 Unadjusted odds ratios (OR) for independent female samples examining relative age effects in sports contexts

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Grondin et al. [18][††]	14–15	Volleyball	Provincial Cadet[Rp]	219	2.28 (1.30, 3.99)	2.13 (1.21, 3.73)	1.44 (0.80, 2.58)
	16–17	Volleyball	Provincial Juvenile[Rp]	188	1.26 (0.70, 2.25)	1.44 (0.81, 2.55)	1.13 (0.62, 2.04)
	17–19	Volleyball	Provincial Junior AA[Rp]	59	1.06 (0.39–2.87)	0.81 (0.29, 2.27)	0.81 (0.29, 2.27)
Helsen et al. [23][††]	U18	Soccer	Union des Associations Européennes de Football (UEFA)[E]	72	1.83 (0.70, 4.79)	2.17 (0.84, 5.58)	1.00 (0.36, 2.81)
Vincent and Glamser [124]	U19	Soccer	Olympic Development Program (ODP) State[Rp]	804	1.12 (0.85, 1.48)	1.15 (0.87, 1.51)	1.10 (0.83, 1.46)
	U19	Soccer	ODP Regional[Rp]	71	1.33 (0.52, 3.41)	1.53 (0.61, 3.87)	0.87 (0.32, 2.34)
	U19	Soccer	National team[E]	39	3.00 (0.78, 11.5)	1.40 (0.33, 5.97)	2.40 (0.61, 9.44)
Liu and Liu [112][‡]	12	Soccer	China Football Association[Rp]	73	3.75 (1.36, 10.3)	2.50 (0.88, 7.11)	1.88 (0.64, 5.50)
	13	Soccer		115	3.00 (1.39, 6.46)	1.56 (0.69, 3.52)	1.63 (0.72, 3.65)
	14	Soccer		163	2.33 (1.25, 4.36)	1.56 (0.81, 2.98)	1.15 (0.58, 2.25)
	15	Soccer		308	2.02 (1.28, 3.17)	1.35 (0.84, 2.15)	1.24 (0.77, 1.99)
	16	Soccer		1081	1.15 (0.91, 1.45)	0.93 (0.73, 1.18)	0.80 (0.62, 1.02)
Baker et al. [52][†]	Adult	Handball	German 1st League[Rp]	372	1.03 (0.69, 1.54)	0.94 (0.63, 1.41)	0.87 (0.57, 1.30)
	Adult	Handball	German 1st League[Rp]	145	1.06 (0.55, 2.03)	0.97 (0.50, 1.88)	1.12 (0.58, 2.13)
	Adult	Handball	German 2nd League[Rp]	345	1.07 (0.69, 1.65)	1.22 (0.79, 1.87)	1.38 (0.91, 2.11)
	Adult	Handball	German 1st League[Rp]	100	0.88 (0.39, 1.98)	1.04 (0.47, 2.28)	1.27 (0.59, 2.74)
	Adult	Handball	German 2nd League[Rp]	270	1.36 (0.83, 2.22)	1.29 (0.79, 2.10)	1.45 (0.89, 2.36)
	Adult	Handball	International players: German 1st League[Rp]	110	1.04 (0.49, 2.20)	0.93 (0.43, 1.98)	1.11 (0.53, 2.34)
	Adult	Handball	German 1st League[Rp]	50	1.40 (0.45, 4.33)	2.00 (0.67, 5.96)	0.60 (0.17, 2.16)
	Adult	Handball	German 2nd League[Rp]	56	0.87 (0.30, 2.47)	0.87 (0.30, 2.47)	1.00 (0.36, 2.80)
	U15, U17, U18	Soccer*	National team[E]	207	4.17 (2.21, 7.87)	3.44 (1.81, 6.56)	2.50 (1.29, 4.84)
	U20, U23, Adult	Soccer*	National team[E]	573	1.15 (0.82, 1.62)	1.50 (1.08, 2.09)	1.35 (0.97, 1.89)
Delorme et al. [34][††]	Adult	Soccer	Professional[E]	242	1.48 (0.88, 2.48)	1.41 (0.84, 2.37)	1.37 (0.81, 2.31)
	Adult	Basketball	Professional[E]	92	1.13 (0.51, 2.50)	1.04 (0.47, 2.33)	0.67 (0.28, 1.57)
	Adult	Handball	Professional[E]	154	1.25 (0.66, 2.38)	1.28 (0.67, 2.44)	1.28 (0.67, 2.44)
Delorme and Raspaud [36][††]	U11	Shooting	French Federation for Shooting Sports (FFT) [Rc/C]	284	1.11 (0.69, 1.77)	1.22 (0.76, 1.93)	1.05 (0.65, 1.68)
	11–12	Shooting		476	0.99 (0.69, 1.42)	1.00 (0.70, 1.43)	1.01 (0.70, 1.44)
	13–14	Shooting		510	1.05 (0.74, 1.49)	1.11 (0.79, 1.58)	1.02 (0.72, 1.44)
	15–16	Shooting		798	1.16 (0.89, 1.53)	0.94 (0.71, 1.25)	0.98 (0.74, 1.30)
	18–20	Shooting		584	1.14 (0.82, 1.58)	1.07 (0.77, 1.48)	1.06 (0.76, 1.47)
	Adult	Shooting		10171	1.04 (0.97, 1.13)	1.12 (1.03, 1.21)	1.09 (1.01, 1.18)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval) *Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Delorme and Raspaud [105]††	7	Basketball	Youth categories of the French Basketball Federation (FFBB)[Rc]	7590	1.21 (1.10, 1.32)	1.27 (1.16, 1.39)	1.16 (1.06, 1.27)
	8	Basketball		9518	1.18 (1.09, 1.28)	1.24 (1.14, 1.34)	1.10 (1.01, 1.19)
	9	Basketball		11,613	1.21 (1.12, 1.30)	1.25 (1.16, 1.34)	1.13 (1.05, 1.22)
	10	Basketball		12,734	1.16 (1.08, 1.24)	1.20 (1.12, 1.29)	1.11 (1.04, 1.19)
	11	Basketball	Youth categories of the FFBB[Rc/C]	11,078	1.23 (1.14, 1.32)	1.28 (1.18, 1.38)	1.15 (1.07, 1.24)
	12	Basketball		10,613	1.29 (1.19, 1.39)	1.32 (1.22, 1.42)	1.18 (1.09, 1.27)
	13	Basketball		10,832	1.36 (1.26, 1.46)	1.28 (1.18, 1.38)	1.23 (1.13, 1.32)
	14	Basketball		10,701	1.26 (1.16, 1.36)	1.28 (1.18, 1.38)	1.14 (1.06, 1.24)
	15	Basketball		8780	1.22 (1.12, 1.33)	1.32 (1.21, 1.44)	1.21 (1.11, 1.32)
	16	Basketball		7522	1.23 (1.12, 1.35)	1.32 (1.20, 1.44)	1.14 (1.04, 1.25)
	17	Basketball		6123	1.29 (1.17, 1.43)	1.41 (1.27, 1.56)	1.19 (1.07, 1.32)
O'Donoghue [114]††††	13	Tennis	ITF Junior Tour (2003)[E]	59	2.44 (0.85, 7.05)	1.78 (0.60, 5.29)	1.33 (0.43, 4.11)
	14	Tennis		176	2.50 (1.36, 4.58)	1.36 (0.71, 2.58)	1.43 (0.75, 2.71)
	15	Tennis		313	2.33 (1.46, 3.73)	1.87 (1.16, 3.01)	1.76 (1.08, 2.84)
	16	Tennis		397	1.61 (1.07, 2.41)	1.55 (1.03, 2.33)	1.44 (0.95, 2.17)
	17	Tennis		343	1.29 (0.84, 1.98)	1.26 (0.82, 1.94)	1.21 (0.78, 1.86)
	18	Tennis		217	1.12 (0.66, 1.90)	1.25 (0.74, 2.12)	0.88 (0.51, 1.53)
	Senior (19+)	Tennis	Grand Slam tournament(s)[E]	211	1.94 (1.12, 3.38)	1.61 (0.92, 2.83)	1.31 (0.73, 2.33)
O'Donoghue [114]††††	13	Tennis	ITF Junior Tour (2008)[E]	62	34.0 (4.12, 280.3)	22.0 (2.63, 184.0)	5.00 (0.52, 47.9)
	14	Tennis		195	2.79 (1.55, 5.01)	1.39 (0.74, 2.61)	1.79 (0.97, 3.29)
	15	Tennis		357	1.91 (1.24, 2.95)	1.65 (1.06, 2.56)	1.70 (1.10, 2.64)
	16	Tennis		506	1.44 (1.01, 2.04)	1.33 (0.93, 1.90)	1.15 (0.80, 1.64)
	17	Tennis		450	0.99 (0.69, 1.43)	1.03 (0.71, 1.48)	0.93 (0.64, 1.35)
	18	Tennis		214	0.89 (0.52, 1.53)	1.00 (0.59, 1.71)	1.07 (0.63, 1.82)
	Senior (19+)	Tennis	Grand Slam tournament(s)[E]	183	1.83 (0.99, 3.37)	1.86 (1.01, 3.43)	1.62 (0.87, 3.01)
Above includes participant sample from Edgar and O'Donoghue [29]							
Schorer et al. [55]†	12–15	Handball	German: D-Squad (regional development system)[Rp]	333	1.90 (1.21, 3.00)	2.00 (1.27, 3.15)	1.63 (1.02, 2.58)
	15–17	Handball	D/C-Squad (youth national)[E]	502	3.01 (2.05,4.41)	2.39 (1.62, 3.53)	1.94 (1.31, 2.89)
	18–20	Handball	C-Squad (junior national)[E]	327	1.89 (1.21,2.96)	1.75 (1.12, 2.75)	1.20 (0.75, 1.92)
	19+	Handball	B-Squad (national team)[E]	138	2.70 (1.34, 5.41)	1.45 (0.69, 3.03)	1.75 (0.85, 3.61)
	19+	Handball	A-Squad (national team)[E]	434	0.97 (0.68, 1.39)	0.71 (0.49, 1.03)	0.59 (0.40, 0.87)
Sample above overlaps with Schorer et al. [121]							
Schorer et al. [119]†	13–15	Handball*	German national youth tryouts[Rp] *Note: Participants passed regional selection*	238	2.19 (1.29, 3.70)	1.81 (1.06, 3.09)	1.25 (0.72, 2.18)
Above includes participant sample from Schorer et al. [53, 120]							
Delorme et al. [56]††	U8	Soccer	French Soccer Federation (FSF)[Rc/C]	5434	1.29 (1.16, 1.43)	1.24 (1.12, 1.39)	1.15 (1.03, 1.28)
	U10	Soccer		7520	1.17 (1.06, 1.28)	1.22 (1.11, 1.33)	1.14 (1.04, 1.25)
	U12	Soccer		7774	0.99 (0.90, 1.08)	1.09 (1.00, 1.19)	1.04 (0.95, 1.14)
	U14	Soccer		5616	1.15 (1.04, 1.28)	1.17 (1.06, 1.30)	1.14 (1.02, 1.26)
	U17	Soccer		8784	1.03 (0.95, 1.12)	1.12 (1.03, 1.22)	1.06 (0.97, 1.15)
	Adult (18+)	Soccer		22,764	0.95 (0.91, 1.01)	1.04 (0.99, 1.09)	1.01 (0.96, 1.06)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Till et al. [10][††]	U14	Rugby	Rugby Football League[Rc]	190	1.15 (0.66, 2.02)	1.04 (0.59, 1.85)	0.93 (0.52, 1.67)
	U16	Rugby		174	1.49 (0.82, 2.69)	0.89 (0.48, 1.67)	1.32 (0.73, 2.41)
	Senior (17+)	Rugby		261	1.03 (0.64, 1.66)	1.00 (0.62, 1.62)	0.87 (0.53, 1.41)
Weir et al. [85][†]	U18	Ice hockey	Provincial team[Rp]	369	1.54 (1.01, 2.35)	1.77 (1.16, 2.69)	1.37 (0.89, 2.11)
	U18, U22, Senior	Ice hockey	National team[E]	291	1.72 (1.05, 2.80)	2.22 (1.38, 3.57)	1.39 (0.84, 2.29)
Above includes participant sample from Wattie et al. [22]							
Okazaki et al. [81][+]	13	Volleyball	Brazilian national youth tournament[Rp]	58	5.00 (1.50, 16.7)	3.80 (1.12, 12.9)	1.80 (0.48, 6.69)
	14	Volleyball		62	3.25 (1.13, 9.38)	2.38 (0.80, 7.03)	1.13 (0.34, 3.68)
Romann and Fuchslocher [115]	10–14	Soccer	J&S[Rc]	2987	1.21 (1.05, 1.40)	1.24 (1.07, 1.43)	1.11 (0.96, 1.29)
	15–20	Soccer		3242	1.01 (0.88, 1.16)	1.11 (0.96, 1.27)	1.07 (0.94, 1.23)
Jugend & Sport (J&S)[††]	10–14	Soccer	Talent development[C]	450	1.85 (1.26, 2.72)	1.68 (1.14, 2.49)	1.63 (1.10, 2.41)
	15–20	Soccer		617	1.22 (0.89, 1.67)	1.18 (0.85, 1.62)	1.11 (0.80, 1.53)
Talent development and national team[†††]	U17	Soccer	National team[E]	87	1.33 (0.54, 3.26)	1.93 (0.82, 4.57)	1.53 (0.64, 3.70)
	U19	Soccer		80	1.71 (0.69, 4.24)	1.43 (0.57, 3.59)	1.57 (0.63, 3.91)
	Senior	Soccer		72	2.09 (0.79, 5.52)	1.55 (0.57, 4.21)	1.91 (0.72, 5.08)
Albuquerque et al. [100][†]	Not specified	Taekwondo	Olympic Games[E]	139	1.45 (0.74, 2.82)	1.14 (0.57, 2.26)	1.21 (0.61, 2.38)
Nakata and Sakamoto [33][††]	Not specified	Softball	Japan Softball Association[E]	530	1.23 (0.87, 1.73)	1.37 (0.97, 1.93)	1.18 (0.83, 1.67)
	Not specified	Soccer	Japan Women's Football League[E]	238	1.30 (0.78, 2.18)	1.22 (0.73, 2.05)	1.24 (0.74, 2.08)
	Not specified	Volleyball	V-League[E]	138	2.09 (1.05, 4.18)	2.18 (1.09, 4.35)	1.00 (0.47, 2.13)
	Not specified	Basketball	Women's Japan Basketball League (WJBL)[E]	172	1.62 (0.87, 3.03)	1.86 (1.00, 3.46)	1.45 (0.77, 2.73)
	Not specified	Track and field	Japan Industrial Track and Field[E]	124	1.03 (0.51, 2.08)	1.16 (0.58, 2.32)	0.81 (0.39, 1.66)
	Not specified	Badminton	Badminton Nippon League[E]	133	0.71 (0.35, 1.44)	1.21 (0.62, 2.34)	1.00 (0.51, 1.97)
van den Honert [123][††]	U15, U17	Australian football	Football Federation Australia (FFA)–State team[Rp]	268	1.41 (0.86, 2.31)	1.27 (0.77, 2.10)	1.57 (0.96, 2.55)
	U20, Senior	Australian football	FFA–National team[E]	52	2.09 (0.73, 5.99)	0.73 (0.22, 2.39)	0.91 (0.29, 2.87)
Costa et al. [28][†]	12	Swimming	Portuguese Swimming Federation (Top 50 in individual events)[Rp]	624	4.72 (3.29, 6.78)	3.70 (2.56, 5.34)	1.53 (1.02, 2.28)
	13	Swimming		650	1.90 (1.38, 2.63)	2.02 (1.47, 2.78)	1.33 (0.95, 1.85)
	14	Swimming		644	0.96 (0.69, 1.32)	1.23 (0.90, 1.68)	1.45 (1.06, 1.97)
	15	Swimming		623	1.39 (1.02, 1.91)	1.19 (0.86, 1.64)	1.11 (0.80, 1.53)
	16	Swimming		519	2.00 (1.37, 2.91)	2.41 (1.67, 3.49)	2.00 (1.37, 2.91)
	17	Swimming		392	1.41 (0.93, 2.13)	2.32 (1.56, 3.45)	0.96 (0.62, 1.48)
	18	Swimming		280	0.67 (0.41, 1.10)	1.52 (0.98, 2.37)	0.64 (0.39, 1.06)
Dixon et al. [107][††]	19–24	Softball	National Collegiate Athletic Association (NCAA)–Division I[Cp]	380	4.57 (2.81, 7.43)	4.50 (2.77, 7.33)	2.60 (1.57, 4.33)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Hancock et al. [84]†	4	Ice hockey	Ontario Hockey Federation: Minor Pre-Novice[Rc/C]	719	1.69 (1.25, 2.28)	1.73 (1.28, 2.34)	1.24 (0.91, 1.70)
	5–6	Ice hockey	Major Pre-Novice[Rc/C]	3879	1.27 (1.12, 1.44)	1.35 (1.19, 1.54)	1.24 (1.09, 1.42)
	7	Ice hockey	Minor Novice[Rc/C]	3279	1.58 (1.37, 1.82)	1.59 (1.38, 1.83)	1.31 (1.13, 1.44)
	8	Ice hockey	Major Novice[Rc/C]	4525	1.46 (1.29, 1.64)	1.45 (1.29, 1.64)	1.28 (1.13, 1.44)
	9	Ice hockey	Minor Atom[Rc/C]	5807	1.45 (1.30, 1.61)	1.51 (1.36, 1.67)	1.32 (1.19, 1.47)
	10	Ice hockey	Major Atom[Rc/C]	6536	1.28 (1.16, 1.41)	1.47 (1.33, 1.62)	1.24 (1.12, 1.37)
	11	Ice hockey	Minor Peewee[Rc/C]	7279	1.29 (1.17, 1.42)	1.42 (1.30, 1.56)	1.24 (1.13, 1.36)
	12	Ice hockey	Major Peewee[Rc/C]	7180	1.25 (1.13, 1.37)	1.39 (1.27, 1.53)	1.19 (1.08, 1.31)
Romann and Fuchslocher [116]†	U17	Soccer	FIFA World Cup[E]	672	1.34 (0.99, 1.82)	1.25 (0.92, 1.70)	1.15 (0.84, 1.57)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	N	OR comparisons, quartiles 1–4 (95% confidence interval)		
					Q1 vs. Q4	Q2 vs. Q4	Q3 vs. Q4
Smith and Weir [20]†	U8	Ice hockey	Ontario Women's Hockey Association: Novice A/AA/AAA^C	156	2.18 (1.12, 4.28)	2.50 (1.29, 4.87)	1.41 (0.70, 2.85)
	U8	Ice hockey	Novice B/BB^C	266	2.15 (1.30, 3.57)	1.75 (1.04, 2.93)	1.75 (1.04, 2.93)
	U8	Ice hockey	Novice C/CC^C	405	1.36 (0.92, 2.01)	1.11 (0.74, 1.65)	1.14 (0.76, 1.69)
	U8	Ice hockey	Novice house league^Rc	2626	1.19 (1.01, 1.39)	1.36 (1.17, 1.59)	1.25 (1.07, 1.47)
	U10	Ice hockey	Atom A/AA/AAA^C	494	2.92 (2.01, 4.24)	2.01 (1.36, 2.95)	1.54 (1.03, 2.29)
	U10	Ice hockey	Atom B/BB^C	894	1.73 (1.31, 2.28)	1.83 (1.39, 2.41)	1.57 (1.19, 2.07)
	U10	Ice hockey	Atom C/CC^C	669	1.41 (1.03, 1.93)	1.45 (1.06, 1.98)	1.41 (1.03, 1.93)
	U10	Ice hockey	Atom house league^Rc	2854	1.12 (0.97, 1.30)	1.18 (1.02, 1.37)	1.14 (0.98, 1.32)
	U12	Ice hockey	Peewee A/AA/AAA^C	942	2.13 (1.63, 2.78)	1.92 (1.46, 2.51)	1.55 (1.17, 2.04)
	U12	Ice hockey	Peewee B/BB^C	1269	1.51 (1.20, 1.90)	1.60 (1.27, 2.00)	1.33 (1.05, 1.67)
	U12	Ice hockey	Peewee C/CC^C	865	1.39 (1.06, 1.83)	1.55 (1.18, 2.04)	1.36 (1.03, 1.80)
	U12	Ice hockey	Peewee house league^Rc	3502	1.15 (1.01, 1.32)	1.29 (1.13, 1.48)	1.20 (1.05, 1.38)
	U14	Ice hockey	Bantam A/AA/AAA^C	1368	1.92 (1.55, 2.40)	1.82 (1.46, 2.27)	1.31 (1.04, 1.65)
	U14	Ice hockey	Bantam B/BB^C	1353	1.40 (1.12, 1.75)	1.68 (1.35, 2.09)	1.41 (1.13, 1.76)
	U14	Ice hockey	Bantam C/CC^C	850	1.21 (0.92, 1.59)	1.49 (1.14, 1.96)	1.18 (0.89, 1.55)
	U14	Ice hockey	Bantam house league^Rc	3232	1.04 (0.91, 1.20)	1.26 (1.10, 1.45)	1.23 (1.07, 1.41)
	U17	Ice hockey	Midget A/AA/AAA^C	1659	1.74 (1.43, 2.13)	1.85 (1.52, 2.26)	1.40 (1.14, 1.71)
	U17	Ice hockey	Midget B/BB^C	1485	1.19 (0.97, 1.46)	1.40 (1.14, 1.71)	1.15 (0.93, 1.42)
	U17	Ice hockey	Midget C/CC^C	941	1.16 (0.90, 1.52)	1.44 (1.11, 1.86)	1.25 (0.96, 1.62)
	U17	Ice hockey	Midget house league^Rc	2431	1.01 (0.86, 1.19)	1.14 (0.98, 1.34)	1.10 (0.94, 1.29)
	U21	Ice hockey	Intermediate A/AA/AAA^C	696	1.78 (1.31, 2.42)	1.87 (1.37, 2.54)	1.34 (0.97, 1.85)
	U21	Ice hockey	Intermediate B/BB^C	132	1.12 (0.57, 2.18)	1.00 (0.51, 1.97)	0.76 (0.38, 1.54)
	U21	Ice hockey	Intermediate C/CC^C	86	1.23 (0.54, 2.79)	0.82 (0.34, 1.94)	0.86 (0.37, 2.03)
	U21	Ice hockey	Intermediate house league^Rc	1656	0.97 (0.80, 1.18)	1.16 (0.96, 1.41)	1.11 (0.91, 1.34)
	Adult	Ice hockey	Senior A/AA/AAA^C	880	1.31 (1.00, 1.72)	1.32 (1.01, 1.73)	1.28 (0.98, 1.68)
	Adult	Ice hockey	Senior B/BB^C	1086	1.18 (0.93, 1.50)	1.16 (0.91, 1.47)	1.01 (0.79, 1.29)
	Adult	Ice hockey	Senior C/CC^C	580	1.11 (0.80, 1.54)	1.00 (0.72, 1.40)	1.18 (0.85, 1.63)
	Adult	Ice hockey	Senior house league^Rc	3178	1.03 (0.89, 1.18)	1.15 (1.00, 1.32)	1.04 (0.90, 1.19)
Albuquerque et al. [101]†	Not specified	Wrestling	Olympic Games^E	146	2.00 (0.58, 2.16)	1.00 (0.51, 1.95)	1.30 (0.68, 2.48)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Baker et al. [78][†]	Born in 1970 or later	Ski jump	International competitions[E]	165	1.47 (0.79, 2.74)	1.47 (0.79, 2.74)	1.22 (0.65, 2.30)
		Cross-country skiing		2571	1.49 (1.27, 1.73)	1.18 (1.00, 1.38)	1.16 (0.99, 1.36)
		Alpine skiing		5828	1.23 (1.11, 1.36)	1.21 (1.09, 1.34)	1.08 (0.97, 1.20)
		Snowboarding		915	1.09 (0.84, 1.42)	1.05 (0.81, 1.37)	1.30 (1.00, 1.68)
	14–28	Figure skating	National team[E]	91	0.78 (0.34, 1.83)	1.13 (0.50, 2.54)	1.04 (0.46, 2.36)
	12–15	Gymnastics*	Junior national team[E]	120	1.56 (0.73, 3.36)	1.94 (0.92, 4.09)	1.75 (0.82, 3.72)
	15–24	Gymnastics*	Senior national team[E]	148	1.06 (0.52, 2.12)	2.11 (1.10, 4.04)	1.39 (0.71, 2.73)
Delorme [106][††]	14–15	Boxing	French Boxing Federation (FBF) – Amateur[C]	124	1.73 (0.84, 3.56)	1.14 (0.53, 2.43)	1.77 (0.86, 3.65)
	16–17	Boxing		168	1.13 (0.62, 2.06)	0.95 (0.51, 1.76)	1.13 (0.62, 2.06)
	18–18+	Boxing		416	0.76 (0.52, 1.13)	1.10 (0.76, 1.59)	0.79 (0.54, 1.16)
Lidor et al. [111][†]	18–36	Basketball	Division I – Professional[E]	46	0.89 (0.25, 3.12)	1.11 (0.33, 3.75)	2.11 (0.68, 6.59)
	16–38	Handball	Division I – Semi-Professional[Rp]	107	0.86 (0.40, 1.84)	1.07 (0.51, 2.25)	0.89 (0.42, 1.91)
	16–35	Soccer		156	1.16 (0.62, 2.15)	0.89 (0.47, 1.70)	1.05 (0.56, 1.97)
	16–36	Volleyball		80	1.05 (0.44, 2.51)	0.90 (0.37, 2.19)	1.05 (0.44, 2.51)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Romann and Fuchslocher [61]	U11	Fencing	J&S[Rc]	327	1.48 (0.95, 2.30)	0.86 (0.53, 1.38)	1.86 (1.20, 2.86)
J&S††	U12	Fencing		276	1.85 (1.11, 3.08)	2.23 (1.35, 3.69)	2.00 (1.20, 3.33)
Talent development†††	U13	Fencing		351	1.81 (1.18, 2.77)	1.71 (1.12, 2.63)	1.05 (0.66, 1.65)
	U14	Fencing		438	1.27 (0.86, 1.86)	1.13 (0.77, 1.67)	1.47 (1.01, 2.14)
	U15	Fencing		387	0.94 (0.63, 1.40)	1.12 (0.76, 1.66)	0.85 (0.57, 1.27)
	U16	Fencing		315	0.81 (0.52, 1.28)	0.89 (0.57, 1.39)	1.19 (0.77, 1.82)
	U17	Fencing		351	1.87 (1.23, 2.83)	1.00 (0.64, 1.56)	1.22 (0.79, 1.88)
	U18	Fencing		330	0.94 (0.61, 1.43)	0.74 (0.48, 1.15)	0.87 (0.57, 1.33)
	U19	Fencing		249	2.58 (1.53, 4.35)	1.33 (0.76, 2.33)	2.00 (1.17, 3.41)
	U20	Fencing		348	0.65 (0.42, 1.00)	0.77 (0.50, 1.19)	1.32 (0.89, 1.98)
	U12–U17**	Fencing	Talent development[C]	143	0.78 (0.40, 1.50)	0.98 (0.51, 1.85)	0.83 (0.43, 1.59)
	U18–U19**	Fencing		52	0.53 (0.18, 1.56)	0.58 (0.20, 1.69)	0.63 (0.22, 1.81)
	U11	Alpine skiing	J&S[Rc]	23,763	1.51 (1.44, 1.59)	1.39 (1.32, 1.46)	1.21 (1.15, 1.28)
	U12	Alpine skiing		17,742	1.20 (1.13, 1.27)	1.14 (1.08, 1.21)	1.09 (1.03, 1.16)
	U13	Alpine skiing		20,961	1.28 (1.21, 1.35)	1.14 (1.08, 1.21)	1.11 (1.05, 1.17)
	U14	Alpine skiing		25,140	1.20 (1.14, 1.26)	1.14 (1.09, 1.20)	1.18 (1.13, 1.25)
	U15	Alpine skiing		25,836	1.01 (0.96, 1.06)	1.07 (1.02, 1.12)	1.13 (1.08, 1.19)
	U16	Alpine skiing		24,147	0.89 (0.84, 0.93)	0.97 (0.92, 1.02)	1.05 (1.00, 1.10)
	U17	Alpine skiing		19,491	0.82 (0.77, 0.87)	0.90 (0.85, 0.95)	0.99 (0.94, 1.04)
	U18	Alpine skiing		13,008	0.68 (0.63, 0.73)	0.80 (0.75, 0.86)	0.93 (0.87, 0.99)
	U19	Alpine skiing		7320	0.68 (0.62, 0.75)	0.79 (0.72, 0.87)	0.99 (0.90, 1.08)
	U20	Alpine skiing		9060	0.85 (0.78, 0.92)	0.87 (0.80, 0.95)	0.97 (0.89, 1.05)
	U11–U14**	Alpine skiing	Talent development[C]	573	2.51 (1.77, 3.56)	2.03 (1.42, 2.89)	1.63 (1.13, 2.33)
	U15–U16**	Alpine skiing		313	2.12 (1.34, 3.36)	1.86 (1.17, 2.96)	1.28 (0.79, 2.08)
	U17–U18**	Alpine skiing		245	1.45 (0.88, 2.39)	1.32 (0.80, 2.18)	0.85 (0.50, 1.45)
	U19–U20**	Alpine skiing		95	0.48 (0.21, 1.11)	0.64 (0.29, 1.40)	0.76 (0.35, 1.64)
	U11	Table tennis	J&S[Rc]	591	1.29 (0.93, 1.78)	1.55 (1.12, 2.13)	0.86 (0.61, 1.21)
	U12	Table tennis		483	1.15 (0.80, 1.65)	1.38 (0.97, 1.98)	1.21 (0.84, 1.74)
	U13	Table tennis		504	0.78 (0.54, 1.12)	1.07 (0.76, 1.52)	1.24 (0.88, 1.75)
	U14	Table tennis		531	1.10 (0.78, 1.55)	1.18 (0.83, 1.65)	1.15 (0.82, 1.62)
	U15	Table tennis		438	0.86 (0.59, 1.26)	1.06 (0.73, 1.53)	1.14 (0.79, 1.65)
	U16	Table tennis		378	0.69 (0.46, 1.05)	0.83 (0.56, 1.24)	0.97 (0.66, 1.44)
	U17	Table tennis		285	0.57 (0.35, 0.93)	0.71 (0.45, 1.14)	1.11 (0.71, 1.72)
	U18	Table tennis		186	0.69 (0.38, 1.25)	1.00 (0.57, 1.77)	1.19 (0.68, 2.08)
	U19	Table tennis		96	0.29 (0.12, 0.67)	0.50 (0.23, 1.08)	0.50 (0.23, 1.08)
	U20	Table tennis		183	0.50 (0.27, 0.93)	0.61 (0.34, 1.11)	1.28 (0.74, 2.20)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Romann and Fuchslocher [61]	U11	Table tennis	Talent development[C]	102	2.29 (1.04, 5.06)	1.65 (0.73, 3.72)	1.06 (0.45, 2.50)
J&S††	U12–U13**	Table tennis		129	0.77 (0.38, 1.59)	1.06 (0.53, 2.13)	1.32 (0.67, 2.60)
Talent development †††	U14–U15**	Table tennis		105	0.92 (0.42, 2.02)	1.21 (0.56, 2.60)	1.25 (0.58, 2.68)
	U16–U18**	Table tennis		80	0.68 (0.27, 1.75)	1.21 (0.51, 2.88)	1.32 (0.56, 3.11)
	U11	Tennis	J&S[Rc]	9207	1.50 (1.38, 1.63)	1.36 (1.25, 1.48)	1.18 (1.08, 1.29)
	U12	Tennis		5700	1.19 (1.07, 1.32)	1.16 (1.04, 1.28)	1.07 (0.96, 1.19)
	U13	Tennis		6552	1.17 (1.06, 1.29)	1.15 (1.05, 1.27)	1.05 (0.95, 1.16)
	U14	Tennis		6972	1.14 (1.03, 1.25)	1.00 (0.91, 1.10)	1.05 (0.96, 1.16)
	U15	Tennis		6699	1.09 (0.99, 1.21)	1.08 (0.98, 1.19)	1.13 (1.02, 1.24)
	U16	Tennis		6204	0.86 (0.78, 0.96)	1.05 (0.95, 1.16)	1.08 (0.98, 1.19)
	U17	Tennis		5508	1.01 (0.91, 1.13)	0.94 (0.85, 1.05)	1.04 (0.94, 1.16)
	U18	Tennis		4122	0.91 (0.81, 1.03)	0.94 (0.83, 1.06)	0.98 (0.87, 1.11)
	U19	Tennis		3222	0.85 (0.74, 0.98)	0.97 (0.84, 1.11)	1.01 (0.88, 1.16)
	U20	Tennis		3969	0.94 (0.83, 1.06)	0.93 (0.82, 1.05)	0.92 (0.81, 1.04)
	U11–U12**	Tennis	Talent development[C]	215	3.63 (2.05, 6.42)	1.81 (0.99, 3.32)	1.52 (0.82, 2.81)
	U13–U14**	Tennis		102	3.08 (1.34, 7.07)	2.15 (0.91, 5.07)	1.62 (0.67, 3.91)
	U15–U18**	Tennis		89	2.69 (1.13, 6.40)	1.77 (0.72, 4.35)	1.38 (0.55, 3.49)
	U11	Snowboarding	J&S[Rc]	81	2.20 (0.92, 5.24)	1.60 (0.66, 3.90)	0.60 (0.21, 1.68)
	U12	Snowboarding		93	2.75 (1.15, 6.60)	2.00 (0.81, 4.92)	2.00 (0.81, 4.92)
	U13	Snowboarding		141	1.33 (0.67, 2.64)	1.22 (0.61, 2.44)	1.67 (0.85, 3.25)
	U14	Snowboarding		198	1.77 (1.01, 3.09)	1.23 (0.69, 2.19)	1.08 (0.60, 1.94)
	U15	Snowboarding		300	0.72 (0.46, 1.14)	1.10 (0.72, 1.70)	0.62 (0.39, 0.99)
	U16	Snowboarding		345	0.91 (0.60, 1.37)	0.94 (0.62, 1.42)	0.75 (0.49, 1.15)
	U17	Snowboarding		324	0.72 (0.46, 1.13)	1.14 (0.75, 1.73)	0.86 (0.56, 1.33)
	U18	Snowboarding		306	1.22 (0.78, 1.91)	1.09 (0.69, 1.71)	1.13 (0.72, 1.78)
	U19	Snowboarding		192	2.43 (1.27, 4.64)	3.00 (1.59, 5.66)	2.71 (1.43, 5.15)
	U20	Snowboarding		198	1.50 (0.82, 2.75)	1.90 (1.05, 3.44)	2.20 (1.23, 3.95)
	U11–U14**	Snowboarding	Talent development[C]	99	1.04 (0.47, 2.30)	0.88 (0.39, 1.96)	1.21 (0.56, 2.63)
	U15–U16**	Snowboarding		98	0.71 (0.32, 1.59)	0.79 (0.36, 1.73)	1.00 (0.46, 2.15)
	U17–U18**	Snowboarding		80	1.06 (0.43, 2.58)	1.11 (0.46, 2.70)	1.28 (0.53, 3.06)
	U11	Track and field	J&S[Rc]	8094	1.55 (1.42, 1.69)	1.30 (1.18, 1.42)	1.21 (1.11, 1.32)
	U12	Track and field		5400	1.16 (1.05, 1.30)	1.17 (1.05, 1.30)	1.09 (0.98, 1.21)
	U13	Track and field		6321	1.24 (1.12, 1.37)	1.21 (1.09, 1.33)	1.10 (1.00, 1.22)
	U14	Track and field		5832	1.15 (1.04, 1.27)	1.22 (1.10, 1.35)	1.09 (0.98, 1.21)
	U15	Track and field		5832	1.23 (1.11, 1.37)	1.10 (0.99, 1.22)	1.21 (1.09, 1.34)
	U16	Track and field		4632	0.91 (0.81, 1.02)	0.99 (0.89, 1.12)	0.96 (0.86, 1.08)
Romann and Fuchslocher [61]	U17	Track and field	J&S[Rc]	3744	1.32 (1.16, 1.50)	1.10 (0.97, 1.25)	1.04 (0.91, 1.18)
J&S††	U18	Track and field		2877	0.92 (0.79, 1.06)	1.05 (0.90, 1.21)	1.02 (0.88, 1.18)
Talent development†††	U19	Track and field		2199	1.35 (1.14, 1.60)	1.21 (1.02, 1.44)	1.13 (0.96, 1.35)
	U20	Track and field		2649	1.12 (0.96, 1.30)	1.25 (1.08, 1.46)	1.09 (0.93, 1.27)
	U15–U16**	Track and field	Talent development[C]	257	2.33 (1.39, 3.93)	2.28 (1.35, 3.84)	1.53 (0.89, 2.63)
	U17–U18**	Track and field		218	2.61 (1.47, 4.63)	2.21 (1.24, 3.97)	1.96 (1.09, 3.54)
	U19	Track and field		87	1.16 (0.49, 2.72)	1.47 (0.64, 3.39)	0.95 (0.39, 2.28)
Romann and Fuchslocher [31]††	U8	Alpine skiing	Migros Ski Grand Prix – Qualification Finisher[C]	747	1.17 (0.87, 1.56)	1.30 (0.97, 1.73)	1.15 (0.86, 1.54)
	U9	Alpine skiing		897	1.06 (0.81, 1.37)	1.07 (0.82, 1.39)	0.99 (0.76, 1.29)
	U10	Alpine skiing		1097	0.95 (0.75, 1.20)	0.96 (0.76, 1.21)	0.95 (0.75, 1.21)
	U11	Alpine skiing		1065	1.11 (0.88, 1.42)	1.06 (0.83, 1.35)	1.04 (0.81, 1.32)
	U12	Alpine skiing		1021	0.98 (0.76, 1.25)	0.98 (0.77, 1.25)	0.95 (0.75, 1.22)
	U13	Alpine skiing		917	0.89 (0.69, 1.15)	0.88 (0.68, 1.14)	0.91 (0.71, 1.18)
	U14	Alpine skiing		688	0.81 (0.60, 1.09)	0.77 (0.57, 1.04)	0.88 (0.66, 1.18)
	U15	Alpine skiing		574	0.91 (0.66, 1.25)	0.81 (0.59, 1.13)	0.87 (0.63, 1.20)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Saavedra-García et al. [79][†]	U17	Basketball	World Championships[E]	144	2.17 (1.11, 4.27)	1.74 (0.87, 3.47)	1.35 (0.66, 2.74)
	U19	Basketball		194	2.54 (1.40, 4.58)	2.04 (1.11, 3.72)	1.36 (0.72, 2.55)
	U21	Basketball		144	1.46 (0.74, 2.88)	1.81 (0.93, 3.52)	1.27 (0.64, 2.53)
Stenling and Holmström [21][†]	5–6	Ice hockey	Licensed youth players[Rc/C]	458	1.92 (1.32, 2.80)	1.42 (0.96, 2.09)	1.46 (0.99, 2.14)
	7–9	Ice hockey		693	1.17 (0.86, 1.58)	1.36 (1.01, 1.84)	1.28 (0.95, 1.74)
	10–12	Ice hockey		495	1.52 (1.06, 2.17)	1.41 (0.99, 2.02)	1.18 (0.81, 1.70)
	13–15	Ice hockey		460	1.29 (0.88, 1.88)	1.60 (1.11, 2.31)	1.22 (0.84, 1.79)
	16–20	Ice hockey		705	1.65 (1.21, 2.24)	1.52 (1.12, 2.07)	1.47 (1.08, 2.00)
	U18	Ice hockey	U18 regional tournament[Rp]	399	1.98 (1.32, 2.99)	1.75 (1.16, 2.65)	1.50 (0.98, 2.28)
	Adult	Ice hockey	National championship; Riksserien league[E]	688	2.07 (1.51, 2.83)	1.96 (1.43, 2.69)	1.59 (1.15, 2.19)
Albuquerque et al. [70][†]	16+	Judo	Olympic Games[E]	665	1.21 (0.89, 1.65)	1.14 (0.84, 1.56)	1.23 (0.90, 1.67)
Fukuda [108][†]	U17–U20/21	Judo	International Judo Federation; Junior World Championships[E]	710	1.39 (1.03, 1.87)	1.16 (0.85, 1.57)	1.32 (0.97, 1.77)
Hancock et al. [110]	U15	Gymnastics	Regional[Rp]	387	1.14 (0.76, 1.71)	1.28 (0.86, 1.91)	1.08 (0.72, 1.62)
	15+	Gymnastics		74	0.46 (0.18, 1.18)	0.62 (0.25, 1.51)	0.77 (0.32, 1.83)
U15 Regional[†]	U15	Gymnastics	Provincial[Rp]	208	1.10 (0.64, 1.89)	1.12 (0.65, 1.92)	0.94 (0.54, 1.63)
All other samples[†††]	15+	Gymnastics		62	0.63 (0.24, 1.62)	0.42 (0.15, 1.16)	0.54 (0.20, 1.44)
	U15	Gymnastics	Elite provincial[Rp]	85	2.42 (0.98, 5.96)	1.92 (0.76, 4.82)	1.75 (0.69, 4.43)
	15+	Gymnastics		28	0.50 (0.10, 2.46)	0.75 (0.17, 3.33)	1.25 (0.31, 5.07)
	U15	Gymnastics	National[E]	56	1.50 (0.47, 4.79)	2.75 (0.92, 8.24)	1.75 (0.56, 5.48)
	15+	Gymnastics		21	0.40 (0.05, 3.07)	2.20 (0.44, 10.97)	0.60 (0.09, 3.91)
Müller et al. [82]	7	Alpine skiing	Kids Cup (Provincial races)[C]	71	1.78 (0.62, 5.07)	2.33 (0.84, 6.48)	2.78 (1.02, 7.60)
Age 7–11 years[†]	8	Alpine skiing		96	1.55 (0.70, 3.44)	1.15 (0.50, 2.62)	1.10 (0.48, 2.52)
Age 12–15 years[†††]	9	Alpine skiing		108	1.22 (0.57, 2.62)	1.22 (0.57, 2.62)	1.26 (0.59, 2.71)
	10	Alpine skiing		144	1.39 (0.71, 2.72)	1.39 (0.71, 2.72)	1.36 (0.69, 2.66)
	11	Alpine skiing		161	2.00 (1.08, 3.69)	1.13 (0.59, 2.17)	1.06 (0.55, 2.05)
	12	Alpine skiing	Teenager Cup (Provincial races)[C]	102	1.20 (0.56, 2.58)	1.20 (0.56, 2.58)	0.68 (0.30, 1.55)
	13	Alpine skiing		110	1.37 (0.62, 3.03)	1.63 (0.75, 3.55)	1.79 (0.83, 3.87)
	14	Alpine skiing		97	1.74 (0.78, 3.85)	1.11 (0.48, 2.55)	1.26 (0.55, 2.88)
	15	Alpine skiing		78	1.00 (0.43, 2.35)	0.78 (0.32, 1.89)	0.61 (0.24, 1.52)
Müller et al. [32][†/††]	9–10	Alpine skiing	Ski boarding school entrance exam[C]	194	1.61 (0.89, 2.90)	1.64 (0.91, 2.95)	1.64 (0.91, 2.95)
	14–15	Alpine skiing		185	1.82 (1.01, 3.28)	1.45 (0.80, 2.66)	1.33 (0.73, 2.45)
Nagy et al. [113][‡]	11–26	Swimming	Champions of Future; National team[C/E]	183	2.92 (1.57, 5.42)	2.33 (1.24, 4.38)	1.38 (0.71, 2.68)
Sedano et al. [122][††]	U10, U12, U14	Soccer	Spanish Royal Federation of Soccer (SRFS): First division[C]	936	1.42 (1.09, 1.85)	1.74 (1.34, 2.25)	1.12 (0.86, 1.48)
	U10, U12, U14	Soccer	Second division[C]	1711	1.26 (1.04, 1.52)	1.33 (1.10, 1.61)	0.92 (0.75, 1.12)
Sedano et al. [122][††]	U10, U12, U14	Soccer	Third division[C]	870	1.21 (0.93, 1.57)	0.88 (0.67, 1.15)	1.04 (0.80, 1.36)
	U17, U19, U21, Senior	Soccer	National team[E]	232	2.42 (1.41, 4.18)	2.21 (1.28, 3.83)	1.39 (0.78, 2.48)
	U17, U19	Soccer	Regional team[Rp]	286	1.95 (1.23, 3.09)	1.62 (1.01, 2.59)	0.64 (0.37, 1.09)
Arrieta et al. [80][††]	U16	Basketball	European Basketball Championships[E]	396	2.03 (1.36, 3.02)	1.58 (1.05, 2.37)	0.97 (0.63, 1.50)
	U18	Basketball		407	2.01 (1.36, 2.98)	1.24 (0.82, 1.88)	1.24 (0.82, 1.88)
	U20	Basketball		299	1.50 (0.95, 2.38)	1.34 (0.84, 2.15)	1.31 (0.82, 2.09)

Table 2 continued

Author(s)	Sample age (years)	Sport	Competition level	*N*	OR comparisons, quartiles 1–4 (95% confidence interval)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
Brazo-Sayavera et al. [103]†	U15	Track and field	Spanish National Athletics Federation (RFEA) – Selected^{Rp}	407	1.96 (1.32, 2.90)	1.55 (1.04, 2.32)	0.99 (0.65, 1.51)
Note: Also used weighted mean scores to compare selected and unselected	U17	Track and field		227	1.12 (0.66, 1.89)	1.42 (0.85, 2.37)	0.83 (0.48, 1.43)
	U15	Track and field	RFEA – Unselected^{C}	9575	1.36 (1.25, 1.47)	1.23 (1.13, 1.33)	1.07 (0.99, 1.16)
	U17	Track and field		3299	1.16 (1.01, 1.33)	1.20 (1.04, 1.37)	1.05 (0.92, 1.21)
Chittle et al. [104]††	18–25	Basketball	NCAA Division I^{C}	265	5.40 (2.98, 9.80)	4.29 (2.35, 7.85)	3.19 (1.72, 5.92)
Lemez et al. [25]††††	8–10	Rugby	Developmental leagues (Can.)$^{Rc/C}$	68	1.36 (0.49, 3.81)	1.91 (0.71, 5.15)	1.91 (0.71, 5.15)
	11–14	Rugby		118	2.26 (1.08, 4.76)	1.58 (0.73, 3.41)	1.37 (0.63, 2.99)
	15	Rugby		213	1.51 (0.87, 2.61)	1.49 (0.86, 2.58)	1.20 (0.68, 2.10)
	16	Rugby		298	1.15 (0.72, 1.83)	1.11 (0.70, 1.78)	1.55 (0.98, 2.44)
	17	Rugby		386	1.38 (0.92, 2.07)	1.28 (0.85, 1.92)	1.23 (0.82, 1.85)
	18–20	Rugby		385	1.20 (0.80, 1.79)	1.05 (0.70, 1.58)	1.23 (0.83, 1.84)
	4	Rugby	Developmental leagues (NZ)$^{Rc/C}$	278	2.49 (1.53, 4.04)	1.70 (1.03, 2.81)	1.28 (0.76, 2.15)
	5	Rugby		519	1.31 (0.93, 1.85)	1.09 (0.77, 1.54)	1.08 (0.76, 1.53)
	6	Rugby		789	1.23 (0.93, 1.62)	1.06 (0.80, 1.40)	0.89 (0.67, 1.18)
	7	Rugby		1080	1.27 (1.00, 1.61)	1.17 (0.92, 1.49)	1.04 (0.82, 1.33)
	8	Rugby		1322	1.09 (0.88, 1.35)	1.12 (0.91, 1.39)	0.91 (0.73, 1.13)
	9	Rugby		1864	1.50 (1.25, 1.81)	1.26 (1.05, 1.52)	1.25 (1.03, 1.50)
	10	Rugby		2023	0.63 (0.53, 0.76)	0.92 (0.77, 1.09)	1.08 (0.91, 1.27)
	11	Rugby		1294	1.51 (1.22, 1.87)	1.03 (0.82, 1.29)	1.05 (0.84, 1.32)
	12	Rugby		1124	0.54 (0.42, 0.69)	0.91 (0.72, 1.14)	1.12 (0.90, 1.40)
	13	Rugby		627	0.84 (0.61, 1.15)	0.99 (0.72, 1.35)	1.07 (0.78, 1.45)
Lemez et al. [25]††††	14	Rugby		622	1.17 (0.85, 1.60)	1.06 (0.77, 1.46)	1.09 (0.79, 1.50)
	15	Rugby	Developmental leagues (NZ)$^{Rc/C}$	710	1.01 (0.75, 1.36)	1.04 (0.77, 1.39)	1.13 (0.84, 1.51)
	16	Rugby		704	0.79 (0.59, 1.07)	1.01 (0.76, 1.35)	0.96 (0.72, 1.29)
	17	Rugby		504	0.43 (0.30, 0.63)	0.72 (0.51, 1.02)	1.16 (0.84, 1.62)
	18	Rugby		187	0.73 (0.41, 1.30)	0.71 (0.40, 1.27)	0.89 (0.51, 1.56)
	19	Rugby		137	1.03 (0.53, 2.01)	0.85 (0.43, 1.69)	1.15 (0.59, 2.22)
	20	Rugby		115	1.10 (0.54, 2.25)	0.70 (0.33, 1.50)	1.03 (0.50, 2.12)
	19–43	Rugby	World Cup^{E}	498	0.86 (0.61, 1.23)	0.93 (0.66, 1.32)	0.95 (0.67, 1.34)
Werneck et al. [125]	27.1 ± 3.9	Basketball	Olympic Games^{E}	147	0.78 (0.40, 1.53)	1.22 (0.65, 2.29)	0.97 (0.51, 1.86)

U under

Odds ratio (confidence interval) calculations were based on the assumption of an equal distribution of birth dates per quartile. The expected distribution used in each study is denoted by the use of the following symbols: †Observed distribution compared to an equal distribution of birth dates (i.e. 25% per quartile); ††observed distribution compared to the birth rate in the general population (i.e. national birth statistics); †/†† assumed 25% based on birth rate in the population; †††observed distribution compared to the birth distribution present in the selection population; ††††observed distribution compared to a birth distribution based on the number of days per quartile; ‡expected birth distribution not stated; *raw numbers were not available and ORs have been estimated based on graphical representation of the data; **age groups were combined in accordance with age bands used in each respective sport. The competition level assigned for subgroup analyses denoted by superscript: Rc = Recreational; C = Competitive; Rp = Representative; E = Elite. 0.5 added to raw data when quartile 4 = 0, preventing OR calculation. Procedure recommended by Sutton et al. [126]

Table 3 Summary sample and participant numbers (and percentages) according to subgroup category as applied in the meta-analyses

Category	No. of samples (%)	No. of participants (%)
Age (y)		
Pre-adolescent (≤ 11)	51 (16.55)	163,292 (25.26)
Adolescent (12–14)	55 (17.85)	165,107 (25.54)
Post-adolescent (15–19)	91 (29.54)	197,368 (30.53)
Adult (> 19)	32 (10.38)	36,051 (5.58)
Not codable into above[a]	79 (25.64)	84,565 (13.08)
Competition level		
Recreational	76 (24.68)	369,216 (57.12)
Competitive	71 (23.05)	47,321 (7.32)
Representative	44 (14.29)	12,095 (1.87)
Overall–elite	61 (19.81)	23,822 (3.68)
Elite adolescent	5 (1.62)	548 (0.08)
Elite post-adolescent	18 (5.84)	5390 (0.83)
Elite adult	12 (3.90)	2186 (0.34)
Elite–combination of age	26 (8.44)	15,698 (2.43)
Not codable into above	56 (18.18)	193,929 (30.0)
Sport type		
Team	154 (50.0)	286,208 (44.28)
Individual		
Physically demanding	88 (28.57)	332,378 (51.42)
Technique/skill based	59 (19.16)	25,429 (3.93)
Weight categorised	7 (2.27)	2368 (0.37)

[a]Not codable = sample age range in studies traversed age categories

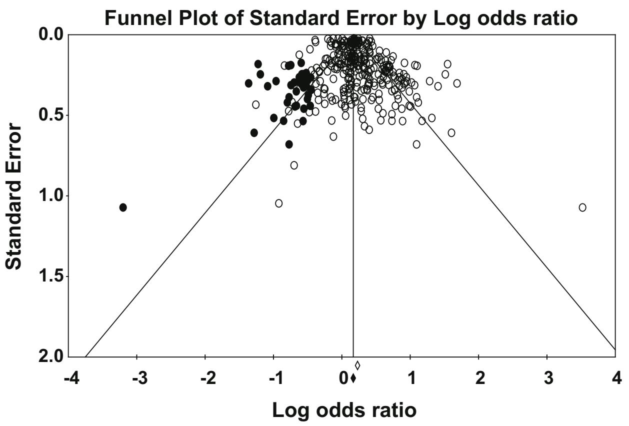

Fig. 2 Funnel plot of standard error by log odds ratio (quartile 1 vs. quartile 4 odds ratio analysis). In the absence of heterogeneity, 95% of the studies should fall within the funnel defined by the two diagonal lines. The plot assumes that those studies with higher precision (higher sample, lower estimates of error) will plot near the overall estimate (vertical line) and will cluster around the line evenly. Those studies with lower precision (lower on the graph) should also spread evenly on both sides, even though they have a smaller sample size and less precise estimates of error. Publication bias is suggested when there is asymmetry in the plot. The results displayed take into account the trim and fill adjustment. Observed studies are shown as open circles, and the observed point estimate is an open diamond. The imputed studies are shown as filled circles, and the imputed point estimate in log units is shown as a filled diamond

follow-up $Q1$ vs. $Q2$ comparison did not suggest asymmetry was apparent ($p < 0.10$).

3.5 Sub-Stratification (Subgroup) Analyses

For a summary of $Q1$ vs. $Q4$ subgroup analyses according to moderating factors refer to Table 4.

3.5.1 Age

When stratified according to defined age categories (i.e. pre-adolescent to adult), significant pooled OR estimates were apparent in all categories, except adults (> 19 years of age). The $Q1$ vs. $Q4$ OR estimates were similar in pre-adolescent (≤ 11 years of age) and adolescent (12–14 years of age) categories (OR = 1.33 and 1.28), before reducing by 14% in post-adolescence (15–19 years of age) and becoming insignificant in adulthood. The between-groups Q statistic and p value suggested changes were significant. Total within-age subgroup variance and heterogeneity estimates identified subgroups did not share a common effect size and substantial dispersion was apparent within pre-adolescent, adolescent and post-adolescent categories. When studies containing samples that traversed the designated age groupings were independently assessed, a similar estimate (n = 79, OR = 1.37, 95% CI

Table 4 Summary of quartile ($Q1$) vs. quartile ($Q4$) subgroup analyses according to identified moderating factors

Random-effects model		Subgroup estimates			Mixed-effects between subgroup analysis			Subgroup heterogeneity		
Moderator variable Subgroup	(No. of samples)	Point estimate[a]	95% CI	Z value[b]	p value[c]	Q[d] Between value	p value	Q in subgroup Q within	p in subgroup p within	I^2 subgroup[e]
Age										
Pre-adolescent [≤ 11 y]	(51)	1.33	1.25–1.42	8.68	0.0001			238.13	0.0001	79.00
Adolescent [12–14 y]	(55)	1.28	1.19–1.37	7.05	0.0001			241.83	0.0001	77.67
Post-adolescent [15–19 y]	(91)	1.14	1.08–1.20	4.79	0.0001			707.57	0.0001	87.28
Adult [> 19 y]	(32)	1.08	0.97–1.19	1.44	0.14			55.10	0.005	43.74
Not codable into above	(79)	1.37	1.29–1.46	9.74	0.0001	31.24	0.0001	1611.78	0.001	78.86
								1611.78	0.0001	
Competition level										
Recreational	(76)	1.08	1.02–1.14	2.83	0.005			1028.85	0.0001	92.71
Competitive	(71)	1.39	1.30–1.50	9.38	0.0001			243.92	0.0001	71.30
Representative	(44)	1.45	1.31–1.61	7.24	0.0001			126.83	0.0001	66.09
Elite adolescent	(5)	2.70	1.76–4.12	4.58	0.0001			6.64	0.15	39.81
Elite post-adolescent	(18)	1.65	1.41–1.92	6.48	0.0001			35.92	0.005	52.67
Elite adult	(12)	1.27	1.02–1.50	2.19	0.02			9.20	0.60	0.00
Elite, combination of age	(26)	1.42	1.26–1.61	5.65	0.0001			56.16	0.0001	55.48
Not codable into above	(56)	1.19	1.12–1.27	5.40	0.0001	77.09	0.0001	357.62	0.0001	84.62
								1865.17	0.0001	
Sport type										
Team	(154)	1.33	1.27–1.39	12.51	0.0001			689.01	0.0001	77.79
Individual	(154)	1.18	1.12–1.2	5.26	0.0001					
Physically demanding	(88)	1.23	1.16–1.30	7.19	0.0001			1125.83	0.0001	92.82
Technique (skill) based	(59)	1.06	0.97–1.16	1.36	0.17			118.20	0.0001	51.77
Weight categorised	(7)	1.18	0.93–1.51	1.38	0.16	20.58	0.001	7.48	0.27	19.81
								2040.54	0.0001	19.81
Study Quality										
Lower [scores 5–9]	(38)	1.63	1.46–1.82	8.55	0.0001			72.48	0.0001	48.95
Medium [10–11]	(92)	1.29	1.22–1.37	8.72	0.0001			348.55	0.0001	73.89
Higher [12–14]	(178)	1.19	1.14–1.25	8.46	0.0001	27.44	0.001	1596.47	0.0001	88.91
								2017.51	0.0001	

CI = confidence interval

[a]Point estimate = pooled overall odds ratio ($Q1$ vs. $Q4$) estimate

[b]Z value = reflects the test for an overall effect

[c]p = indicating probability of significance ($p \leq 0.05$)

[d]Q value = dispersion of studies about the point estimate overall or within the subgroup

[e]I^2 = reflects heterogeneity within the subgroup

1.29–1.46) to the overall pooled estimate was evident, and a common effect size was not apparent.

3.5.2 Competition Level

When stratified according to competition level (i.e. recreational to elite combined), significant OR estimates were consistently apparent with ORs ranging from 1.08 (recreational level; $n = 76$ samples) to 2.70 (elite adolescent; $n = 5$ samples). Odds ratio estimates increased with competition level, prior to an OR reduction at the elite adult stage. In samples traversing competition categories ($n = 56$), the OR = 1.19 was similar to the recreational level. Changes identified across subgroup categories were regarded as systematic ($Q = 77.09$; $p = 0.0001$). Total within-subgroup variance and heterogeneity estimates identified high dispersion was apparent (or a high proportion of variance remained unexplained) in the recreational and 'not-codable' categories ($I^2 = 92.71$ and 84.62). Moderate-to-high heterogeneity was apparent in competitive, representative, elite post-adolescent and 'elite combined' subgroup categories. Whilst acknowledging fewer samples in elite adolescent and elite adult categories, a more common effect size was estimated as lower/no evidence of estimate dispersion was apparent.

3.5.3 Sport Type

When samples were stratified according to individual vs. team sports, subgroup differences were apparent ($p = 0.001$) as team sports were associated with higher RAE estimates (OR = 1.33 vs. 1.18). A large proportion of variance within the subgroups was unexplained ($I^2 = 88.70$ and 77.79), and when individual sports were further analysed, significant estimates remained for physically demanding sports (OR = 1.23). Meanwhile, technique/skill-based (OR = 1.06) and weight-categorised (OR = 1.18) sport types were generally not associated with RAEs. The proportion of variance still unexplained was reduced for technique/skill and weight-categorised sport types ($I^2 = 51.77$ and 19.81, respectively), but remained high for physically demanding sports ($I^2 = 92.82$).

3.5.4 Sport Context

Table 5 summarises $Q1$ vs. $Q4$ subgroup analyses according to more specific sport contexts. Of the 25 sports examined to date, 15 had six or more independent samples available for analysis. Eight of these had pooled OR estimates exceeding the overall pooled OR estimate (1.25). Those most notable with higher $Q1$ representations were volleyball (OR = 1.81), swimming (OR = 1.67), handball (OR = 1.41) and ice hockey (OR = 1.39). In contrast, contexts associated with no RAEs included table tennis (OR = 0.85), gymnastics (OR = 1.06), rugby (OR = 1.06), shooting (OR = 1.07) and snowboarding (OR = 1.16).

3.5.5 Study Quality

When stratified according to study quality, effect sizes again differed ($p = 0.001$). Lower quality-rated studies ($n = 38$ samples from 13 studies, OR = 1.63) had significantly higher OR estimates than medium (n samples = 92 from 23 studies, OR = 1.29) and higher quality-rated studies (n samples = 178 from 21 studies; OR = 1.19). The finding suggests that studies with lower rated methodological and reporting qualities were more likely to be associated with higher RAE $Q1$ vs. $Q4$ OR estimates. Again, across studies categorised as medium and higher quality, a large proportion of variance remained unexplained (refer to Table 4).

4 Discussion

4.1 Overview of Main Findings

The present study represents the most comprehensive systematic review and meta-analysis of RAEs amongst female sport participants and athletes to date. The primary objective was to determine RAE prevalence and magnitude across and within female sport. The secondary objective was to determine whether moderator variables affected RAE magnitude. Based on data available, findings identify RAEs are consistently prevalent in female sport contexts, with 25% (21% adjusted) more relatively older ($Q1$) participants than relatively younger ($Q4$) participants. Compared to males, and generally speaking, findings identify a smaller overall RAE magnitude. Nonetheless, the factors of age, competition level, sport type and context significantly moderated overall RAE magnitude estimates; generally confirming original hypotheses, along with some novel additions. Unlike males, greater RAE ($Q1$ vs. $Q4$) magnitude was associated with both the pre-adolescent ($\leq$ 11 years of age) and adolescent (12–14 years of age) age categories. Relative age effects then reduced afterwards coinciding with completion of biological maturation. As expected, RAEs were lower at the recreational level and increased with higher competition, particularly in the elite adolescent (12–14 years of age) to post-adolescent years (15–19 years of age) where anthropometric and physical variability may have affected performance and selection processes. Relative age risk did reduce in the adult elite category; remaining significant but with smaller effect sizes in adult/professional athletes. Collectively, findings now provide female-specific estimates that have only previously been speculated upon.

Table 5 Summary of quartile ($Q1$) vs. quartile ($Q4$) subgroup analyses according to sport context

Random-effects model		Subgroup estimates			
Sport context subgroup	(no. of samples)	Point estimate[a]	95% CI	Z value[b]	p value[c]
Sport context (≥ 6 samples)					
Alpine skiing	(34)	1.09	1.01–1.19	1.96	0.05
Basketball	(22)	1.36	1.22–1.51	5.67	0.0001
Fencing	(12)	1.21	1.01–1.45	2.12	0.03
Gymnastics	(10)	1.06	0.80–1.41	0.44	0.65
Handball	(16)	1.41	1.19–1.68	3.95	0.0001
Ice hockey	(45)	1.39	1.30–1.50	9.11	0.0001
Rugby	(27)	1.06	0.95–1.18	1.10	0.26
Shooting sports	(6)	1.07	0.87–1.32	0.72	0.46
Snowboarding	(14)	1.16	0.97–1.40	1.63	0.10
Soccer	(33)	1.31	1.19–1.45	5.65	0.0001
Swimming	(8)	1.67	1.37–2.04	5.10	0.0001
Table tennis	(14)	0.85	0.71–1.01	− 1.81	0.07
Tennis	(27)	1.28	1.15–1.42	4.73	0.0001
Track and field	(18)	1.26	1.12–1.40	4.07	0.0001
Volleyball	(7)	1.81	1.30–2.53	3.51	0.0001
Sport context (< 6 samples)					
Australian Rules Football	(2)	1.55	0.89–2.70	1.55	0.11
Badminton	(1)	0.70	0.31–1.59	− 0.83	0.40
Boxing	(3)	1.02	0.69–1.51	0.12	0.90
Cross-country skiing	(1)	1.48	0.96–2.28	1.80	0.07
Figure skating	(1)	0.78	0.30–1.99	0.51	0.60
Judo	(2)	1.30	0.91–1.85	1.44	0.14
Ski jumping	(1)	1.46	0.70–3.08	1.01	0.31
Softball	(2)	2.11	1.40–3.17	3.61	0.0001
Taekwondo	(1)	1.44	0.66–3.15	0.93	0.35
Wrestling	(1)	1.12	0.58–2.15	0.34	0.73

CI = confidence interval

[a]Point estimate = pooled overall odds ratio (Q1 vs. Q4) estimate

[b]Z value = reflects the test for an overall effect

[c]p value = probability of significance ($p \leq 0.05$)

4.2 Summary of Subgroup Analyses

Related to the age subgroup analyses, the highest level of RAE risk was associated with the youngest age category (≤ 11 years of age; OR = 1.33); a finding partially contradicting the prior meta-analysis [37] where the highest risk was associated with adolescence. This may be explained by the large proportion of male samples in previous work (i.e. female individuals comprised only 2% of participants in Cobley et al. [37]), and genuinely different RAE patterns could be evident in females. If accurate, the earlier emergence of RAEs pre-maturation implicates the influences of both normative biological growth disparities (pre-maturation) within age-grouped peers and other psycho-social processes. For instance, growth charts tracking stature and body mass across chronological age highlight the potential for important relative (within-age group) differences in a given year [71, 72]. These may also relate to motor coordination, control and physical (e.g. muscular force) characteristic development advantages that assist sport-related performance (e.g. soccer). Interacting with age-related biological differences, parental and young participants' choices may also account for increased RAE magnitude. As part of initial recreation and participation experiences, the identification of an appropriate 'sporting fit' relative to physical characteristics of similarly aged girls (and possibly boys in early age mixed-sport contexts; e.g. soccer) may occur.

Age findings also partially resonate with the general findings of prior literature. After the adolescent age category (12–14 years; OR = 1.28), RAE magnitudes reduced with age; possibly suggestive of a declining influence of growth and maturational processes on sporting involvement. However, the overall adolescent age estimates could have been confounded by competition level as approximately two-thirds of adolescents were recreational-level participants. This may explain why RAE magnitude estimates in adolescence were potentially smaller than expected when compared with prior reviews and given existing explanatory mechanisms. Finally, there were many samples (79) that could not be coded into subgroup categories; likely for several reasons including the analyses of samples in original studies that were collapsed across multiple age groups. Future studies will need to be mindful of such collapsing, as they may be potentially missing important changes in RAE estimates.

Competition level also moderated RAE risk, with increasing magnitude at higher competition levels. The interaction of elite competition level with ages coinciding with adolescence (12–14 years) and post-adolescence (15–19 years) was associated with the greatest RAE risk (i.e. OR = 2.70 and 1.65). These findings corroborate previous studies examining representative athletes in talent identification and development systems, and the maturation-selection hypothesis [9, 24, 37, 38]. As higher tiers of representation necessitate the requirement for higher performance levels at a given age or developmental stage, selection is likely to favour those with more advantageous anthropometric and physical characteristics, and thereby relatively older in a given junior/youth grouping process [38]. Distinct trends within epidemiological (national) data samples support the hypothesis in accounting for RAE perpetuation. For instance, Romann and Fuchslocher [61] provided data at recreational levels and sport organisation-imposed age categories in alpine skiing, tennis and track/field. At recreational levels, significant RAEs existed in these contexts until approximately 15 years of age (i.e. post-*peak height velocity* for female individuals [42]). Relative age effects then continued in competitive tiers where selection processes were present, perpetuating early growth and physical advantages. Furthermore, a slow reversal of recreational-level RAE trends at post-15 years was observed, possibly indicating the relatively older individuals were either participating at higher levels of competition or had ceased participation.

At elite representative levels, significant pooled RAEs remained, although they did decrease with age (e.g. elite adult; OR = 1.27). Prior study findings have also been inconsistent at the elite adult (i.e. professional athlete) level, suggesting potential variability in RAE risk, which may be associated with context-specific conditions and performance demands. The definitive explanations for why RAEs reduce and even reverse at the elite adult stage remain somewhat speculative and deserving of further attention. Initial explanations from male contexts suggest later ages benefit from anthropometric and physical development [4, 13] 'equalisation' and a delayed, less intensive sporting involvement, with training specialisation occurring later in development [73–75]. One alternative, referred to as the 'underdog' hypothesis [76], suggests that challenges (e.g. non-selection; physical dominance by relatively older players) encountered at younger ages may ultimately facilitate longer term athlete development [77] through a combination of needing to develop greater resiliency and coping skills in such psycho-social conditions, alongside enhanced or alternative skill development to circumvent performance hurdles. Such successful transitions may partially account for the greater presence of the relatively younger in adult professional sport [12, 55, 76].

Related to sport type, the highest RAE risk was found in team sports (OR = 1.33), where athlete comparisons occur on the field of play and tend to be subjective in nature; thus, potentially temphasising anthropometric and physical differences [78]. Accordingly, higher RAEs were apparent in elite-level basketball [79, 80] and representative volleyball [18, 81], sports associated with increased stature. Other team sports with a notably higher RAE risk included handball, ice hockey, and soccer (see Table 4). Overall, these findings adhere to those found in the predominantly male meta-analytical review [37]. Perhaps most surprising, given game physicality requirements, was that rugby [10, 25] did not show significant RAEs (OR = 1.06, 95% CI 0.95–1.18) despite estimates being based on 27 samples from three countries (Canada, New Zealand, UK). However, it should be noted that both rugby union and rugby league samples were combined, and independent RAE estimates were significant at pre-adolescent ($\leq$ 11 years of age) levels in rugby union when sample size was more robust [25]. There were no pre-adolescent rugby league samples available for comparison.

Individual sport types were initially examined holistically, identifying an RAE below the pooled estimate (i.e. *Q*1 vs. *Q*4 OR = 1.18 vs. 1.25) with a high level of within-group heterogeneity. To follow-up, individual sports were re-categorised with consideration of predominant sport demands (i.e. physical/endurance, technique/skill) as well as those implementing weight categorisation instead of age-based cohort grouping. Findings identified variable RAE risk. Individual sports associated with strength and/or endurance requirements illustrated some of the highest RAEs at particular age and competition levels. For instance, alpine skiing ORs ranged between 2.00−2.51 between 11–14 years of age at competitive/representative levels [61, 82]. In track and field, Romann and Fuchslocher [61] reported ORs of 2.30–2.6 in competitive 15- to 16-year-olds; while Costa et al. [28] identified ORs exceeding 4.00 in a sample of junior representative swimmers. Overall, these findings are novel for individual-sport contexts, and the efficacy for these estimates can be derived from the multiple large samples spanning age groups and competition settings.

Based on the 59 samples containing varying age and competition levels, skill/technique-based sports (e.g. table tennis, OR = 0.85; gymnastics, OR = 1.06) were not associated with any RAE risk (OR = 1.06, 95% CI 0.97–1.16); a finding consistent with suggestions in previous studies [35]. Such a contrast between pooled estimates of individual skill/technique-based sports and those with physical/endurance requirements again points toward the importance of physical and maturation disparities driving RAEs, and to a lesser extent selection processes. Likewise, when weight-categorised sports were examined, RAE magnitudes were lower. However, this finding should be interpreted with caution because of the limited samples available and the absence of samples at lower competition levels. Further assessment in weight-categorised sport (e.g. martial arts) is warranted as such processes attempt to mitigate and neutralise the effect of anthropometric and physical discrepancies from impacting performance in competition.

With reference to study quality, findings highlighted that higher study quality was associated with a lower RAE estimate and vice versa. Though no prior RAE reviews have identified such a trend; the finding is aligned with meta-analytical reviews in other sport science [83] areas. This finding highlights the importance of detailed reporting on the sport context (e.g. characteristics of competition and selection across age groups), sufficient sampling of participants and reporting of participant characteristics (e.g. quartile distributions, ages, 1-year age groupings, levels of competition), and implementation of appropriate data analysis steps (i.e. techniques for comparison; effect size) [84] to enable valid estimates of true RAE sizes. The adapted reporting checklist used in this review may be useful to help enable appropriate sampling and reporting in future RAE studies.

4.3 Unexpected Findings

One unexpected finding, even though OR comparisons showed no differences, was that $Q2$ representation was either similar or descriptively higher than $Q1$. Marginal $Q2$ over-representation has previously been reported in Canadian ice hockey [20, 84, 85] and adult female soccer [52, 56]. Canadian ice-hockey samples provided 12.63% of relative weight to the present analyses, and thus their influence may be apparent. Further examination in this context also identifies subtle but pervasive shifts in $Q1 + Q2$ over-representation according to age and competition categories. Specifically, $Q1$ over-representations are apparent at pre-adolescent ($\leq$ 11 years of age) competitive levels, while $Q2$ over-representation is evident at age-equivalent recreational levels. By adolescence (12–14 years of age) however, $Q2$'s were over-represented at both recreational and competitive levels in the same sport system. These transitions potentially suggest adverse effects from intensified involvement at a younger age (where RAE ORs are highest) and possible interactions with growth and maturational processes. Rather than an accumulated advantage as suggested by the 'maturation-selection' hypothesis, intensified involvement in pre-adolescence and during adolescence (maturation) in female Canadian ice hockey may be associated with greater risks of injury, burnout and sport withdrawal [11, 86, 87]. By contrast, a lower intensity-level involvement until adolescence (or post-peak growth) may be more protective and conducive to long-term participation. Nonetheless, caution is necessary for recognising the specificity of $Q2$ trends and in attempting to account for them accurately.

4.4 Limitations

Several limitations can be acknowledged in the present study. First, it is plausible that despite comprehensive searches, some published literature may not have been identified even though systematic steps were taken (as reported) to avoid such possibilities. Second, the sporting landscape has changed in recent decades and it was not possible to assess whether the intensification of competitive youth sport was associated with increased RAE magnitude. Third, within identified studies, inconsistency and variability in data reporting were apparent, and therefore multiple authors had to be contacted for data verification and further extraction to enable present analyses. In conducting subgroup meta-analyses, pooled estimates may have been affected by 'non-codable' data that traversed categories (e.g. age). Those data were still examined to determine if data dispersions were apparent. That said, and as was often the case, multiple data samples still remained likely generating valid pooled subgroup estimates. Finally, in subgroup analyses, a large amount of heterogeneity often remained unaccounted for, suggesting other variables (not examinable) may still moderate RAEs. It also highlights the potential for multi-factorial explanations of RAEs across and within sport contexts.

4.5 Implications: Relative Age Effect Intervention and Removal

Relative age research is fundamentally concerned with participation and development inequalities. Present findings are therefore concerning with respect to the relatively younger who are more likely to refrain from engagement in the early years (e.g. 6–11 years of age) of recreational sport and/or withdraw, possibly owing to less favourable participation experiences and conditions. With the inequality continuing into the (post-) adolescent years and being exacerbated by forms of selection and representation, the need for organisational policy, athlete development system structure and practitioner intervention is recommended. Previous recommendations have suggested changes to age-grouping policies, such as rotating cut-off dates [6], creating smaller age bands (e.g. 9-month rotating bands) [88] and increasing RAE awareness via education for sport-system practitioners (e.g. coaches, scouts) [37, 46]. However, despite increasing RAE awareness, few prior recommendations have been implemented organisation wide and in the long term. Meanwhile, a cultural performance emphasis in many junior/youth sports systems has grown, possibly leading to further RAE prevalence and greater magnitudes [5, 89].

With consideration of emerging literature and sport organisation trends, Cobley [90] recently summarised a range of feasible organisational and practitioner strategies for national sporting organisations. At an organisation level, these included a general recommendation to delay age time-points for structured competition, and to delay tiers of selective representation (e.g. post-maturation). These strategies would help enable inclusive participation and dissociate with an early-age performance emphasis (and RAE bias [39, 91]). Potentially more relevant for individual sport contexts (e.g. sprinting, track and field), the application of corrective performance adjustments could potentially remove performance differences associated with growth and development [9]. For team sports (e.g. soccer, ice hockey), body mass or biological maturity banding at particular development time-points (e.g. maturation years) could help dissipate performance inequalities and improve participation experiences [7, 92, 93]. With organisational alignment and support, recommended practitioner strategies included the development of psycho-social climates that emphasised 'personal learning and development' in junior/youth sport as opposed to inter-individual/team competition *per se*; explicit cueing of relative age or biological maturity differences (e.g. ordered shirt number) in player evaluation/selection [89]); and, the benefit of longer term athlete tracking on various indicators (i.e. physiological and skill based) [94, 95]. Notwithstanding these strategies, there is still further developmental work required in identifying effective and feasible interventions for female sport.

4.6 Future Research

Based on current evidence and findings, future research should seek to further examine female sport contexts where minimal samples and data are available (as highlighted). Sampling across and within these contexts will help establish a better understanding for how growth and biological development interacts with sport development systems and their psycho-social climate to affect sporting experience and behaviour. Further, moving beyond reporting RAEs in female sport to better isolate and confirm underlying causes will prove beneficial. Such work will likely inform the necessary interventions that attempt to remove RAEs and/or organisation/practitioner strategies mitigating their effects. To this end, a shift in research methodologies may also prove valuable, including qualitative investigations with sport stakeholders (e.g. athletes, coaches, parents, administrators) [20, 21, 96] to consider the influence of sport organisation processes and practitioner behaviours. Qualitative idiographic investigations examining child/athlete experiences within sporting structures at early and onward stages of participation would also strengthen understanding of how RAEs manifest and operate in the pre-maturational years.

Connected to early sporting experiences, the examination of dropout may also provide an additional perspective. Growth and particularly maturation (puberty onset and duration) may contribute differentially to dropout in each sex. The relatively younger ($Q4$) male individuals may disengage in greater numbers than $Q1$ peers, owing to the early emphasis on physical dominance and performance, which becomes exacerbated in the maturational years [46, 97]. Preliminary work in female athletes has been inconclusive, and the relevant factors involved may be different [46, 98]. For female individuals, entering maturation may be associated with negative outcomes (e.g. increased body mass-to-height ratio [41]) impacting performance in particular contexts, and other psycho-social concerns (e.g. body image). Thus, longitudinal and multivariate studies of RAEs in terms of sport participation, dropout, and experiences are likely to be insightful. Recently, Sabiston and Pila [99] asked female adolescent sport participants to complete a questionnaire targeting their emotions and sport experience over 3 years. They identified that across tracking, 14% withdrew from all sporting participation and 58% disengaged from at least one sport. Negative body image emotions, derived from interactions with parents, coaches and peers, increased over the 3 years and were associated with lower commitment and enjoyment levels of their sport. Such work demonstrates how interactions between several biological, sport context/system and psycho-social factors are likely to affect individual sporting behaviour, whether in terms of early-age initiation, continued participation, or continued progressive involvement across athlete development stages.

5 Conclusions

Overall, RAEs have a consistent but likely small-to-moderate influence on female sport participation. Findings highlight the impact of interactions between athlete developmental stages, competition level, sport context demands and sociocultural factors on RAE magnitudes across and within female contexts. To reduce and eliminate RAE-related inequalities in female athletic development, direct policy, organisational and practitioner interventions are required.

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Compliance with Ethical Standards

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