Title:

Differences in sprinting and jumping performance between maturity status groups in youth: a systematic review & meta-analysis.

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Blind Title:

Differences in sprinting and jumping performance between maturity status groups in youth: a systematic review & meta-analysis.

Short title:

Maturity differences in sprinting and jumping performance in youth athletes.

Abstract

Background: Large inter-individual differences can exist in the timing and tempo of growth and maturation of youth athletes. This can provide significant physical performance advantages to young athletes that mature in advance of their peers.

Purpose: To determine the magnitude of differences in sprinting and jumping performance in youth of different maturity status (classified as pre-, circa- or post-peak height velocity (PHV)) (aged <18 years) to enhance the evaluation of performance.

Participants and methods: Eligibility criteria for inclusion was as follows: 1) the study had cross-sectional data available; 2) participants were male and/or female ≤18 years of age; 3) a somatic measure of maturity was used to identify maturity status (e.g. Mirwald or Khamis-Roche methods) with at least two maturity status classifications present; 4) the study included a measurement of sprinting speed (e.g., 10-100m sprint data) and/or jump tests commonly used to assess power (e.g., countermovement jump [CMJ]). Searches were conducted up to November 2024 in PubMed, Embase, SportDiscus and preprint servers SportRxiv and medRxiv to identify any unpublished trials. Risk of bias and study quality was assessed using the Appraisal tool for Cross-Sectional Studies (AXIS). Meta-analysis was computed using a random-effects model.

Results: The search identified 1578 studies. From those, forty studies were identified for qualitative assessment and quantitative synthesis. In the primary analysis, 21 studies provided data for measures of speed, and 19 studies provided data for measures of power using jump tests. Sprinting and jumping performance increased with advancing maturity status and overall effects were predominantly moderate to large between maturity groups. Pre- vs. post-PHV comparisons found moderate to large overall effect sizes for sprinting performance (10m ES 1.34, 95% CI [0.87, 1.80]; 20m ES 140, 95% CI [0.85, 1.96];

and 30m ES 0.93, 95% CI [0.15, 1.76] sprint times) and large to very large effect sizes for the jump tests (CMJ ES 1.53, 95% CI [1.14, 1.92], squat jump ES 1.32, 95% CI [0.70, 1.94]; standing long jump ES 2.18, 95% CI [1.32, 3.04]). When comparing consecutive maturity groups (i.e. pre- to circa-PHV and circa- to post-PHV) effect sizes were predominantly moderate across the sprinting and jumping measures, with only a trivial difference found in 30m sprint time (ES 0.45, 95% CI [0.21, 0.69]) for the circa- to post-PHV comparisons.

Conclusion: Large differences exist in sprinting and jumping performance between male athletes of the last and most mature athletes (pre- and post-PHV), with trivial to moderate effect sizes indicated between consecutive groups (e.g.pre- and circa-PHV). Practitioners working with youth athletes should consider how these differences may impact performance in the athlete's sport, and regularly assess individual maturity to accurately evaluate performance against age and maturity group benchmarks to account for large differences in maturity that exist within chronological age groups. It should be noted we observed inconsistencies in maturity thresholds and test methods; thus, standardisation is required for future research.

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Registered on the OSF register (https://osf.io/27ja8)

Key points

- Meta-analytic comparisons between maturity status groups shows moderate to large effect size in sprinting and jumping performance with large to very large overall effect sizes between the least and most mature groups (i.e. pre and post-PHV).
- It is important to assess an individual's maturity status to accurately evaluate current sprinting speed and jumping performance and improve the assessment of athletes' future potential, given large inter-individual differences exist in maturation within chronological age groups.

- Reference data (mean[SD]) for pre-, circa- and post-PHV maturity groups for the sprint (10m, 20m and 30m sprint time) and jump test outcome measures (CMJ, SJ and SLJ) has been provided to enable maturity-based evaluations of performance.

1.0 Introduction

Sprinting speed and jumping performance are key to success in short distance sprint events and sports requiring high power outputs, including successful execution of tasks, within a limited timeframe (e.g., jumping to contest a header in soccer, or sprinting to evade a defender). Previous meta-analyses have examined the adaptive response to sprint [1] and plyometric training [2] in youth athletes at different stages of maturity. However, due to a lack of studies including measures of maturity status (pre-, mid- and post-PHV), these were assumed based on chronological age instead of using calculated values. Researchers have more recently sought to understand how the physical characteristics of young athletes vary at different stages of maturation. These data indicate speed and power to typically improve with advancing maturity in cohorts primarily from team sports and school children [3–7].

The increase in research has been supported by the development of practical methods to assess maturity status that include somatic measurements (Mirwald et al. [8]; Moore et al., [9]; Khamis & Roche [10]) combining stature, body mass and sitting height, age, and sex. Regression equations are then used to provide estimates according to maturity offset (i.e. years from peak height velocity [YPHV][8,9]; or percentage of predicted adult height [10]). However, a range of different methods have been used to determine maturation status and different thresholds applied to classify youth athletes as either pre-, circa-, or post PHV. Further examination of the available literature is required to provide a clearer synthesis of the available data, and approaches used that may allow recommendations to be made for the application of these methods in future research. Which in time will allow for the development of more robust maturity-based reference data for common measures of performance. This kind of data may allow coaches and practitioners to make more accurate evaluations of current performance and future potential of the young athletes they work with.

It is important to assess maturity status because of the large inter-individual differences that exist in the timing and tempo of growth and maturation. Previous research has identified differences of up to 6 years in biological (skeletal) age within a single chronological age group [11], and that coaches are not very good at identifying the maturity status correctly without this data [12]. This creates a challenge for coaches and practitioners working in youth sports, particularly when the aim is to identify and select talented individuals with the potential to become elite athletes. Earlier maturing athletes are afforded significant advantages in size, strength, speed, and power allowing them to physically outperform their later maturing peers [13]. For the purpose of identifying and nurturing talented young athletes, having a clearer understanding how sprinting speed and jump performance differs between maturity groups (pre-, circa-, post-PHV) will improve practitioners' ability to evaluate the performance of individual athletes in accordance with their maturity status at a given point in time, providing an alternative perspective to age based evaluations where maturity isn't considered. Recent research has highlighted this aspect in youth rugby academies [14] and tennis players [15].

A range of methods have been used to assess sprinting speed and jumping performance in youth athletes. The data indicate that running speed [4,5,7]and power improve significantly with age and changes in maturity status [7,16,17] largely because of age- and growth-related changes in muscle size, fibre type, architecture, activation, mechanical tendon properties, and neuromuscular capacity [18]. The greatest divergences in sprinting speed and jumping performance exist between the least and most mature groups (i.e. pre- vs. post-PHV), but the differences are less clear between the least mature groups (i.e. pre- vs. circa-PHV) [4,5]. Due to the wide variety of assessments used, a literature synthesis is required to elucidate the magnitude of these differences across the available body of research, and whether they remain consistent across the different sprinting speed and jump test modes and/or if there are any sports specific differences.

In summary, there is a growing body of evidence that has examined sprinting speed and jumping performance with advancing maturity. However, a literature synthesis and meta-analysis is required. The aims of this study are to: 1) determine the magnitude of differences in sprinting speed and jumping performance across maturity status groups (i.e. pre-, circa and post-PHV) and 2) provide reference values based on the current body of literature to help practitioners make more accurate evaluations of sprinting and jumping performances of the youth athletes they work with when differences in maturity status exist. We also reviewed the quality of the research available and endeavoured to identify current gaps in the literature to provide direction for future research.

2.0 Methods

This systematic review was prospectively registered in the OSF register (https://osf.io/27ja8) and followed guidelines by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [19] and Cochrane Handbook [20].

2.1 Study Design

The study was designed to determine the magnitude of differences in sprinting speed and jumping performances between different maturity status groups (i.e. pre-, circa-, post-PHV) using cross sectional data. To maximise the amount of data that could be analysed, we also included studies where athletes were grouped by maturity status within a training intervention study. However, in these cases, only the pre-intervention (baseline) data were extracted and analysed. The review did not assess the effect of any training intervention.

2.2 Search Design

Searches were conducted by two authors (JB & TJ) in the electronic databases PubMed, Embase, and SportDiscus up to November 2024. We also searched the SportRxiv and medRxiv preprint servers up to November 2024 to identify any ongoing or unpublished trials. Standard 8oolean operators (AND, OR) were used to concatenate the search terms. The search string used in all the search engines is displayed in Table 1 . Furthermore, we manually searched the reference lists and forward citations of included studies to identify potentially eligible studies.

<INSET TABLE 1 HERE >

2.3 Inclusion & exclusion criteria

Original research articles were included if they met the following inclusion criteria: 1) participants were male and/or female adolescents ≤18 years of age; 2) a somatic measure of maturation status was used (e.g. Mirwald, et al. [8], Khamis & Roche [10]) to identify maturity status 3) the study had cross-sectional data available for two or more maturity groups (pre-, circa-, post-PHV); 4) included a measurement of sprinting speed (i.e. 10-100m sprint data, peak velocity during sports performance) and/or power (i.e. countermovement jump, Olympic lifting, Wingate cycling test). 5) The full-text was peer reviewed, indexed and available in English language.

Articles were excluded if they were not original research studies (e.g. reviews, book chapters, editorials); contained participants over the age of 18; grouped athletes by age group; only included participants from one of three maturity status classifications (i.e. pre-, circa-, or post-PHV), used solely a non-somatic measure of maturity status (e.g. Tanner staging) or used maturity timing as the group classification (i.e. early, on-time, late).

2.4 Selection Process

After deleting duplicates and obtaining titles and abstracts, two authors (JB & TJ) independently screened the results based on the inclusion criteria. In cases where titles and abstracts were insufficient to decide on an exclusion, full text articles were consulted before a decision was made. Once the independent screening was completed, a comparison of inclusions and exclusion decisions was made by the two authors, and where there was a disagreement in selection, discussion took place and consensus was reached. The full texts were retrieved for all remaining of the studies and checked against the exclusion criteria. The final list of articles was then included in the quality assessment and data extraction.

2.5 Study Quality Assessment

The quality assessment was conducted using an Appraisal tool for Cross-Sectional Studies (AXIS) [21] independently by two researchers (JB and MC). This is a 20-item appraisal tool developed in response to the increase in cross-sectional studies informing evidence-based medicine and the consequent importance of ensuring that these studies are of high quality and low bias [21]. . The AXIS assesses the quality of cross-sectional studies based on the following criteria: clarity of aims/objectives and target population; appropriate study design and sampling framework; justification for the sample size; risk factors/outcome variables measured in the study; clarity of methods and statistical approach; appropriate result presentation, including internal consistency; justified discussion points and conclusion; discussion of limitations; and identification of ethical approval and any conflicts of interest [21]. The scoring system conforms to a “yes,” “no,” or “do not know/comment” design with papers scored from a total of 20. Studies were categorized into quartiles: >15 AXIS criteria met, 10-15 AXIS criteria met, 5-9 AXIS criteria met, and ≤4 AXIS criteria met similar to previous research [22].

2.6 Data Extraction

Study characteristics were manually extracted into a Microsoft Office Excel Spreadsheet (version 2203) for by all authors (JB [13], TJ [6], PGS [6], PR [5], MC [6]). The data set included information on the lead author, year of publication, sample size, population, sex, maturity assessment method used, equipment used and set-up. The participants' data (mean [SD]) was extracted from each maturity status group (pre, circa & post-PHV) including sample size, age, stature, body mass, measure of maturity and finally the outcome measures for the tests of sprinting speed and jumping performance used in the study. Only the pre-training data were extracted from interventions studies to make the comparisons between the maturity status groups. Baseline data from control groups was included but treated as a separate study in analysis. Male and female data were also extracted and analysed separately. Due to a lack studies including female athletes, it was not possible to meta-analyse the female data. However, in cases where there were two of more studies with the same outcome measures, mean and standard deviations are reported by maturity group (see table 5).. In all cases, we classified participants according to how the maturity groups were described within the included studies. In instances where studies had more than one group for a specific maturity status [5,17,23] and there were not significant differences between the groups in question the data for these groups was combined using the approach outlined in the Cochrane Handbook chapter 6, section 6.5.2.10) [24] . In order to enable the calculation of effect sizes and meta-analytic comparison between the three maturity status classifications.

2.7 Statistical Analysis

A total of ten different sprinting speed, jumping test and power variables were extracted and analysed from the studies, with the results from six selected as primary measures selected to present. Primary measures for reporting were selected based on there being 1) a minimum of 5 studies/comparisons [25] in all 3 maturity group comparisons being presented (i.e., pre- v circa-PHV, circa- v post-, pre v post-

PHV), 2) similar test protocols used across studies, to ensure the most accurate and robust comparisons, 3) high ecological validity and likeliness of the test protocol/outcome measure being utilized in a youth sport setting due to ease of data collection. The meta-analyses for the four variables (RSI, sprinting speed, power output and vertical jump) that have not been presented have been included in appendices 2-5.

Between-group standardized mean differences for each maturity group comparison were calculated using Microsoft Excel (version 2203) [SMD = (mean maturity group 1 – mean maturity group 2)/pooled standard deviation. Subsequently SMDs were adjusted for the respective sample size (1-(3/(4N-))) [26]. The calculated effect sizes (ES) and standard errors (SE) for the outcome measures from all maturity group comparisons and the individual outcome measures were meta-analysed using Jamovi (version 2.3.21.0, Sydney Australia). Separate meta-analyses were conducted for outcome measures that had been used for 5 or more studies. Heterogeneity was assessed using I2, with classifications: low 25%, moderate 50% and high 75% [27]. Moderate to high heterogeneity was indicated (range 68.5% to 93.5%). Three comparisons (of 18 total) sat beneath this range (circa- to post-PHV for 10m and 30m sprint and SJ). A random effects model was applied to all meta-analyses for consistency. Effect sizes and 95% confidence intervals for each study plus an overall effect across the studies were generated for each outcome measure. Effect sizes were interpreted as followed: 0.6–1.2, moderate; >1.2–2.0, large; >2.0–4.0, very large; >4.0, extremely large [28].

3.0 Results

The systematic database searches resulted in 1578 studies (figure 1). After removing duplicates (n=297) and excluding studies based on the title and abstract screening (n=1124), the full texts of 157 studies were reviewed. After further assessment of the full text articles, 123 were removed. This included 6 papers that were removed when requests for unavailable full texts (n=2) and raw data when results for male and female athletes were not presented separately (n=4) did not receive a response. An additional 6 studies were identified through forward citation tracking and included. Forty studies were included in the final analysis. An additional 6 studies were identified through forward citation tracking and included. Forty studies were included in the final analysis.

<Insert Figure 1: Flow chart displaying the search's workflow>

Figure 1: Flow diagram illustrating the study selection process for the systematic review, including identification, screening, eligibility, and inclusion stages.

3.1 Quality Assessment

Twelve studies scored >15; and the remaining studies (n=28) scored between 10 and 15 on the AXIS system based on Bull et al. [22] (see Appendix 1). The main areas of low quality were lack of justification of sample size (73%); not discussing the limitations of the study (40%), lack of internally consistency in results (10%), authors' discussions and conclusions not justified by the results (8%), basic data not adequately described (3%), not all results for the analyses described in the methods presented (3%) and presence of funding sources or conflicts of interest that may affect authors interpretation of results. In the context of the current review, the questions relating to non-response do not apply whatsoever because this is only relevant for intervention studies. When data was taken from intervention studies in the current review, only baseline data was extracted and analysed. Therefore, non-responders during any intervention will not impact the results of the current study.

3.2 Assessment methods for maturity status

Four different methods were used to estimate maturity status. The most common was the maturity off set method developed by Mirwald et al. [8] (n=36). Others included a simplified version of the maturity off set, Moore et al. [9] (n=2), Khamis & Roche [10] (n=1) and Koziel & Malina [29] (n=1). All are estimates of maturity that utilize somatic measures. The thresholds used to classify athletes as pre-, circa- or post-PHV were not consistent through the studies. For example, some studies used pre-PHV (<-1 years from PHV), circa-PHV (-1 to 1 year), post-PHV (>1 year from PHV). Others had two groups pre-PHV (<0 years from PHV) and post-PHV (>0 years from PHV).

3.3 Descriptive statistics

All the articles were published during or after 2013 (n=40), with the majority since 2018 (n=25). There were 5311 participants across all the studies. Ninety-two percent of the participants were male (n=4864), only 8% were female (n=447). Table 2 provides the number of participants and the mean (SD) for their chronological age, maturity status, anthropometrics for the three maturity status groups (pre-, circa- and post-PHV).

<Insert Table 2>

Extracted data are displayed in Table 3. The most common sports within the studies were soccer (n=15), field hockey (n=3), handball (n=3), and basketball (n=2). The remaining sports were cricket (n=1), Australian rules football (n=2), tennis (n=1), badminton (n=1), rugby league (n=1). Two included cohorts of athletes from multiple individual and/or Olympic sports [16,30]. Three also contained control/non-athlete groups studies.

<Insert Table 3>

3.4 Meta-analysis

The meta-analysed sprint performance measures were: 10m, 20m and 30m sprint times. The jump performance measures were countermovement jump (CMJ) height, squat jump (SJ) height and standing long jump (SLJ). Figures 2-7 show the forest plots for the outcome measures including effect sizes and 95% confidence interval for each study included and an overall effect all studies. A separate forest plot is presented within each figure for the three between group comparisons A) pre- vs. circa-PHV B) circa- vs. post and C) pre- vs. post-PHV.

3.5 Sprinting outcome measures

Figures 2, 3 and 4 present the forest plots with effect sizes for the 10m time, 20m time, and 30m time respectively. For all distances and comparisons, the sprint times were faster in the more mature groups. For the 10m and 20m sprint times, overall effect sizes indicated moderate to large differences favouring the more mature group in each comparison. Moderate effect sizes were present for the differences between the pre- and circa-PHV groups and circa- to post-PHV comparisons. A large overall effect size was present for the pre- to post-PHV comparison for these distances. For 30m time, the overall effect sizes for the differences were moderate from pre- to circa-PHV, trivial circa to post-PHV and moderate pre- to post-PHV.

<INSERT FIGURE 2 HERE>

Figure 2. Forest plot of individual study effect sizes with 95% confidence intervals (CI) and overall effect size for 10m sprint time for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV; control = separate analysis of control group within the study. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.

<INSERT FIGURE 3 HERE>

Figure 3. Forest plot of individual study effect sizes with 95% CI and overall effect size for 20m sprint time for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV;

control = separate analysis of control group within the study. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.

<INSERT FIGURE 4 HERE>

Figure 4. Forest plot of individual study effect sizes with 95% CI and overall effect size for 30m sprint time for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV; control = separate analysis of control group within the study. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.

3.6 Jump performance outcome measures

Forest plots with effect sizes for the jump performance outcome measures are displayed in figures 5 to 7. Overall effect sizes for the CMJ indicated moderate differences when comparing consecutive groups (i.e. pre- to circa-PHV and circa- to post-PHV); and a large effect size for the pre- to post-PHV comparison (see fig. 5). In the SJ (fig. 6), overall effect sizes were moderate pre- to circa-PHV, trivial from circa- to post-PHV and large pre- to post-PHV. Overall effect sizes in the SLJ (fig. 7) were large in both pre- to circa-PHV and circa- to post-PHV comparisons, whilst the overall effect pre- to post-PHV was very large.

<INSERT FIGURE 5 HERE >

Figure 5. Forest plot of individual study effect sizes with 95% CI and overall effect size for the countermovement jump (CMJ) for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV; control = separate analysis of control group within the study. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.

<INSERT FIGURE 6 HERE>

Figure 6. Forest plot of individual study effect sizes with 95% CI and overall effect size for the squat jump (SJ) for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV; control = separate analysis of control group within the study. Abbreviations: RE = Random Effects.

<INSERT FIGURE 7 HERE>

Figure 7. Forest plot of individual study effect sizes with 95% CI and overall effect size for the standing long jump (SLJ) for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV; control = separate analysis of control group within the study. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.

3.7 Summary of sprint time and jump performances

Table 4 provides a summary the mean (SD) data for the primary outcome measures (10m, 20m 30m, SJ, CMJ, SLJ) from all the studies that contained these measures for male athletes by maturity group:

<INSERT TABLE 4>

Table 5 provides a summary mean (SD) for CMJ, 5m and 10m sprint time for female athletes according to maturity status.

<INSERT TABLE 5>

4.0 Discussion

The purpose of this systematic review with meta-analysis was to determine the magnitude of differences in sprinting and jumping performance in youth athletes of differing maturity status (e.g., pre-, circa-, and post-PHV), measured by somatic assessment methods and to provide reference values for each group to enhance practitioners' ability to the evaluate performance. Meta-analytic comparisons between the three maturity groups displayed sequential improvements in performance. Sprint times were faster and jump height/distance (used as a surrogate for power) increased with advancing maturity status and effect sizes were predominantly moderate to large between the groups. Practitioners working with male youth athletes, where large inter-individual differences in maturity status are likely to exist, should consider how these differences may impact performance in the athlete's sport, and regularly assess individual maturity status to be able to accurately evaluate sprinting and jumping performance using maturity-based benchmarks, such as those provided in the current study.

Between the pre- to post-PHV groups, effect sizes were large to very large, with post-PHV groups having faster sprint times across all three distances (10m, 20m and 30m) and improved jumping performance in the SJ, CMJ and SLJ. The large magnitude of these differences is likely due to the significant anthropometric and physiological changes that occur through puberty. Age- and growth-related changes occur in muscle size, fibre type, architecture, activation and mechanical tendon properties, and neuromuscular capacity [18] that enhance force producing capabilities and stretch shortening cycle function with advancing age and maturity, improving performance in all the speed and jumping indices. Anthropometric changes (increased height and leg length) associated with growth and maturation result in changes to spatiotemporal characteristics of sprint performance seen in the different maturity groups [5,33]. Sprinting speed is the product of stride length and stride frequency, therefore maturity related changes in stature and leg length (and thus stride length) will likely contribute to improvements in sprinting performance, alongside the improvements in force producing capability. The magnitude of these differences highlights the importance of assessing maturity status to better understand sprinting and jumping performance when making comparisons between groups of young male athletes, where large differences in maturity status are likely to exist within chronological age groups.

In the circa- to post-PHV comparisons, SJ and 30m sprint time improved for the more mature group, but the effect sizes were trivial. Moderate overall effect sizes were observed between consecutive maturity groups (i.e. pre- vs. circa-PHV and circa- vs. post-PHV) with faster in sprint performances (10m, 20m and 30m time) and improved jump height/distance in the more mature groups. (CMJ, SLJ). Rapid changes in body mass that occur in adolescent athletes around peak weight velocity (PWV) that will likely coincide with the post-PHV period, may also explain why there were smaller effects. Athletes that experience a significant increase in body mass, that will not necessarily increase their force producing abilities to an equivalent extent in the same period, thus negatively affecting their relative strength and power levels. Reduced relative strength and power will most likely negatively affect their ability to overcome the inertia of their body in the start and acceleration of a short sprint such as the distances included in many of the studies in this review. An athlete experiencing PWV may maintain their speed but will have a higher momentum. Therefore, it could be advised to monitor changes in running momentum as well as sprint times with youth athletes in future research as recently suggested by Owen et al. [14]. Future research should also aim to examine differences in sprint performance beyond 30m. Given this was the longest sprint distance that appeared in the studies, it remains unknown how maximal sprint speed varies at different maturity statuses.

The findings of our literature synthesis confirm that moderate to large increases in sprinting speed and jumping performance in exist between athletes of different maturity status. But also, that there are situations where performance maybe disrupted around periods of rapid increases in stature and body mass. Evaluating athletes solely against chronological age group standards, without consideration of their maturity status, could lead to erroneous judgements about current performance and future potential. If athletes exist that are pre- and post-PHV within the same chronological age group, they will be significantly disadvantaged and advantaged, respectively. The data we present here indicate there will be more moderate differences when athletes are close in maturity status (i.e. pre- vs. circa-PHV or circa-PHV vs. post-PHV), but again the more mature athletes would still appear to be at an advantage. For athletes, that are circa-PHV or PWV selection processes may occur at a time where their performance is negatively impacted by their growth and maturity status. Therefore, the recommendation for practitioners and coaches working in youth sport would be to assess and identify each individual athlete's maturity status, then aim to evaluate their performance according to both their age and maturity status.

In tables 4 and 5, reference data (mean[SD]) has been provided for the sprint times (10m, 20m and 30m) and jump outcome measures (CMJ, SJ and SLJ) for each maturity group using the data from the synthesized studies. Using these values coaches and practitioners working with youth athletes can evaluate sprint and jump performances when differences in maturity status exist within a chronological age group by creating Z-scores using the mean and standard deviations for each group [62]. Other methods of improving the evaluation of performance data from youth athletes have been proposed in the form of maturity corrective adjustment procedures [63,64] and rolling Z scores for individual test metrics using regression equations from linear models created from age and maturity status [65]. These methods may be preferable once sufficient data has been collected to generate the linear models, given that they avoid the reduction of statistical power that occurs when a continuous variable (i.e. Maturity Offset [YPHV] or PPAH) is changed to a categorical variable [66].

The current systematic review and meta-analysis has highlighted certain gaps in the literature. Firstly, only a small percentage (8%) of the participants in the studies were female, with insufficient studies (<5, with 447 participants) to meta-analyse the outcome measures for them separately. Therefore, further research is required to understand the magnitude of differences in sprinting and jumping performance at different stages of maturity status differences in youth female athletes. Secondly, the studies in the current review contained athletes from team sports (n=21, 2673 participants), school or regional sports academies (n=5, 292 participants) and school children (n=5; 942 participants). Athletes from an individual sport (tennis, n=1; 45 participants) and elite youth athletes from Olympic sports (n=2; 727 participants) were less represented. There was a very limited representation of participants competing in centimetre, grams, and seconds (CGS) sports such as track and field.

In team sports, that comprised most of the studies in this review, technical skills and tactical ability can significantly influence the performance outcome. An athlete competing in these sports may be able to moderate the negative impact of being a later developer by excelling in these areas in these types of sports. In contrast, in track and field disciplines, such as the short sprints and horizontal jumps, sprinting speed and the ability to generate large relative force to bodyweight are critical to success. Therefore, the maturity-related differences identified in this review are likely to have a more significant impact on competition results and make it more difficult for stakeholders in these sports to evaluate performance accurately without consideration of individuals’ maturity status. Currently, the magnitude differences in a track and field cohort remain unknown. so warrants further investigation to understand the differences in performance at a youth level where maturity differences exist.

Readers should be aware of the limitations of the current study whilst interpreting the results of the review. The meta-analysis did not include a sub-group analysis, meaning that moderators of the effect of maturity status, such as chronological age or training age may go unnoticed. Whilst reviewing the literature, we also identified inconsistent approaches to determine thresholds for the pre-, circa- and post-PHV. This limitation should be considered when interpreting the results of our meta-analysis, as differences in the grouping thresholds may have increased or decreased the effect sizes in individual studies. Authors utilized a range of different thresholds to classify the groups. For example, some studies used pre-PHV (<-1 years from PHV), circa-PHV (-1 to 1 year), post-PHV (>1 year from PHV), others had only two groups pre-PHV (<0 years from PHV) and post-PHV (>0 years from PHV). Despite these inconsistencies, the mean maturity status values presented (Table 1) shows the participants are a good representation of pre-PHV (-1.7±0.7 YPHV), circa-PHV (0.1±0.3 YPHV) and post-PHV (1.7±0.7 YPHV) maturity groups. Future research should aim to establish consensus on maturity group thresholds for the different methods of maturity assessment to enable more consistent comparisons to be made across studies. A limitation of the current approach is the reduction in statistical power and the potential for misclassification that arises from categorizing continuous data into maturity groups (i.e., pre-, circa-, and post-PHV). This approach to grouping athletes, adopted in all included studies and within this review, can lead to misclassification, particularly at the boundaries of each maturity group. The risk of misclassification is increased further by the known error (±0.5 years) of the Mirwald et al. [8] regression equation that was used in 90% of the studies. This may explain why only moderate effect sizes were present in consecutive maturity groups. The known error was accounted for by some researchers who removed participants from the analysis in certain ranges of maturity offset (e.g. -0.5 and 0.5) [33], but the majority did not. One study, by Peña-González et al. [43] used an updated maturity offset equation [29] that addressed the fact that the mass by stature ratio should have been multiplied by 100 in the original publication by Mirwald et al. [8].

Therefore, future researchers may wish to consider utilizing these updated equations. Another potential limitation in the review processes of this systematic review is there are fewer robust tools available to conduct quality assessments on studies with a cross-sectional design compared to the tools available to assess intervention studies.

5.0 Conclusion

In conclusion, the data presented in this systematic review and meta-analysis indicate that between maturity status groups there are typically moderate to large differences in sprinting and jumping performance. Large to very large differences will exist in performance when large interindividual differences in maturity exist within a chronological age group (i.e., pre and post-PHV). Therefore, to confidently interpret individual sprinting and jump performance it is recommended that coaches and practitioners working with youth athletes regularly assess maturity status. Applying this approach consistently in testing or competition windows will enhance coach or practitioner's ability to assess an individual athlete's current performance against both age and maturity status benchmarks and this may enable a better interpretation of their future potential. Particularly in instances where athletes are later or earlier maturing within their age group because they may be significantly disadvantaged and advantaged, respectively, when it comes to sprinting and jumping performance. Without consideration of maturity status, practitioners and coaches involved in selection processes may not be able to appreciate an athlete's full potential. This may be of greater concern in centimetre, grams and seconds sports, such as track and field at a youth level when maturity differences exist because higher levels of performance are associated faster sprinting speeds and generating high forces relative to bodyweight [67,68]. Whereas in team sports technical, tactical, and decision-making abilities have greater influence on performance outcomes. Coaches and practitioners involved in the identification, selection/deselection of male youth athletes are advised to consider the magnitude of differences in sprinting and jumping performance shown in this review and consider how this may influence performance in the context of their sport. Bio-banding [13] is a process that has been successfully utilized in team sports [69,70] that could be considered as an alternative learning environment and/or competition experience, if stakeholders wish to reduce any maturity status related advantages or disadvantages based on the differences shown in sprinting speed and jumping performance in the current review.

Practical applications

Coaches and practitioners wishing to incorporate maturity-based assessments into their programmes must commit to regularly assessing maturity status (i.e., quarterly) as part of routine monitoring [71]. However, the time between the maturity assessment measurement and physical testing or competition event should not exceed ±30 days and would ideally be within a 7-day time frame. Therefore, it may be prudent to re-assess maturity status at specific points of interest such as testing, competition or trial days to ensure the maturity estimate is up to date and accurate. With maturity statuses available for individual athletes, coaches can utilize the maturity benchmark data shared in tables 4 and 5 to create age and maturity Z scores evaluations for the sprinting and jumping outcome measures. Alternatively, benchmark tables can be created for each outcome measure and maturity group using the mean and standard deviations and the following Z-score thresholds: excellent (>1.5), good (0.5 to 1.5), average (-0.5 to 0.5), below average (-0.5 to -1.5) and poor <-1.5). Whilst the data available within the tables 4 and 5 are a useful starting point, it is important to note they data is predominantly from team sport athletes, with many of the participants youth soccer players. Therefore, practitioners are encouraged to generate their own data for the sports they are working to ensure the comparisons and evaluations are appropriate and meaningful for their athletes.

Declarations

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Conflicts of interest

The authors have no financial or proprietary interests in any material discussed in this article.

Author contributions

All authors contributed to the study conception and design of the review. Literature searches and filtering were conducted by JB and TJ. Data extraction from full texts was completed by all authors. Quality assessments were conducted by JB and MC. Data analysis was completed by JB and TJ. Manuscript was drafted by JB and TJ and critically reviewed by PR, PGS and MC. All authors read and approved the final version of the manuscript.

Data availability

Data supporting this study are included with the article and supporting materials.

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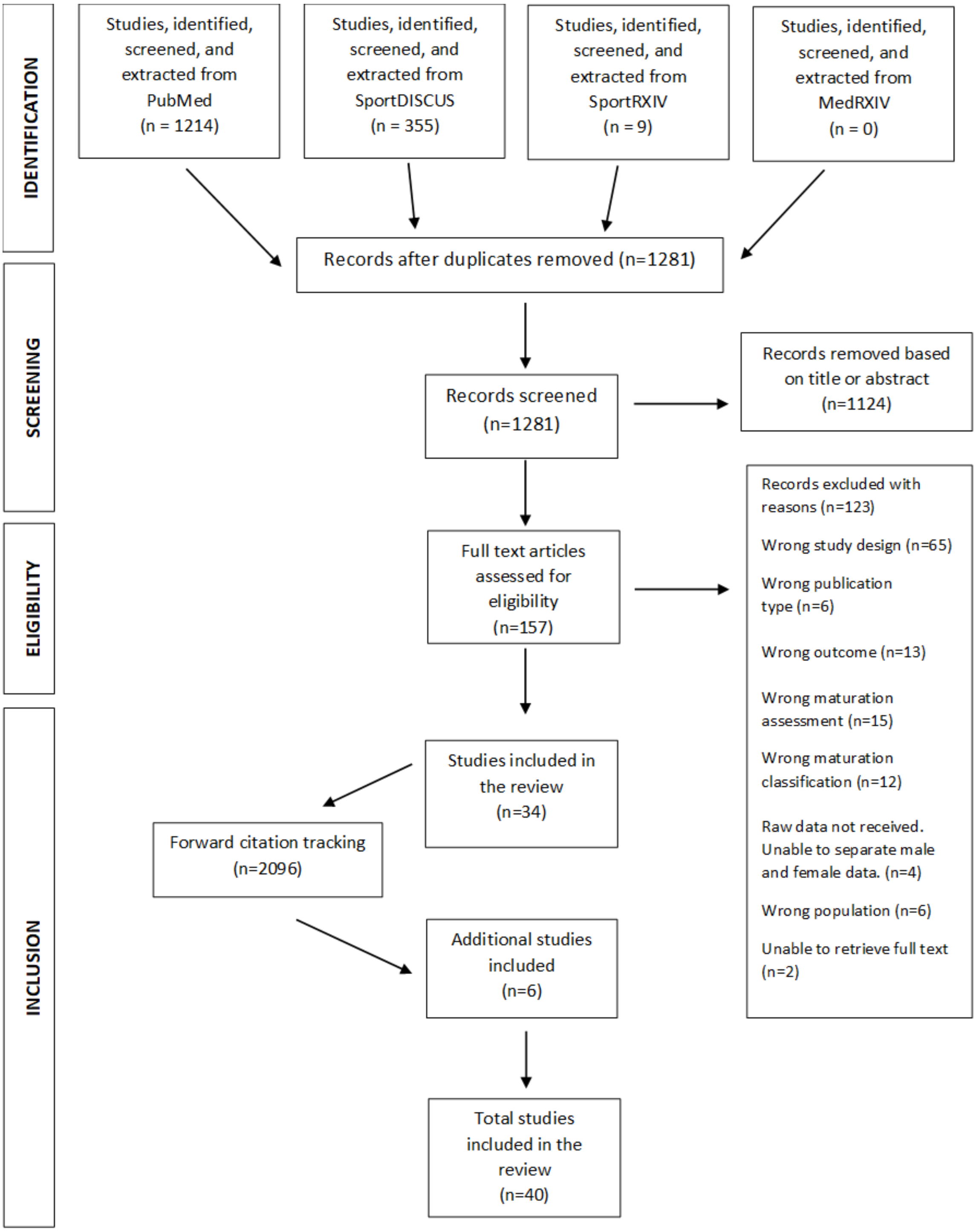

IDENTIFICATION
SCREENING
ELIGIBILITY
INCLUSION
Studies, identified, screened, and extracted from PubMed (n = 1214)
Studies, identified, screened, and extracted from SportDISCUS (n = 355)
Studies, identified, screened, and extracted from SportRXIV (n = 9)
Studies, identified, screened, and extracted from MedRXIV (n = 0)
Records after duplicates removed (n=1281)
Records screened (n=1281)
Records removed based on title or abstract (n=1124)
Full text articles assessed for eligibility (n=157)
Records excluded with reasons (n=123)
Wrong study design (n=65)
Wrong publication type (n=6)
Wrong outcome (n=13)
Wrong maturation assessment (n=15)
Wrong maturation classification (n=12)
Raw data not received. Unable to separate male and female data. (n=4)
Wrong population (n=6)
Unable to retrieve full text (n=2)
Studies included in the review (n=34)
Forward citation tracking (n=2096)
Additional studies included (n=6)
Total studies included in the review (n=40)

Table 1. Search terms used in PubMed and other search engines

[All fields] ("growth and maturation" OR "maturity" OR "bio-banding") AND ("speed" OR "sprinting" OR "sprint speed" OR "power output" OR “power")

Table 2. Descriptive data (Mean[SD]) for male and females for each maturity status

	Male (N=4864)			Female (N=447)		
	Pre-PHV	**Circa-PHV**	**Post-PHV**	**Pre-PHV**	**Circa-PHV**	**Post-PHV**
N	1933	1113	1818	49	109	289
Age (years)	12.0±0.9	14.0±0.7	15.6±1.3	12.5±0.9	12.9±0.8	14.4±0.4
Maturity Offset (YPHV)	-1.8±0.7	0.1±0.3	1.6±0.6	-1.3±0.5	0.1±0.2	1.9±0.6
Height (cm)	149.9±10.2	164.2±6.9	175.5±4.1	147.0±1.0	155.9±2.2	172.1±6.8
Body Mass (kg)	42.9±6.1	55.8±5.0	68.4±4.9	40.4±2.6	55.3±9.8	65.8±7.5

Abbreviations: PHV = Peak Height Velocity; YPHV = Years from PHV

3. Characteristics of studies included in the systematic review (mean±SD)

Study	**Sex**	**Population**	**Maturity Assessment**	**Maturity Status**	**N**	**Age (years)**	**Maturity Offset (YPHV)**	**PPAH (%)**	**Stature (cm)**	**Mass (kg)**	**Outcome measures**
Meylan et al., [31]	Male	Young athletes	Mirwald et al. [8]	Pre-PHV	25	12.2±0.6	-1.7±0.5	85.3±2.2	154.0±6.0	40.9±4.8	20m sprint time, Peak Power
				Circa-PHV	26	13.4±0.6	-0.2±0.4	91.8±2.1	166.0±8.0	54.6±9.0	
				Post-PHV	15	14.4±0.4	1.0±0.4	96.4±1.4	172.0±4.0	63.3±9.9	
Hammami et al. [32]	Male	Handball players	Moore et al. [9]	Pre-PHV	34	12.9±0.5	-0.68±0.4		156.7±7.0	48.3±9.77	10-m sprint time, 30-m sprint time CMJ height, RSI, SJ height
				Post-PHV	22	14.9±0.8	1.44±0.6		175.1±5.1	66.7±8.92	
Meyers et al. [33]	Male	PE students	Mirwald et al. [8]	Pre-PHV	271	12.4±0.8	-1.8±0.7		150.0±9.0	45.4±11.4	Sprint speed
				Post-PHV	52	15.1±0.6	1.2±0.6		174.0±6.0	71.8±15.8	
Murtagh et al.	Male	Elite youth soccer players	Mirwald et al. [8]	Pre-PHV	97	10.9±1.3			144.1±7.6	35.9±5.2	

[7]				Circa-PHV	24	13.8±0.8			163.3±3.2	48.3±5.8	10-m & 20m sprint, CMJ height, SJ height, SLJ distance
				Post-PHV	70	17.5±2.1			180.0±6.5	72.0±9.6	
	Male	Non elite youth soccer players	Mirwald et al. [8]	Pre-PHV	26	11.2±1.3			145.1±7.6	37.5±5.8	
				Circa-PHV	14	13.6±0.6			162.6±5.2	51.2±5.1	
				Post-PHV	32	18.6±3.7			175.0±6.2	69.3±8.9	
Sariati et al. [34]	Male	Elite male youth soccer players	Moore et al. [9]	Pre-PHV	15	10.9±0.4	-1.5±0.3		164.9±5.0	55.0±6.4	10m & 30m sprint, 5 Jump Test
				Post-PHV	15	17.4±0.3	3.2±0.5		177.3±6.5	67.0±7.2	
Uzelac-Sciran et al. [35]	Male	Schoolboys, 12-14 years old	Mirwald et al. [8]	Pre-PHV	59	13.1±0.5	-0.83±0.5		161.5±7.0	52.0±10.1	20-m sprint, CMJ height, RSI, SJ height
				Post-PHV	43	14±0.4	0.73±0.4		175.6±6.8	67.1±10.9	
Arede et al. [36]	Male	Young male basketball players	Mirwald et al. [8]	Pre-PHV	9			93.1±1.4	170.7±3.8	57.6±6.3	20-m Power Output, 20-m sprint, VJ height, CMJ
				Circa-PHV	10			95.7±0.7	179.5±6.1	69.1±7.2	

				Post-PHV	15			97.7±0.3	187.4±5.1	78.6±7.8	height, CMJ Power, SJ height, SJ Power
Beyer et al. [37]	Male	Youth male athletes	Mirwald et al. [8]	Pre-PHV	7	11.6±0.6	-2.21±0.5		148.4±8.8	39.8±7.1	Peak Power Output
				Circa-PHV	10	14.3±1.1	0.25±0.9		167.6±6.9	55.1±6.7	
				Post-PHV	10	17.1±0.6	2.81±0.5		178.5±7.6	76.8±12.8	

Table 3 (continued)

Study	Sex	Population	Maturity Assessment	Maturity Status	N	Age	Maturity Offset (YPHV)	PPAH (%)	Stature (cm)	Mass (kg)	Outcome measures
Moran et al. [38]	Male	Youth field hockey players	Mirwald et al. [8]	Pre-PHV	21	12.7±0.7	-1.5±0.3		157.3±5.7	51.5±9.1	10m, 30m sprint times, CMJ height
				Circa-PHV	17	14.4±0.6	0.4±0.3		172.8±6.0	62.1±9.2	
Morris et al. [39]	Male	Elite youth soccer players	Mirwald et al. [8]	Pre-PHV	55	12.5±0.7	-1.95±0.6		152.7±7.9	41.4±6.4	10m Sprint, 30m Sprint, CMJ height
				Circa-PHV	21	14.2±0.9	-0.09±0.6		168.9±6.9	56.4±8.2	
				Post-PHV	36	15.7±1.2	1.52±0.9		177.6±8.4	65.6±8.4	
	Male	Active participants	Mirwald et al. [8]	Pre-PHV	18	11.6+0.7	-2.21±0.6		149.6±8.4	44.2±10.9	
				Circa-PHV	10	14.3±1.3	0.17±0.5		163.7±5.1	58.6±14.8	
				Post-PHV	10	15.8±1.1	2.13±0.6		177.4±6.3	74.4±14.3	

Borges et al. [40]	Male	Regional soccer players, 70	Mirwald et al. [8]	Pre-PHV	9	13.5±0.4		162.3±2.9	46.3±1.1	Sprint speed
				Circa-PHV	13	13.7±0.2		171.4±1.6	58.8±3.0	
				Post-PHV	15	15.6±0.5		174.2±2.9	63.4±2.7	
Dobbs et al. [3]	Male	Young male cricketers	Mirwald et al. [8]	Pre-PHV	130		-2.17±0.7	148.0±7.7	41.2±8.0	CMJ height, CMJ power, SJ height, SJ power,
				Circa-PHV	33		-0.01±0.4	164.1±5.7	55.4±8.1	
				Post-PHV	43		1.92±0.7	175.9±7.0	70.1±10.5	
Edwards et al. [4]	Male	Junior Australian Football Academy	Mirwald et al. [8]	Pre-PHV	16	13.3±0.6	-0.84±0.3	158.2±6.8	47.3±7.8	10m, 20m, 30m sprint time, Sprint Absolute Power Max
				Circa-PHV	36	13.3±0.6	0.06±0.3	166.6±5.9	53.4±6.3	
				Post-PHV	57	14.1±0.6.	1.29±0.7	174.8±7.6	66.9±8.8	
	Male	Youth Academy Rugby League	Mirwald et al. [8]	Pre-PHV	25	13.1±0.7		152.8±7.1	44.0±5.5	10m, 20m sprint time, VJ height

Till & Jones [17]				Circa-PHV	85	14.4±0.8			169.3±6.2	61.9±8.2	
				Post-PHV	96	15.3±0.6			177.7±5.3	77.0±9.6	
Rumpf et al. [41]	Male	Developing school or regional athletes	Mirwald et al. [8]	Pre-PHV	19	10.6±1.6	-2.78±0.9		141.0±6.7	35.0±4.9	Power, sprint speed
				Circa-PHV	21	14.9±0.3	0.5±0.5		166.0±6.2	55±7.3	
				Post-PHV	34	15.1±0.3	1.71±0.5		178.0±8.7	73.1±8.7	

Table 4. Summary (Mean[SD]) of sprint time and jump performance for males by maturity status

	Pre-PHV		Circa-PHV		Post-PHV	
Outcome	**N**	**Mean[SD]**	**N**	**Mean[SD]**	**N**	**Mean[SD]**
10-m sprint time (s)	683	2.08±0.15	405	1.99±0.14	997	1.93±0.15
20-m sprint time (s)	536	3.66±0.32	361	3.45±0.21	911	3.28±0.25
30-m sprint time (s)	232	5.18±0.31	148	4.88±0.38	223	4.86±0.41
CMJ height (cm)	884	24.5±4.5	521	28.1±5.0	755	32.0±5.8
SJ height (cm)	415	22.3±4.5	169	23.5±4.7	341	27.8±4.36
SLJ (cm)	472	137.6±17.7	283	156.4±23.0	755	180.1±22.2

Abbreviations: CMJ =. Countermovement Jump; SJ = Squat Jump; SLJ = Standing Long Jump; PHV = Peak Height Velocity

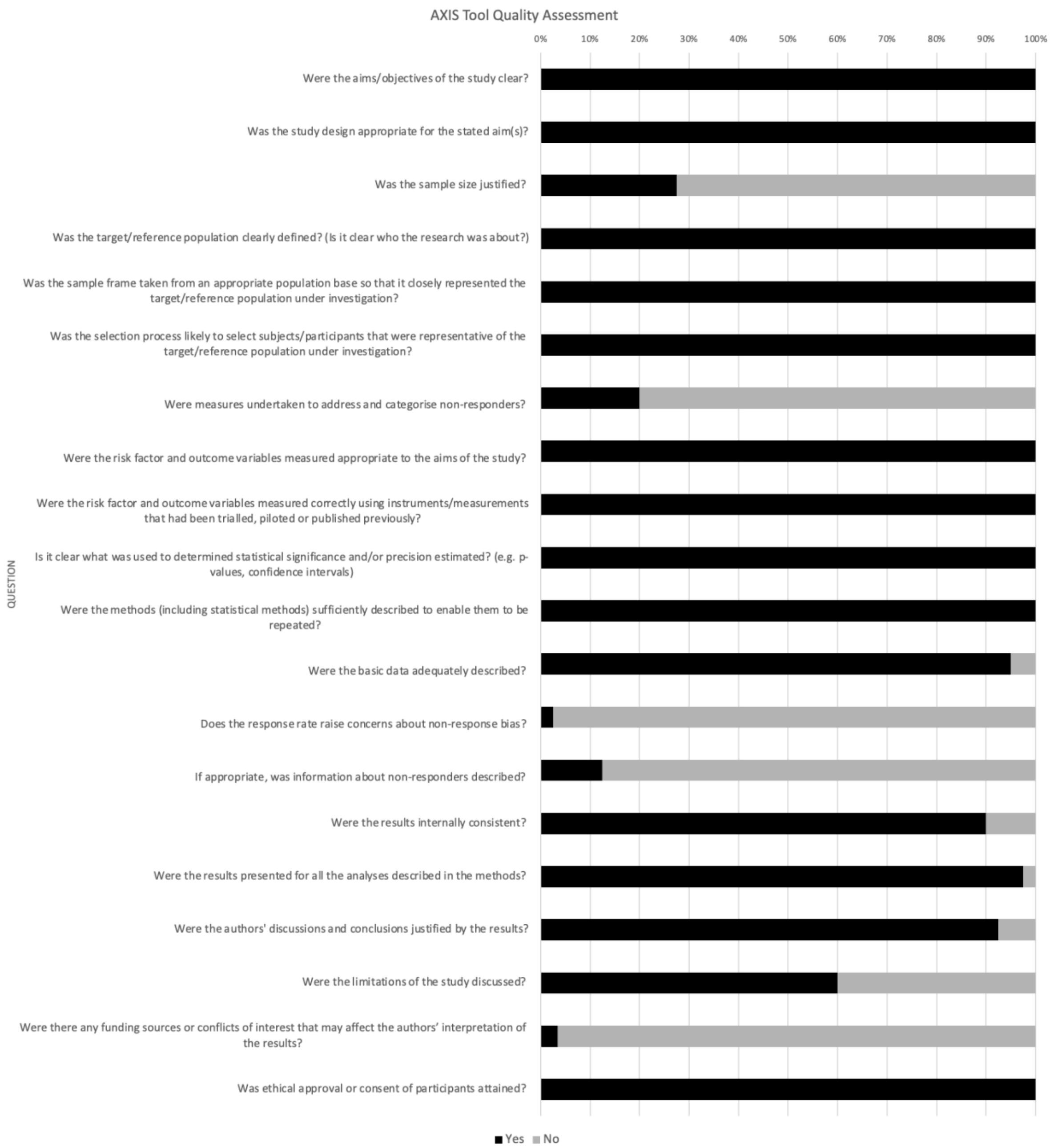
Table 5. Summary (Mean[SD]) of sprint time and jump performance for females by maturity status

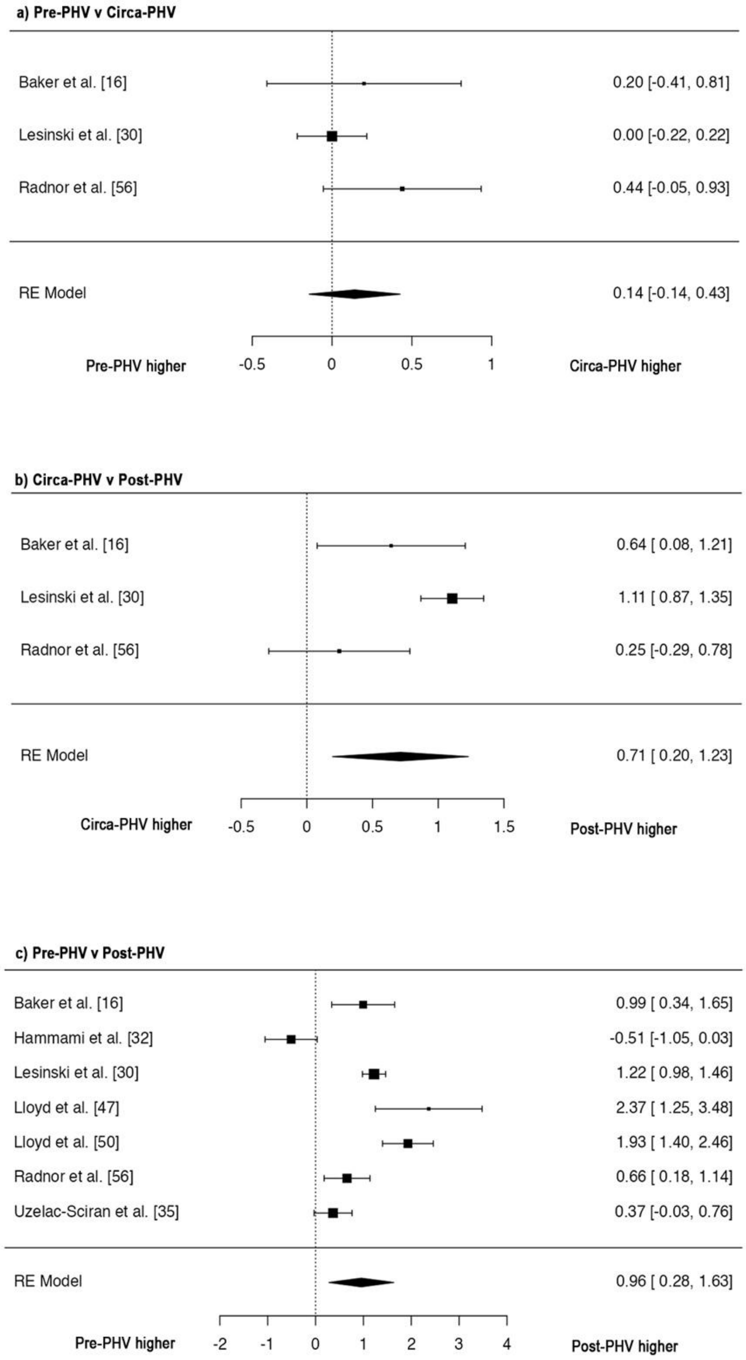
	Pre-PHV		**Circa-PHV**		**Post-PHV**	
Outcome	**N**	**Mean[SD]**	**N**	**Mean[SD]**	**N**	**Mean[SD]**
5-m sprint time (s)	30	1.30±0.2	53	1.29±0.13	71	1.20±0.08
10-m sprint time (s)	30	2.28±0.2	53	2.22±0.16	71	2.11±0.12
CMJ height (cm)	30	19.7±3.9	107	22.6±4.5	287	24.9±4.1

Abbreviations: CMJ =. Countermovement Jump; PHV = Peak Height Velocity

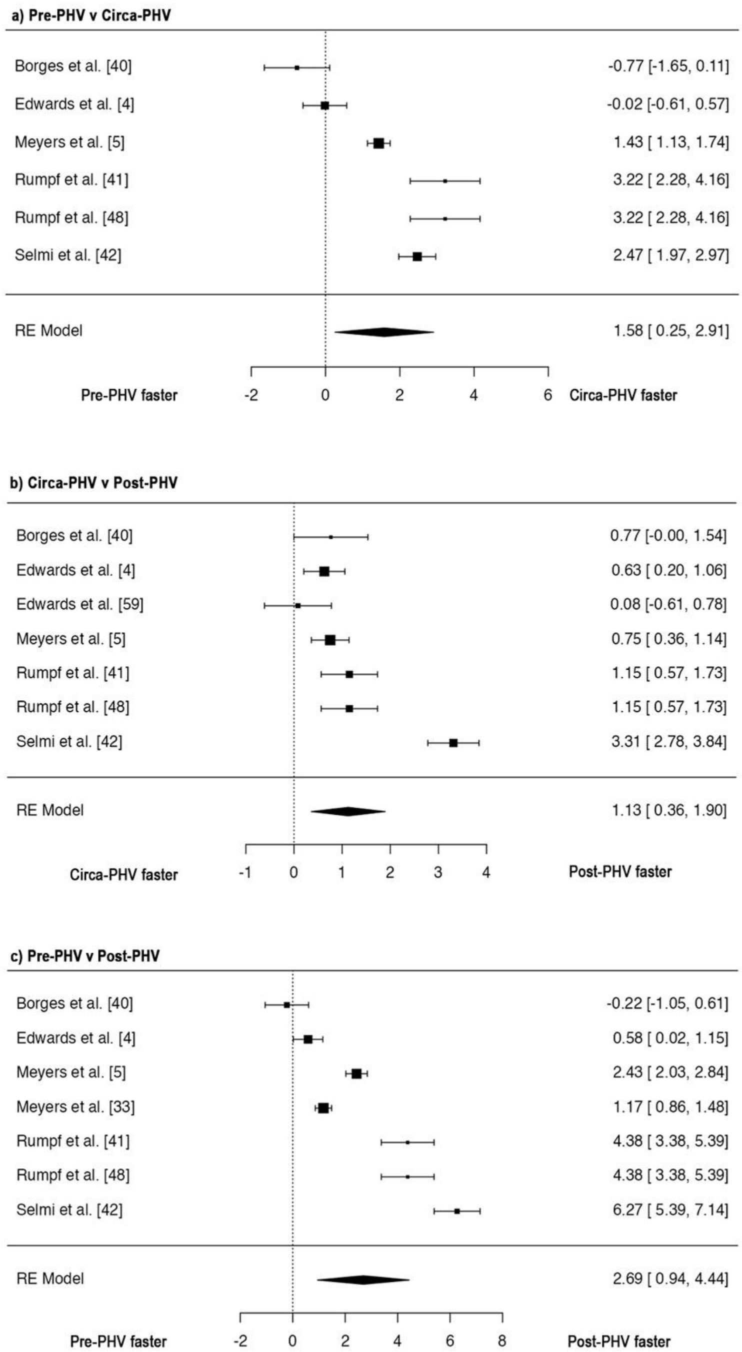
Appendices

Appendix 1: Results of AXIS quality assessment tool

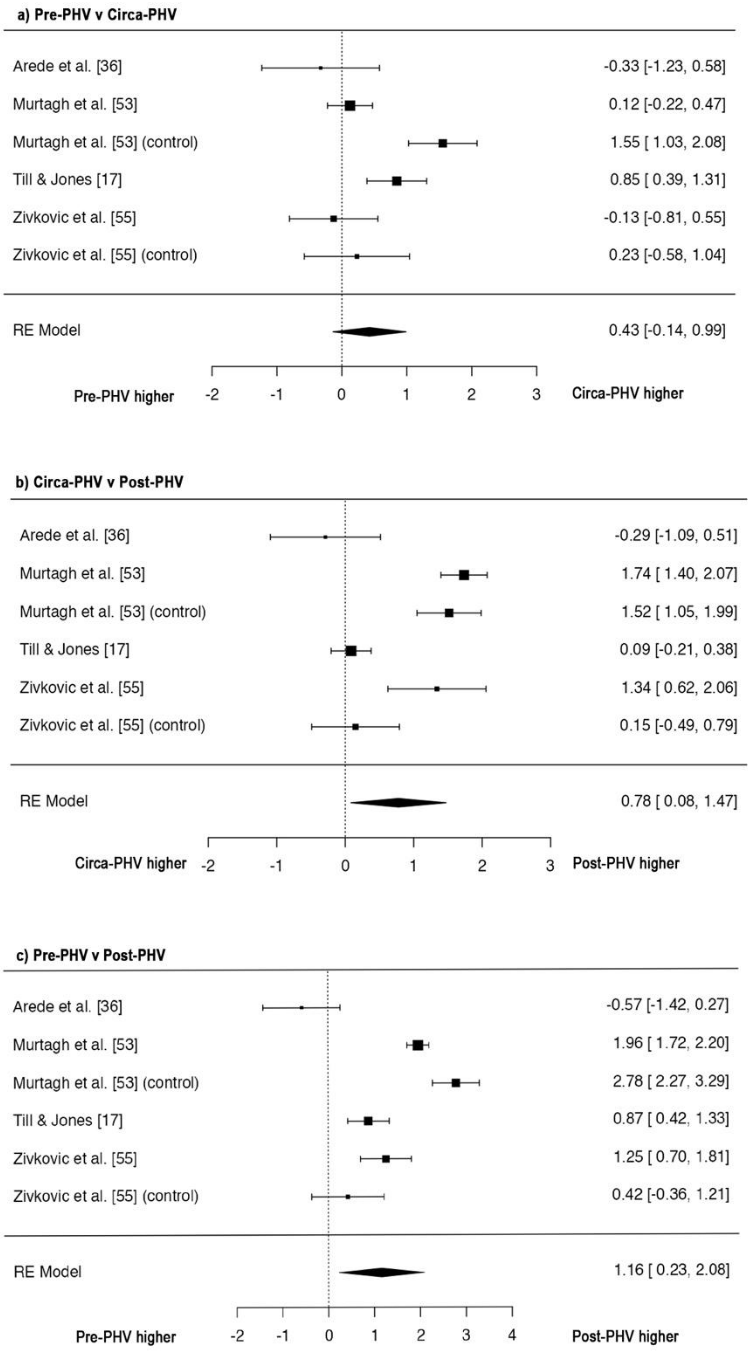



a) Pre-PHV v Circa-PHV
Baker et al. [16]
0.20 [-0.41, 0.81]
Lesinski et al. [30]
0.00 [-0.22, 0.22]
Radnor et al. [56]
0.44 [-0.05, 0.93]
RE Model
0.14 [-0.14, 0.43]
Pre-PHV higher
-0.5
0
0.5
1
Circa-PHV higher
b) Circa-PHV v Post-PHV
Baker et al. [16]
0.64 [0.08, 1.21]
Lesinski et al. [30]
1.11 [0.87, 1.35]
Radnor et al. [56]
0.25 [-0.29, 0.78]
RE Model
0.71 [0.20, 1.23]
Circa-PHV higher
-0.5
0
0.5
1
1.5
Post-PHV higher
c) Pre-PHV v Post-PHV
Baker et al. [16]
0.99 [0.34, 1.65]
Hammami et al. [32]
-0.51 [-1.05, 0.03]
Lesinski et al. [30]
1.22 [0.98, 1.46]
Lloyd et al. [47]
2.37 [1.25, 3.48]
Lloyd et al. [50]
1.93 [1.40, 2.46]
Radnor et al. [56]
0.66 [0.18, 1.14]
Uzelac-Sciran et al. [35]
0.37 [-0.03, 0.76]
RE Model
0.96 [0.28, 1.63]
Pre-PHV higher
-2
-1
0
1
2
3
4
Post-PHV higher

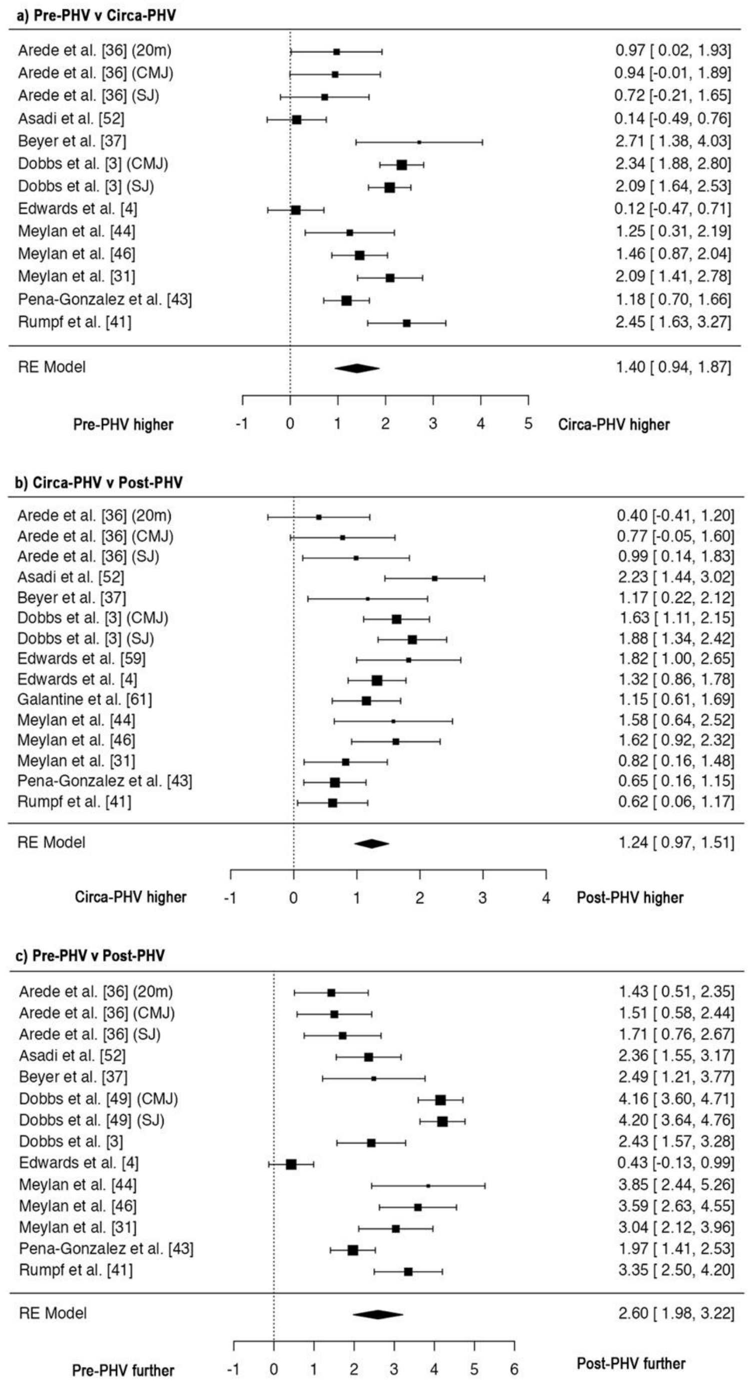
Appendix 2: Forest plot of individual study effect sizes with 95% CI and overall effect Reactive Strength Index (RSI) for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.



Appendix 3: Forest plot of individual study effect sizes with 95% CI and overall effect for sprint speed for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.


a) Pre-PHV v Circa-PHV
Arede et al. [36] -0.33 [-1.23, 0.58]
Murtagh et al. [53] 0.12 [-0.22, 0.47]
Murtagh et al. [53] (control) 1.55 [1.03, 2.08]
Till & Jones [17] 0.85 [0.39, 1.31]
Zivkovic et al. [55] -0.13 [-0.81, 0.55]
Zivkovic et al. [55] (control) 0.23 [-0.58, 1.04]
RE Model 0.43 [-0.14, 0.99]
Pre-PHV higher
-2 -1 0 1 2 3
Circa-PHV higher
b) Circa-PHV v Post-PHV
Arede et al. [36] -0.29 [-1.09, 0.51]
Murtagh et al. [53] 1.74 [1.40, 2.07]
Murtagh et al. [53] (control) 1.52 [1.05, 1.99]
Till & Jones [17] 0.09 [-0.21, 0.38]
Zivkovic et al. [55] 1.34 [0.62, 2.06]
Zivkovic et al. [55] (control) 0.15 [-0.49, 0.79]
RE Model 0.78 [0.08, 1.47]
Circa-PHV higher
-2 -1 0 1 2 3
Post-PHV higher
c) Pre-PHV v Post-PHV
Arede et al. [36] -0.57 [-1.42, 0.27]
Murtagh et al. [53] 1.96 [1.72, 2.20]
Murtagh et al. [53] (control) 2.78 [2.27, 3.29]
Till & Jones [17] 0.87 [0.42, 1.33]
Zivkovic et al. [55] 1.25 [0.70, 1.81]
Zivkovic et al. [55] (control) 0.42 [-0.36, 1.21]
RE Model 1.16 [0.23, 2.08]
Pre-PHV higher
-2 -1 0 1 2 3 4
Post-PHV higher

Appendix 4: Forest plot of individual study effect sizes with 95% CI and overall effect for the vertical jump for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV; control = control group analysed as separate study. Abbreviations: RE = Random Effects; PHV = Peak Height Velocity.



Appendix 5: Forest plot of individual study effect sizes with 95% CI and overall effect for power output for maturity group comparisons a) pre- vs. circa-PHV b) circa- vs. post-PHV c) pre- vs. post-PHV; 20m = peak power from 20m sprint; CMJ = peak power from countermovement jump; SJ = peak power from squat jump; RE = Random Effects; PHV = Peak Height Velocity.