Sports Med
https://doi.org/10.1007/s40279-018-0890-8

SYSTEMATIC REVIEW

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

Kristy L. Smith[1] · Patricia L. Weir[1] · Kevin Till[2] · Michael Romann[3] · Stephen Cobley[4]

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.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s40279-018-0890-8) contains supplementary material, which is available to authorized users.

✉ Stephen Cobley
stephen.cobley@sydney.edu.au

1 Faculty of Human Kinetics, University of Windsor, Windsor, ON, Canada

2 Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, UK

3 Swiss Federal Institute of Sport Magglingen, Magglingen, Switzerland

4 Exercise and Sport Sciences, Faculty of Health Sciences, The University of Sydney, Cumberland Campus, 75 East St, Lidcombe, Sydney, NSW 2141, Australia

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.

Published online: 13 March 2018

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 (≥ 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.

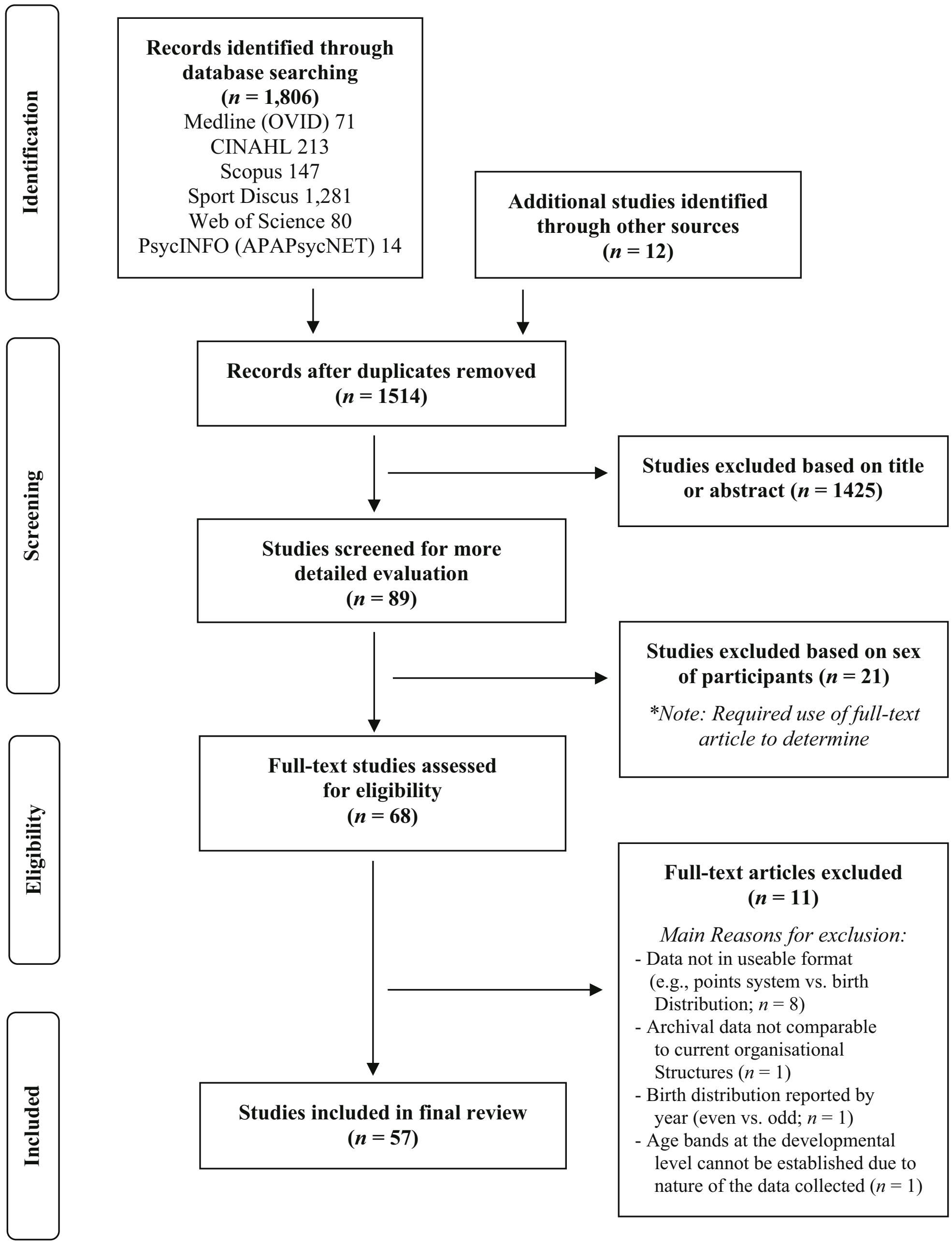

Fig. 1 Flow diagram for screening and selection of studies according to preferred reporting items for systematic reviews and meta-analysis [57]

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 FFBBRc/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 tryoutsRp *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)		
					Q1 vs. Q4	Q2 vs. Q4	Q3 vs. Q4
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)		
					*Q*1 vs. *Q*4	*Q*2 vs. *Q*4	*Q*3 vs. *Q*4
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)		
					Q1 vs. Q4	Q2 vs. Q4	Q3 vs. Q4
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)		
					Q1 vs. Q4	Q2 vs. Q4	Q3 vs. Q4
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)		
					Q1 vs. Q4	Q2 vs. Q4	Q3 vs. Q4
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

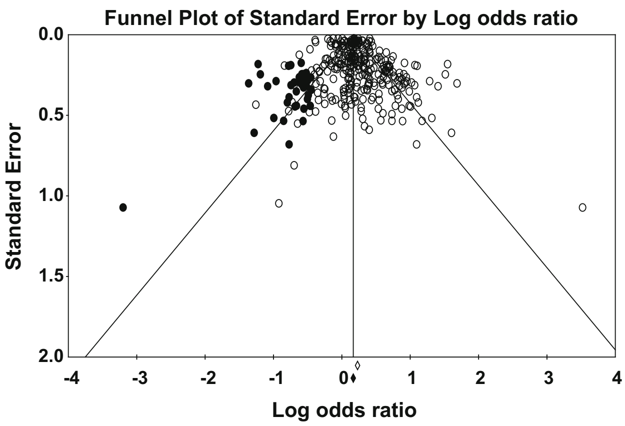

Fig. 2 Funnel plot of standard error by log odds ratio (quartile 1 vs. quartile 4 odds ratio analysis). In the absence of heterogeneity, 95% of the studies should fall within the funnel defined by the two diagonal lines. The plot assumes that those studies with higher precision (higher sample, lower 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.

Acknowledgements Support for this study was received from a Social Sciences and Humanities Research Council Doctoral Fellowship (K. Smith). The authors would also like to thank Kanchana Ekanayake (The University of Sydney), Allan Fu (The University of Sydney) and Trish Dubé (University of Windsor) for their assistance.

Compliance with Ethical Standards

Funding No funding was received for the preparation of this article.

Conflict of interest Kristy Smith, Patricia Weir, Kevin Till, Michael Romann and Stephen Cobley have no conflicts of interest directly relevant to the content of this article.

References

1. Baker J, Horton S. A review of primary and secondary influences on sport expertise. High Abil Stud. 2004;15(2):211–28.
2. Stambulova N, Alfermann D, Statler T, Côté J. ISSP position stand: career development and transitions of athletes. Int J Sport Exe Psychol. 2009;7(4):395–412.
3. Cobley S, Abraham C, Baker J. Relative age effects on physical education attainment and school sport representation. Phys Educ Sport Peda. 2008;13(3):267–76.
4. Deaner RO, Lowen A, Cobley S. Born at the wrong time: selection bias in the NHL draft. PLoS One. 2013;8(2):e57753.
5. Helsen WF, Baker J, Michiels S, Schorer J, Van Winckel J, Williams AM. The relative age effect in European professional soccer: did ten years of research make any difference? J Sport Sci. 2012;30(15):1665–71.
6. Barnsley RH, Thompson AH, Barnsley PE. Hockey success and birthdate: the relative age effect. Can Assoc Health Phys Educ Recreat J. 1985;51:23–8.
7. Musch J, Grondin S. Unequal competition as an impediment to personal development: a review of the relative age effect in sport. Dev Rev. 2001;21(2):147–67.
8. Wattie N, Cobley S, Baker J. Towards a unified understanding of relative age effects. J Sport Sci. 2008;26(13):1403–9.
9. Romann M, Cobley S. Relative age effects in athletic sprinting and corrective adjustments as a solution for their removal. PLoS One. 2015;10(4):e0122988.
10. Till K, Cobley S, Wattie N, O'Hara J, Cooke C, Chapman C. The prevalence, influential factors and mechanisms of relative age effects in UK Rugby League. Scand J Med Sci Sport. 2010;20(2):320–9.
11. Wattie N, Cobley S, Macpherson A, Howard A, Montelpare WJ, Baker J. Injuries in Canadian youth ice hockey: the influence of relative age. Pediatr. 2007;120(1):142–8.
12. Baker J, Logan AJ. Developmental contexts and sporting success: birth date and birthplace effects in national hockey league draftees 2000–2005. Br J Sport Med. 2007;41(8):515–7.
13. Till K, Cobley S, Morley D, O'Hara J, Chapman C, Cooke C. The influence of age, playing position, anthropometry and fitness on career attainment outcomes in rugby league. J Sport Sci. 2016;34(13):1240–5.
14. Cobley SP, Till K. Participation trends according to relative age across youth UK Rugby League. Int J Sports Sci Coach. 2017;12(3):339–43.
15. Armstrong H. A comparison of the performance of summer- and autumn-born children at eleven and sixteen. Br J Educ Psychol. 1966;36(1):72–6.
16. Freyman R. Further evidence on the effect of date of birth on subsequent school performance. Educ Research. 1965;8:58–64.
17. Jinks P. An investigation into the effect of date of birth on subsequent school performance. Educ Research. 1964;6:220–5.
18. Grondin S, Deshaies P, Nault L-P. Trimestre de naissance et participation au hockey et au volleyball. La Revue Québecoise de l'Activité Physique. 1984;2:97–103.
19. Barnsley RH, Thompson AH. Birthdate and success in minor hockey: the key to the NHL. Can J Behav Sci. 1988;20(2):167–76.
20. Smith KL, Weir PL. An examination of the relative age effect in developmental girls' hockey in Ontario. High Abil Stud. 2013;24(2):171–84.
21. Stenling A, Holmström S. Evidence of relative age effects in Swedish women's ice hockey. Talent Dev Excell. 2014;6(2):31–40.
22. Wattie N, Baker J, Cobley S, Montelpare WJ. A historical examination of relative age effects in Canadian hockey players. Int J Sport Psychol. 2007;38(2):178–86.
23. Helsen WF, Van Winckel J, Williams AM. The relative age effect in youth soccer across Europe. J Sport Sci. 2005;23(6):629–36.
24. Lovell R, Towlson C, Parkin G, Portas M, Vaeyens R, Cobley S. Soccer player characteristics in English lower-league development programmes: the relationships between relative age, maturation, anthropometry and physical fitness. PLoS One. 2015;10(9):e0137238.
25. Lemez S, Macmahon C, Weir P. Relative age effects in women's rugby union from developmental leagues to World Cup tournaments. Res Q Exerc Sport. 2016;87(1):59–67.
26. Cobley S, Hanratty M, O'Connor D, Cotton W. First club location and relative age as influences on being a professional Australian Rugby League player. Int J Sports Sci Coach. 2014;9(2):335–46.
27. Baxter-Jones ADG. Growth and development of young athletes: should competition levels be age related? Sports Med. 1995;20(2):59–64.
28. Costa AM, Marques MC, Louro H, Ferreira SS, Marinho DA. The relative age effect among elite youth competitive swimmers. Eur J Sport Sci. 2013;13(5):437–44.
29. Edgar S, O'Donoghue P. Season of birth distribution of elite tennis players. J Sport Sci. 2005;23(10):1013–20.
30. Giacomini CP. Association of birthdate with success of nationally ranked junior tennis players in the United States. Percept Motor Skill. 1999;89:381–6.
31. Romann M, Fuchslocher J. Survival and success of the relatively oldest in Swiss youth skiing competition. Int J Sports Sci Coach. 2014;9(2):347–56.
32. Müller L, Müller E, Kornexl E, Raschner C. The relationship between physical motor skills, gender and relative age effects in young Austrian alpine ski racers. Int J Sports Sci Coach. 2015;10(1):69–85.
33. Nakata H, Sakamoto K. Sex differences in relative age effects among Japanese athletes. Percept Motor Skill. 2012;115(1):179–86.

34. Delorme N, Boiché J, Raspaud M. The relative age effect in elite sport: the French case. Res Q Exerc Sport. 2009;80(2):336–44.
35. Côté J, Macdonald DJ, Baker J, Abernethy B. When 'where' is more important than 'when': birthplace and birthdate effects on the achievement of sporting expertise. J Sport Sci. 2006;24(10):1065–73.
36. Delorme N, Raspaud M. Is there an influence of relative age on participation in non-physical sports activities? The example of shooting sports. J Sport Sci. 2009;27(10):1035–42.
37. Cobley S, Baker J, Wattie N, McKenna J. Annual age-grouping and athlete development: a meta-analytical review of relative age effects in sport. Sports Med. 2009;39(3):235–56.
38. Helsen WF, Starkes JL, Van Winckel J. The influence of relative age on success and dropout in male soccer players. Am J Hum Biol. 1998;10(6):791–8.
39. Baker J, Schorer J, Cobley S. Relative age effects: an inevitable consequence of elite sport? Sportwiss. 2010;40(1):26–30.
40. Haywood K, Getchell N. Life span motor development. 5th ed. Champaign: Human Kinetics Publishers; 2009.
41. Malina RM. The young athlete: biological growth and maturation in a biocultural context. In: Smoll FL, Smith RE editors. Children and youth in sport: a biopsychosocial perspective. Dubuque (IA): Brown & Benchmark; 1996.
42. Tanner J, Whitehouse R, Takaishi M. Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. Part I. Arch Dis Child. 1966;41(219):454–71.
43. Cobley SP, Schorer J, Baker J. Relative age effects in professional German soccer: a historical analysis. J Sport Sci. 2008;26(14):1531–8.
44. Till K, Cobley S, Hara J, Cooke C, Chapman C. Considering maturation status and relative age in the longitudinal evaluation of junior rugby league players. Scand J Med Sci Sport. 2014;24(3):569–76.
45. Cobley S, Miller P, Till K, McKenna J. The good and bad of youth sport today: what about the unforseen ethical issues. In: Harvey S, Light RL, editors. Ethics in youth sport: policy and pedagogical applications. Oxfordshire: Routledge; 2013.
46. Delorme N, Chalabaev A, Raspaud M. Relative age is associated with sport dropout: evidence from youth categories of French basketball. Scand J Med Sci Sport. 2011;21(1):120–8.
47. Bergeron MF, Mountjoy M, Armstrong N, Chia M, Côté J, Emery CA, et al. International Olympic Committee consensus statement on youth athletic development. Br J Sports Med. 2015;49(13):843–51.
48. Côté J, Abernethy B. A developmental approach to sport expertise. In Murphy SM, editor. The Oxford Handbook of Sport and Performance Psychology. Oxford: Oxford University Press; 2012. p. 251–306.
49. Koz D, Fraser TJ, Baker J. Accuracy of professional sports drafts in predicting career potential. Scand J Med Sci Sport. 2012;22(4):e64–9.
50. Till K, Cobley S, O'Hara J, Morley D, Chapman C, Cooke C. Retrospective analysis of anthropometric and fitness characteristics associated with long-term career progression in Rugby League. J Sci Med Sport. 2015;18(3):310–4.
51. Hancock DJ, Adler AL, Côté J. A proposed theoretical model to explain relative age effects in sport. Eur J Sport Sci. 2013;13(6):630–7.
52. Baker J, Schorer J, Cobley S, Bräutigam H, Büsch D. Gender, depth of competition and relative age effects in team sports. AJESS. 2009;6(1):1–7.
53. Schorer J, Cobley S, Bräutigam H, Loffing F, Hütter S, Büsch D, et al. Developmental contexts, depth of competition and relative age effects in sport: a database analysis and a quasi-experiment. Psychol Test Assess Model. 2015;57(1):126–43.
54. Daniel T, Janssen C. More on the relative age effect. Can Assoc Health Phys Educ Recreat J. 1987;53:21–4.
55. Schorer J, Cobley S, Büsch D, Bräutigam H, Baker J. Influences of competition level, gender, player nationality, career stage and playing position on relative age effects. Scand J Med Sci Sport. 2009;19(5):720–30.
56. Delorme N, Boiché J, Raspaud M. Relative age effect in female sport: a diachronic examination of soccer players. Scand J Med Sci Sport. 2010;20(3):509–15.
57. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6(7):e1000100.
58. Albuquerque MF, Fukuda DH, Da Costa VT, Lopes MC, Franchini E. Do weight categories prevent athletes from the relative age effect? A meta-analysis of combat sports. Sport Sci Health. 2016;12(2):133–9.
59. Vandenbroucke JP, Von Elm E, Altman DG, Gøtzsche PC, Mulrow CD, Pocock SJ, et al. Strengthening the reporting of observational studies in epidemiology (STROBE): explanation and elaboration. Epidemiology. 2007;18(6):805–35.
60. Tompsett C, Sanders R, Taylor C, Cobley S. Pedagogical approaches to and effects of fundamental movement skill interventions on health outcomes: a systematic review. Sports Med. 2017;47(9):1795–819.
61. Romann M, Fuchslocher J. The need to consider relative age effects in women's talent development process. Percept Motor Skill. 2014;118(3):651–62.
62. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials. 1986;7(3):177–88.
63. Cochran WG. The combination of estimates from different experiments. Biometrics. 1954;10(1):101–29.
64. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315(7109):629–34.
65. Duval S, Tweedie R. Trim and fill: a simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics. 2000;56(2):455–63.
66. Malina RM, Bouchard C, Bar-Or O. Maturity-associated variation in growth and performance. In: Malina RM, Bouchard C, Bar-Or O, editors. 2nd ed. Growth, maturation, and physical activity. Champaign (IL): Human Kinetics Publishers; 2004.
67. Ward S, Bélanger M, Donovan D, Caissie I, Goguen J, Vanasse A. Association between school policies and built environment, and youth's participation in various types of physical activities. J School Health. 2015;85(7):423–32.
68. Raschner C, Müller L, Hildebrandt C. The role of a relative age effect in the first winter Youth Olympic Games in 2012. Br J Sport Med. 2012;46(15):1038–43.
69. Müller L, Hildebrandt C, Schnitzer M, Raschner C. The role of a relative age effect in the 12th Winter European Youth Olympic Festival in 2015. Percept Motor Skill. 2016;122(2):701–18.
70. Albuquerque MR, Franchini E, Lage GM, Da Costa VT, Costa IT, Malloy-Diniz LF. The relative age effect in combat sports: a analysis of Olympic judo athletes, 1964–2012. Percept Motor Skill. 2015;121(1):300–8.
71. Tanner JM, Whitehouse RH. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. Arch Dis Child. 1976;51(3):170–9.
72. Freeman JV, Cole TJ, Chinn S, Jones PR, White EM, Preece MA. Cross sectional stature and weight reference curves for the UK, 1990. Arch Dis Child. 1995;73(1):17–24.

73. Güllich A, Emrich E. Considering long-term sustainability in the development of world class success. Eur J Sport Sci. 2014;14(Suppl. 1):S383–97.
74. Moesch K, Elbe A-M, Hauge M-LT, Wikman JM. Late specialization: the key to success in centimeters, grams, or seconds (cgs) sports. Scand J Med Sci Sport. 2011;21(6):e282–90.
75. Baker J, Cobley S, Fraser TJ. What do we know about early sport specialization? Not much! High Abil Stud. 2009;20(1):77–89.
76. Gibbs BG, Jarvis JA, Dufur MJ. The rise of the underdog? The relative age effect reversal among Canadian-born NHL hockey players: a reply to Nolan and Howell. Int Rev Sociol Sport. 2011;47(5):644–9.
77. Collins D, MacNamara Á. The rocky road to the top. Sports Med. 2012;42(11):907–14.
78. Baker J, Janning C, Wong H, Cobley S, Schorer J. Variations in relative age effects in individual sports: skiing, figure skating and gymnastics. Eur J Sport Sci. 2014;14(Suppl. 1):S183–90.
79. Saavedra-García M, Aguilar ÓG, Romero JJF, Lastra DF, Oliveira GE. Relative age effect in lower categories of international basketball. Int Rev Sociol Sport. 2014;49(5):526–35.
80. Arrieta H, Torres-Unda J, Gil SM, Irazusta J. Relative age effect and performance in the U16, U18 and U20 European Basketball Championships. J Sport Sci. 2016;34(16):1530–4.
81. Okazaki FHA, Keller B, Fontana FE, Gallagher JD. The relative age effect among female Brazilian youth volleyball players. Res Q Exerc Sport. 2011;82(1):135–9.
82. Müller L, Hildebrandt C, Raschner C. The relative age effect and the influence on performance in youth alpine ski racing. JSSM. 2015;14(1):16–22.
83. Soomro N, Sanders R, Hackett D, Hubka T, Ebrahimi S, Freeston J, et al. The efficacy of injury prevention programs in adolescent team sports: a meta-analysis. Am J Sport Med. 2016;44(9):2415–24.
84. Hancock DJ, Seal K, Young BW, Weir PL, Ste-Marie DM. Examining mechanisms that contribute to relative age effects in pre-pubescent female ice hockey players. Talent Dev Excell. 2013;5(2):59–66.
85. Weir PL, Smith KL, Paterson C, Horton S. Canadian women's ice hockey: evidence of a relative age effect. Talent Dev Excell. 2010;2(2):209–17.
86. Fraser-Thomas J, Côté J. Understanding adolescents' positive and negative developmental experiences in sport. Sport Psychol. 2009;23(1):2–23.
87. Wall M, Côté J. Developmental activities that lead to dropout and investment in sport. Phys Educ Sport Peda. 2007;12(1):77–87.
88. Boucher J, Halliwell W. The Novem system: a practical solution to age grouping. Can Assoc Health Phys Educ Recreat J. 1991;57(1):16–20.
89. Mann DL, van Ginneken PJMA. Age-ordered shirt numbering reduces the selection bias associated with the relative age effect. J Sport Sci. 2017;35(8):784–90.
90. Cobley S. Growth and maturation in athlete development: an educational resource for sporting organisations. Canberra (ACT): Australian Institute of Sport; 2016.
91. Cobley S. Talent identification and development in youth sport. In: Green K, Smith A, editors. Routledge handbook of youth sport. Abingdon: Routledge; 2016. p. 476–91.
92. Cumming SP, Lloyd RS, Oliver JL, Eisenmann JC, Malina RM. Bio-banding in sport: applications to competition, talent identification, and strength and conditioning of youth athletes. Strength Cond J. 2017;39(2):34–47.
93. Cumming SP, Lloyd RS, Oliver JL, Eisenmann JC, Malina RM. A renaissance in bio-banding: applications in competition, talent identification, and training. Strength Cond J. (**in press**).
94. Till K, Cobley S, O'Hara J, Chapman C, Cooke C. An individualized longitudinal approach to monitoring the dynamics of growth and fitness development in adolescent athletes. J Strength Cond Res. 2013;27(5):1313–21.
95. Cobley S, Till K, O'Hara J, Cooke C, Chapman C. Variable and changing trajectories in youth athlete development: further verification in advocating a long-term inclusive tracking approach. J Strength Cond Res. 2014;28(7):1959–70.
96. Andronikos G, Elumaro AI, Westbury T, Martindale RJJ. Relative age effect: implications for effective practice. J Sport Sci. 2016;34(12):1124–31.
97. Lemez S, Baker J, Horton S, Wattie N, Weir P. Examining the relationship between relative age, competition level, and dropout rates in male youth ice-hockey players. Scand J Med Sci Sport. 2014;24(6):935–42.
98. Wattie N, Tietjens M, Cobley S, Schorer J, Baker J, Kurz D. Relative age-related participation and dropout trends in German youth sports clubs. Eur J Sport Sci. 2014;14(Suppl. 1):S213–20.
99. Sabiston C, Pila E, editors. Body-related emotional experiences in sport among adolescent girls: participation outcomes over time. Knowledge transfer papers. In: Sport Canada Research Initiative Conference; 19–20 Sep 2017.
100. Albuquerque MR, Lage GM, Da Costa VT, Fereira RM, Penna EM, De Albuquerque Moraes LCC, et al. Relative age effect in Olympic Taekwondo athletes. Percept Motor Skill. 2012;114(2):461–8.
101. Albuquerque MR, Da Costa VT, Faria LO, Lopes MC, Lage GM, Sledziewski D, et al. Weight categories do not prevent athletes from relative age effect: an analysis of Olympic Games wrestlers. Arch Budo. 2014;10:127–32.
102. Bidaurrazaga-Letona I, Badiola A, Granados C, Lekue JA, Amado M, Gil SM. Efecto relativo de la edad en futbol: Estudio en un club Vasco profesional. [Relative age effect in soccer: a study in a professional Basque club]. Retos: Nuevas Perspectivas de Educación Física, Deporte y Recreación. 2014;(25):95–9.
103. Brazo-Sayavera J, Martínez-Valencia MA, Müller L, Andronikos G, Martindale RJ. Identifying talented track and field athletes: the impact of relative age effect on selection to the Spanish National Athletics Federation training camps. J Sport Sci. 2017;35(22):2172–8.
104. Chittle L, Horton S, Dixon JC. Time out or fast break? The relative age effect in NCAA Division I basketball. J Sport Behav. 2016;39(2):107–25.
105. Delorme N, Raspaud M. The relative age effect in young French basketball players: a study on the whole population. Scand J Med Sci Sport. 2009;19(2):235–42.
106. Delorme N. Do weight categories prevent athletes from relative age effect? JSSM. 2014;32(1):16–21.
107. Dixon JC, Liburdi V, Horton S, Weir PL. An examination of the impact of relative age effects and academic timing on intercollegiate athletics participation in women's softball. J Intercoll Sport. 2013;6(2):147–63.
108. Fukuda DH. Analysis of the relative age effect in elite youth judo athletes. Int J Sport Physiol Perform. 2015;10(8):1048–51.
109. Gorski T, Rosser T, Hoppeler H, Vogt M. Relative age effect in young Swiss alpine skiers from 2004 to 2011. Int J Sport Physiol. 2016;11(4):455–63.
110. Hancock DJ, Starkes JL, Ste-Marie DM. The relative age effect in female gymnastics: a flip-flop phenomenon. Int J Sport Psychol. 2015;46(6):714–25.
111. Lidor R, Arnon M, Maayan Z, Gershon T, Côté J. Relative age effect and birthplace effect in Division 1 female ballgame players: the relevance of sport-specific factors. Int J Sport Exerc Psychol. 2014;12(1):19–33.
112. Liu W-M, Liu D. A research on the relative age effect among excellent youth female football players in China. J Beijing Sport Univ. 2008;31(1):135–7.

113. Nagy N, Ökrös C, Sós C. Research on relative age in Hungarian swimming. Phys Cult Sport Stud Res. 2015;68(1):5–13.
114. O'Donoghue P. Relative age in elite tennis. Stud Phys Cult Tourism. 2009;16(4):379–88.
115. Romann M, Fuchslocher J. Influence of the selection level, age and playing position on relative age effects in Swiss women's soccer. Talent Dev Excell. 2011;3(2):239–47.
116. Romann M, Fuchslocher J. Influences of player nationality, playing position, and height on relative age effects at women's under-17 FIFA World Cup. J Sport Sci. 2013;31(1):32–40.
117. Saavedra García M, Gutiérrez Aguilar Ó, Galatti L, Fernández Romero JJ. Efecto de la edad relativa en los mundiales de baloncesto FIBA en cateogrías inferiores (1979-2011). Cuadernos de Psicología del Deporte. 2015;15(3):237–42 [Relative age effect in lower categories of FIBA basketball world championships (1979-2011)].
118. Saavedra-García M, Gutiérrez-Aguilar Ó, Sa-Marques P, Fernández-Romero JJ. Efecto de la edad relativa en el atletismo español. Cuadernos de Psicología del Deporte. 2016;16(1):275–85 [Relative age effect in lower categories of FIBA basketball world championships (1979-2011)].
119. Schorer J, Baker J, Büsch D, Wilhelm A, Pabst J. Relative age, talent identification and youth skill development: do relatively younger athletes have superior technical skills? Talent Dev Excell. 2009;1(1):45–56.
120. Schorer J, Baker J, Lotz S, Büsch D. Influence of early environmental constraints on achievement motivation in talented young handball players. Int J Sport Psychol. 2010;41(1):42–58.
121. Schorer J, Wattie N, Baker JR. A new dimension to relative age effects: constant year effects in German youth handball. PLoS One. 2013;8(4):e60336.
122. Sedano S, Vaeyens R, Redondo JC. The relative age effect in Spanish female soccer players: influence of the competitive level and a playing position. J Hum Kinet. 2015;46(1):129–37.
123. van den Honert R. Evidence of the relative age effect in football in Australia. J Sport Sci. 2012;30(13):1365–74.
124. Vincent J, Glamser FD. Gender differences in the relative age effect among US Olympic Development Program youth soccer players. J Sport Sci. 2006;24(4):405–13.
125. Werneck FZ, Coelho EF, de Oliveira HZ, Ribeiro Júnior DB, Almas SP, de Lima JRP, et al. Relative age effect in Olympic basketball athletes. Sci Sport. 2016;31(3):158–61.
126. Sutton AJ, Abrams KR, Jones DR, Jones DR, Sheldon TA, Song F. Methods for meta-analysis in medical research. Chichester: Wiley; 2000.