Title: Methods Used to Reduce the Influence of Biological Maturity on Talent Selection and Development in Youth Team Sports – A Systematic Review.

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Abstract:

Background: Chronological age groups in youth sports aim to encourage fair competition. Yet, within chronological age groups, "maturation biases" which favour the selection of relatively early maturing athletes over their peers are often observed. Several strategies that can be used to mitigate this maturity bias have been reported in the literature, yet the studies in which these strategies have been used to alleviate maturational biases have not been systematically identified, evaluated and summarised in order to make the available literature more accessible to researchers and practitioners.

Methods: Three electronic databases (i.e. PubMed, SPORTDiscus and Web of Science) were searched for articles that exposed at least one group of team sport athletes aged 10-16y for Males or 8-14y for Females, to an intervention aiming to reduce maturation bias, and included a measure of task performance or athlete selection. The risk of bias and quality of reporting of the two included articles identified as randomised control trials (RCT) were assessed using the Joanna Briggs Institute critical appraisal checklists for RCT's and the

Consolidated Standards of Reporting Trials (CONSORT). The nine included articles identified as quasi-experimental were assessed using the JBI critical appraisal checklist for quasi-experimental trials and the Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) statement checklist.

Results: The eleven articles included in this review highlight bio-banding and player labelling as the only strategies that have directly addressed the reduction of maturation bias in youth sport. However, the findings of all included articles should be interpreted with caution due to potential risks of bias. Despite all ten articles on bio-banding reporting a number "effects" of bio-banding on performance, there is no direct evidence in the available research to suggest that these also have a meaningful impact on reducing bias during the selection of youth athletes. While less commonly reported on, player labelling was reported to reverse the maturation bias in favour of later maturing youth soccer players, although this study may have observed a fairly homogeneous group of individuals who had not yet commenced a period of increased growth velocity.

Conclusions: Although bio-banding and player labelling have been explored as strategies to reduce maturity bias in youth team sports, potential biases identified in the literature underscore the need for further investigation before practical recommendations can be made.

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1. Introduction

In most youth sporting competitions, cut-off dates are used to group athletes according to their chronological age [1]. While the aim of these chronological age groups is to create fair competition and equal opportunity, it is important to highlight that individuals of the same chronological age can differ dramatically in their degree of biological maturity [2]. Biological maturity is a specific state of an individual's biological maturation, which refers to the progress towards the adult state, and is characterised by structural and functional changes within the body [2,3]. The process of maturation includes the two components of timing and tempo, both of which can vary between individuals [4,5]. Timing refers to the age at which a specific maturational event occurs such as the age at peak height velocity (APHV), where the maximum rate of growth occurs during the adolescent growth spurt. Tempo refers to the rate at which an individual progresses toward their biologically mature state [4,5]. Beunen & Malina [4] report that the estimated age at initiation of the adolescent growth spurt occurs earlier in females than males in samples of North American and European children, with the average age at initiation occurring between 8.5-10.3 and 10.3-12.1 years respectively. Additionally, females reach their peak height velocity earlier than males, with the mean ages of peak height velocity being 11.6-12.5 and 13.4-14.2 years respectively [6]. The adolescent growth spurt is not a linear process as it can last anywhere between 2-5 years for both males and females, depending on individual factors [4,6]. Thus, it is important for practitioners to be aware of inequities resulting from differences in biological maturity between participants belonging to the same chronological age band who are grouped together in the context of sports competition and training.

The development of key physical attributes including upper body strength, muscular endurance, running speed and cardiorespiratory endurance has been observed to reach peak rates around the same time as the occurrence of peak growth [7]. Thus, youth athletes who are first to reach their APHV, may be able to use their superior physical size and physical attributes as a competitive advantage against their later maturing peers, especially in sports where physical size can be advantageous. For example, Arede et al., [8] reported that early maturing youth basketball players were able to significantly outperform their later maturing counterparts in power output tests including the counter movement jump, squat jump and 2kg medicine ball throws. Additionally, early maturing basketball and soccer athletes outperformed their peers in functional capacity tests, including the Yo-yo endurance test and sprint times [8,9]. Furthermore, in order to compete with early maturing athletes, late maturing soccer players have been observed to complete significantly more high speed running efforts during matches regardless of playing position [10]. Despite having a smaller physical capacity compared to their earlier maturing couterparts, the requirement for late matruing players to display greater physical outputs during game play such as high speed running efforts, may have implications for their performance [10].

The enhanced physical attributes of early maturing youth athletes can also impact their skill involvements during performance in youth sport. For example, Saward et al., [11] report that early maturing soccer players completed a higher number of tackles, blocks and interceptions compared to the "on-time" maturing players which could be related to advantages in size, strength, power, and speed associated with advanced maturity. Similar trends have also been observed in basketball with early maturing basketball players having a higher number of rebounds and blocks compared to late maturing players [8]. Furthermore, Torres-Unda et al., [12] reported a significant association between the age of peak height velocity, points per game and overall game performance in favour of early maturing basketball players. Given that physical attributes and skill involvement are often key factors in team selections, biological maturity could play a vital role in the selection of youth athletes into a talent development program.

Youth talent development programs provide athletes with better development opportunities as they generally have access to high quality training from experienced and expert coaches. While training time and experience are often key factors for selection, biological maturity is also a contributing factor. Indeed, there exists a tendency to mistake physical advantages related to early maturation for "physical talent" during the selection process [13,14]. Selection biases favouring early maturing youth athletes have been observed across a number of team sports including basketball, volleyball, and soccer, with selected players being chronologically older, taller and more mature than de-selected players [15,16]. This "maturation bias" may be created by the lack of consideration for biological maturity in chronological age grouping and talent identification practises, particularly during the initial stages of the process. For example, Johnson et al., [17] reported a selection bias in favour of early maturing players in their sample of English academy soccer players. The observed bias increased from the under 9's all the way to the under 17's, where early maturing players were 20 times more likely to be selected. This suggests that as players age, they are selected from a biased sample of early maturing players and the late maturing players that are excluded in the initial years of selection may not be afforded another opportunity to re-join the academy system [17]. Thus, maturation bias may be detrimental to the development of skilled, later maturing athletes who are more likely to be de-selected and subsequently miss out on opportunities to receive higher level coaching due to their maturity status at the time of selections [12,18].

A considerable body of research exists on the prevalence of maturity biases in youth sports. As a result, there is an increasing volume of research studying potential solutions for reducing maturity bias. However, to date, no study has systematically analysed and synthesised the available literature on potential solutions for maturation bias in youth sports. Thus, the extent of solutions as well as their viability for use in practice is currently unclear. Furthermore, there is a lack of clarity about the gaps in the current literature on strategies used to mitigate maturity bias, which may limit researchers exploring this topic to engage in cumulative science. Therefore, the aim of this review is to identify, appraise and summarise the literature on potential solutions used to mitigate maturation bias in youth sports performance and selection.

2. Methods

2.1 Eligibility

The review was registered with Open Science Framework on the 11th of July 2022 (registration link: https://osf.io/2fb8p/?view_only=4ca30312d9384bbd97d2d4b05a3f2054). After a scoping search of the literature revealed that the majority of articles meeting our inclusion criteria only investigated bio-banding as a potential solution for reducing maturation bias, we decided to add a critical appraisal and an analysis of the quality of reporting of the studies included in the review, and hence we changed this review from a scoping to a systematic review of the literature. Thus, the aim was to not only identify and synthesise the relevant literature but also to critically appraise it. No other changes were made after completing registration. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [19]. The Population, Intervention, Comparison, Outcome (PICO) framework was employed to develop the inclusion and exclusion criteria for this review. For inclusion in the review, articles needed to meet the following criteria: 1. Peer reviewed journal articles containing original empirical data, 2. Published in English (or could be translated into English), 3. Had at least one group of team sport participants exposed to an intervention aiming to reduce maturation bias, 4. Include a measure of task performance or athlete selection. Studies were excluded if they had the following: 1. Recruited individual sport athletes, 2. Participants aged outside 10-16y for males or 8-14y for females. These bands were chosen based on the average onset of the peak height velocity (APHV) and the average of the adolescent growth spurt, where the largest inter-individual variations in body size and functional performance are expected [4,6].

2.2 Information sources and search strategy

Three electronic databases (SPORTDiscus, PubMed and Web of Science) were searched on the 12th of July 2022. Additional searches of these data bases were completed on the 13th of April 2023 and the 20th of March 2024 to ensure the review remained up to date. Additionally, backward searches of the reference lists and forward searches of the "cited by" section in Google Scholar of all included articles were performed to ensure any relevant articles outside of these databases were accounted for. This process identified one additional article meeting the inclusion criteria for this review [20]. Key words/phrases were formulated using the PICO framework and through consultation with a librarian at the lead author's institution. Scoping searches were also performed to further refine the search terms and to explore synonyms for search terms that may have been missed initially. The following search string was searched in combination as they appear:

1. Sport* OR competition OR training OR game*.
2. Adolescen* OR player* OR youth* OR athlete* OR pubert* OR pediatric OR paediatric.
3. "Biological matur*" OR "maturity timing" OR "matur* bias" OR "early matur*" OR "late matur*" OR "somatic matur*" OR "maturity matched" OR bioband* OR "bio-band*" OR "bio band*".
4. Select* OR develop* OR identif* OR performance OR detect* OR recruit* OR retain* OR retention OR talent*.

2.3 Study selection

Results of the searches from all three databases were uploaded to the systematic review software, Covidence [21]. This software automatically removed duplicates before the screening process was performed. Two reviewers (CB and JO) independently completed two stages of screening. The first stage involved screening titles and abstracts of each article, to ensure eligibility against the inclusion criteria. The second stage involved the full text screening of all accepted articles from stage one against the inclusion criteria. In the event of conflicts between the two reviewers, Covidence allowed the reviewers to resolve conflicts by blinding them to their original answers. The two reviewers (CB and JO) were able to come to a consensus on all conflicts and did not require a third reviewer for a deciding vote. Cohen's Kappa agreement was used to assess the inter-rater reliability of the two reviewers during the screening process. Cohen's Kappa agreement was interpreted as poor (<0.00), slight (0-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80) and almost perfect (0.81-1) [22]. The data collection process is presented in Figure 1.

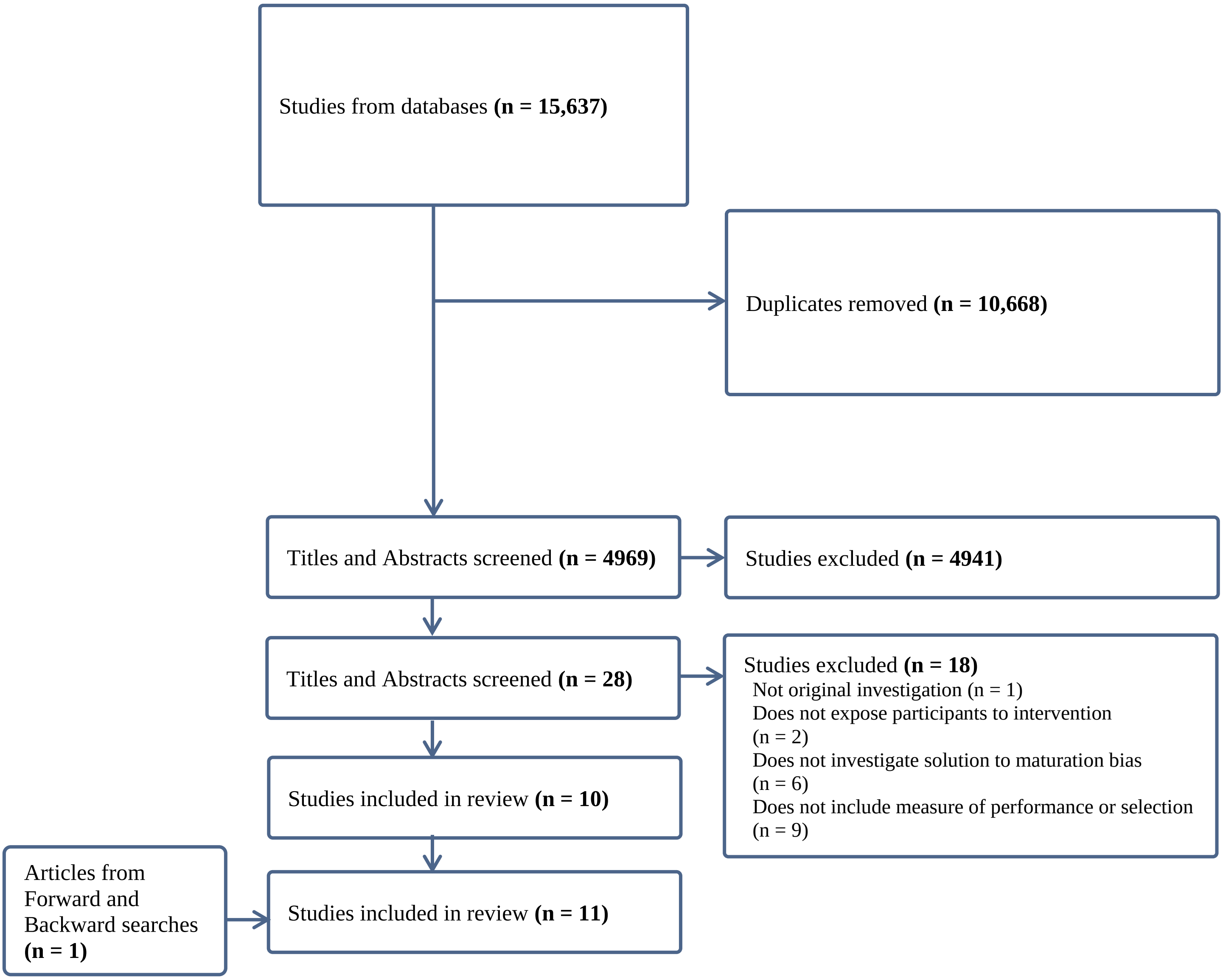

Fig. 1 Prisma flowchart for study selection

2.4 Data extraction and synthesis of results

One reviewer (CB) extracted data from all accepted articles based on the guidelines provided in the Joanna Briggs Institute manual for evidence synthesis [23]. Data extraction was completed in Covidence [21], using an edited version of the extraction 2.0 template provided by the software to align with the JBI manual. The extracted data included author information, study characteristics, intervention type and key outcomes of included articles.

2.5 Quality assessment

Two reviewers (CB and JO) assessed the risk of bias and the quality of reporting for all included articles using specific tools based on the type of study that was included. The two studies identified as randomised control trials

(RCT) [24,25] were assessed using the Johanna Briggs Institute (JBI) critical appraisal tool for randomised control trials [26], and the Consolidated Standards of Reporting Trials (CONSORT) checklist [27] for the quality of reporting for these articles. The nine remaining studies were identified as quasi-experimental and were assessed for risk of bias using the JBI critical appraisal tool for quasi-experimental studies [28], and the Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) statement checklist [29] for the quality of reporting. The JBI RCT and Quasi-experimental appraisal tools consisted of 13 and nine questions respectively, and were answered with "Yes", "No", "Unclear" or "N/A" with unclear being given when there was not enough information within an article to definitively answer "Yes" or "No". The CONSORT and TREND checklists consisted of 25 and 22 items and were answered with "Yes", "Yes with limitations" "No", "Unclear" or "N/A". The answer "Yes with limitations" was selected when an article partially met the requirements for a particular item. For example, item one of the CONSORT checklist "Title and abstract" consisted of two components including 1a: Identification as a randomised trial in the title and 1b: Structured summary of trial design, methods, results, and conclusions. Studies that only met one of the two components were allocated "Yes with limitations" [30]. The two reviewers (CB and JO) were also able to come to a consensus on any disagreements during the quality assessment and did not require a third reviewer.

Results:

3.1 Study selection

A total of 4969 articles were screened, of which 11 met the inclusion criteria for this review (Figure 1). The reviewers demonstrated moderate agreement (0.56) during the screening of titles and abstracts, and substantial agreement (0.79) during the full text screening. The lower kappa agreement observed during the screening of titles and abstracts vs full texts may be attributed to the reviewers' cautious approach based on some abstracts being less informative, leaning towards the inclusion of articles until more comprehensive information was made available during the full-text screening.

3.2 Study characteristics

The characteristics of all eleven included articles are presented in Table 1. Ten of the eleven studies included in this review were conducted on the European continent with four in the UK, three in Switzerland, and three in Portugal. One study was conducted in New Zealand. The earliest included article was published in 2019 [31], while the majority (7) were published in 2021 [20,25,32–36]. In terms of sample size, the number of youth athletes recruited to participate in the bio-banding articles ranged from 18-116, with an average sample size of 55 participants. Twenty-four youth athletes competed in games while wearing "player labels", and 83 scouts in total were recruited to conduct player rankings based on their performance. Only two articles recruited youth basketball athletes [32,33], one recruited youth cricket players [20], while the rest recruited youth soccer athletes. Only one article included both males and females in their study [37], while seven recruited male participants only [20,24,31,34–36,38] and three did not explicitly state the biological sex of their participants [25,32,33]. Although, email confirmation from the leading authors revealed that these articles only recruited male participants as well.

The skill levels of recruited participants ranged from regional-level players to national-level youth athletes. All studies utilised non-invasive estimation equations to quantify the maturity status of participants. The Khamis & Roche, [39] method was the most frequently used (9), while the Fransen et al., [40] and Mirwald et al., [41] methods were used twice respectively.

Table. 1 Characteristics of included studies

Author	Country	Sex	Sample Size	Chronological Age	Skill Level/Experience	Sport	Type of Task	Method of Measuring Maturity	Intervention(s) Used	Comparator	Additional Suggested Solutions
Abbott et al.[31]	UK	Male	25	12.7 ± 1.0y	Premier League academy category one	Soccer	Full field 11 vs 11 soccer games; 8 x 20 min quarters	Khamis Roche 1994 equation	Bio-Band	Chronological age groups	None
Arede, et al.[33]	Portugal	Male	30	13.45 ± 1.22y	National level Junior players	Basketball	Full court 5 vs 5 basketball games; 6 x 8mins	Khamis Roche 1994 equation	Bio-Band	Maturity un-matched games	None
Arede, et al.[32]	Portugal	Male	18	13.45 ± 1.22y	National level players	Basketball	Full court 5 vs 5 basketball games; 6 x 8 mins	Khamis Roche 1994 equation	Bio-Band	Maturity un-matched games	None
Arede et al..[38]	Portugal	Male	116	Under 13-14's	Regional level players	Soccer	Small-sided 7 vs 7 soccer games; 8 x 20mins	Khamis Roche 1994 equation	Bio-Band	Chronological age groups	None
Lüdin et al.[25]	Switzerland	Male	65	11.7 - 13.7y	Elite youth players 4.2± 0.7 y	Soccer	Small-sided 9vs9 soccer games; 2 x 70mins	Mirwald, Baxter-Jones, Bailey, & Beunen 2002 equation	Bio-Band	Chronological age groups	Longitudinal and multi-dimensional testing, delayed selection
Romann et al.[37]	Switzerland	Male & Female	60 M 2 F	Under 13's: 12.2 ± 0.3y Under 14's: 13.2 ± 0.4y	National talent development players 4.3 ± 0.7 y	Soccer	Small-sided 9 vs 9 soccer games; 8 x 20mins	Mirwald, Baxter-Jones, Bailey, & Beunen 2002 equation	Bio-Band	Chronological Age Groups	None
Towlson et al.[34]	UK	Male	32	12.9 ± 0.9y	English championship clubs	Soccer	Small-sided 4 vs 4 soccer games; 24 x 5mins	Khamis Roche 1994 equation	Bio-band	Mixed maturation games (2 early, 2 Late)	None
Towlson et al.[35]	UK	Male	72	Under 13-16's	Academy players	Soccer	Small-sided 4 vs 4 soccer games; 15 x 5 mins	Khamis Roche 1994 equation & Fransen et al. 2018	Bio-band	Mixed maturity games	None

Towlson et al.[36]	UK	Male	72	Under 13-16's	Academy players	Soccer	Small-sided 4 vs 4 soccer games; 15 x 5mins	Khamis Roche 1994 equation & Fransen et al. 2018	Bio-band	Mixed Maturity games	None
Walters et al.[20]	New Zealand	Male	Games: 57 players Interview: 15 players 3 coaches	Players: 13.3±0.29y	Players: Regional talent development camp Coaches: Level 2-3	Cricket	Small-sides 7 vs 7; 3 x 10 over games	Khamis Roche 1994 equation	Bio-Band	None	None
Lüdin et al.[24]	Switzerland	Male	83 Scouts 24 Players	11.0 ± 0.3y	Scouts: Certified 4.8 ± 2.4y Players: Elite talent pathway	Soccer	Small-sided 3 vs 3 & 7 vs 7 soccer games; 4 x 5mins each condition	Khamis Roche 1994 equation	Player Labelling	Uninformed scouts	None

3.3 Interventions utilised and proposed

The majority of included articles (10) investigated bio-banding as an intervention to reduce biological maturation bias in youth sports performance. Player labelling was utilised in only one included article as the intervention for reducing selection bias during games grouped by chronological age [24]. Only one of the included articles suggested additional solutions that could be utilised as interventions to reduce maturation bias [25]. The suggestions included longitudinal and multi-dimensional testing, and delayed selection. Importantly, only four bio-banding studies used chronological age groups as the comparator condition to the intervention [25,31,37,38]. The other comparator conditions used in bio-banding studies included mixed maturity games in which teams were comprised of both early and late maturing players [34–36], or un-matched games where early, on-time and late maturing teams competed against each other [32,33]. One article did not utilise a comparator condition and instead compared performance between bio-banded teams [20]. In the investigation into player labelling, the player rankings of scouts who were informed that the player numbers indicated players' biological maturity were compared to those of scouts who were not made aware of the meaning behind the shirt numbers [24]. Eight studies assessed performance during small-sided games [20,24,25,34–38], while the other three replicated competition conditions during full-field/court match play [31–33].

3.4 Key outcomes

All key outcomes from the included articles are presented in Table 2. The one included article investigating player labelling reported an increase in the rankings of late maturing players for informed scouts compared to the uninformed scouts [24]. Two articles reporting significant increases in running distance covered for the more mature players during bio-banded games basketball games, and vice versa for the less mature players during maturity un-matched games when competing against the most mature players [32,33]. Conversely, two articles reported significant decreases in distance covered during bio-banded soccer games [37,38]. Two articles also reported significant increases in accelerations and decelerations during bio-banded basketball games [25,32,33]. Interestingly, Lüdin et al., [25] reported decreases in high speed accelerations, and Arede et al., [38] reported fewer decelerations during soccer games. Two studies reported significantly higher player loads during their comparator conditions of mixed maturity games [36] and maturity un-matched games [32], while one article reported higher player loads for "on-time" maturers during bio-banded games [33]. Furthermore, one article reported significantly greater RPE's for the early maturing players during bio-banded soccer games [31], while two articles reported higher RPE's for the later maturing soccer players during the comparator conditions of chronological age groups [31] and maturity un-matched games [36]. In terms of skill involvements, which were described as technical and tactical involvements, two articles reported significant increases in successful passes and short passes for soccer athletes during bio-banded games [31,35]. Conversely Romann et al., [37] reported a significant decrease in successful passes during bio-banded soccer games. Additionally, two articles reported increases in dribbling frequency for "on-time" maturers [31,35], while Abbott et al., [31], reported a decrease in dribbling frequency for early maturing players during bio-banded soccer games. Regarding psychological variables, increases in confidence, competitiveness, positive attitude and total psychological score were reported for late maturing players when competing against early maturing players during maturity un-matched soccer games [36]. Key psychological themes including learning, challenge, curiosity and player enjoyment were also reported during interviews with players who competed in bio-banded cricket games [20].

Table. 2 Key outcomes of included studies

Author	Key Outcomes for Intervention	Key Outcomes for Comparator	Other Variables
Abbott et al.[31]	Early developers: ↑ RPE ↑ Short pass ↓ Dribbles On-time developers: ↑ Short pass ↑ Dribbles Late developers: ↑ Tackles	On-time: ↑ Long pass Late developer: ↑ RPE (compared to Early) ↑ Total running distance (compared to Early) ↑ Explosive running distance (Compared to Early & On-time) ↑ Long pass	High speed running -distance Shots Crosses
Arede, et al.[33]	Pre-PHV: ↑ Accelerations ↑ Decelerations ↑ Spatial exploration index	Pre-PHV (vs Post): ↑ Distance covered ↑ High intensity accelerations ↑ Average speed ↑ Body impacts ↑ Player load	Heart rate zones Training impulse High intensity -decelerations
Arede, et al.[32]	Pre APHV: ↑ Accelerations ↑ Decelerations ↑ Spatial exploration index Mid APHV: ↑ Distance covered ↑ High intensity accelerations ↑ Average speed ↑ Player load Post APHV: ↑ Distance covered	Pre-APHV ↑ Distance covered ↑ Average speed ↑ Body impacts ↑ Player load Post APHV: ↓ Average speed (vs Pre)	Heart rate average Heart rate sample entropy Training impulse Distance per speed zone High intensity -decelerations Peak accelerations Peak decelerations Peak speed
Arede et al..[38]	↓ Distance covered ↓ Decelerations ↓ Average speed ↓ Body impacts ↓ Peak heart rate	None	Spatial exploration index Accelerations Peak speed Heart rate average
Lüdin et al.[25]	U13 MO Low: ↓ High accelerations ↑ Conquered balls U13 MO High: ↑ High accelerations ↓ Conquered balls U14 MO Low: ↓ High accelerations ↑ Conquered balls ↑ Attacked balls	U14 MO High: ↑ Attacked balls (vs 14 MO Low & 13 MO High)	Total Distance High speed running Neutral balls Lost balls Volume off ball

	↑ Efficiency on ball ↑ Volume on ball U14 MO High: ↓ High accelerations ↑ Conquered balls		
Romann et al.[37]	↓ Total running distance ↓ Jogging distance ↓ Running distance ↓ High speed running ↑ Duels ↑ Set Pieces ↓ Mean possession time ↓ Successful passes	None	Walking distance Sprint distance Maximal running velocity Maximal accelerations Number of passes Goals Fouls Possession changes Shots
Towlson et al.[34]	None	Early: ↓ Degree centrality (vs Mixed) ↓ Closeness centrality (vs Mixed) ↑ Betweenness centrality (vs Mixed) ↑ Page rank (vs Mixed) Late: ↓ Game technical scoring chart sum score (vs Early)	Game technical scoring chart passing score Mean Possession Pass Attempts Percentage Completion Pass per possession Density Intensity
Towlson et al.[35]	Pre: ↑ Successful passes ↑ Turning ↑ Shots on Target (Khamis) ↑ Cover (Khamis) ↑ Decision making (Khamis) ↑ Assist ↑ Marking (Fransen) Circa: ↑ Successful passes ↑ Turning (Khamis) ↑ Goals (Fransen) ↑ Shots off target (Khamis) ↑ Aerial challenge (Fransen) ↑ Ground ball challenge ↑ Dribbling ↑ Cover ↑ Decision making (Fransen) ↑ Control (Khamis) ↑ One v one (Fransen) ↑ Assist (Khamis) ↑ Marking ↑ Spatial exploration index Post:	Pre vs Post: ↑ Successful passes (Khamis) ↑ Shots on target (Khamis) ↑ Cover (Fransen) Pre vs Circa: ↑ Successful passes (Khamis) ↑ Aerial challenge (Khamis) ↑ Shooting (Fransen) Circa vs Post: ↑ Successful passes ↑ Ground ball challenge ↑ Passing ↑ Control (Khamis)	Interceptions Passing

	↑ Successful passes ↑ Unsuccessful passes (Khamis) ↑ Turning (Khamis) ↑ Shots on Target (Khamis) ↑ Ground ball challenge (Khamis) ↑ Communication ↑ First touch (Khamis) ↑ Control (Fransen) ↑ Shooting (Khamis) ↑ Marking ↑ Nearest teammate ↑ Distance to opponent centroid ↑ Nearest opponent ↑ Distance to centroid		
Towlson et al.[36]	Post PHV: ↑ High-speed running distance	Pre: ↑ Player load medial lateral (vs Post) ↑ Session RPE (vs Post) ↑ Confidence (Khamis vs Post) ↑ Competitiveness (Khamis vs Post) ↑ Positive attitude (Khamis vs Post) ↑ Total psychological scores (Khamis vs Post) Circa: ↑ Session RPE (vs Post) Post: ↑ Player load anterior posterior (vs Pre)	X Factor Heart rate mean Max velocity Player load vertical
Walters et al.[20]			
Walters et al.[20]	Group 1 (early mature): vs group 4 (late mature): ↑ Absolute isometric mid-thigh pull ↑ Throwing distance (20m pitch 156gball and 18m pitch 142g ball) ↑ Throwing velocity (20m pitch 156gball and 18m pitch 142g ball) Key interview themes (Players): Learning Challenge Play without fear Key interview themes (Coaches): Curiosity Player enjoyment Benefits of bio-band for skill development	None	Bowling velocity Broad jump
Lüdin et al.[24]	Informed group: ↑ Ranking for later maturing players	Uninformed group: No selection bias	None

3.5 Risk of bias

The risk of bias and quality of reporting tables can be found in the supplementary files using the following link https://osf.io/2fb8p/?view_only=4ca30312d9384bbd97d2d4b05a3f2054. The risk of bias results are presented in online resource table 1 (O1) and online resource table 2 (O2). The review included two RCT studies (O1) and nine quasi-experimental studies (O2). Regarding risk of bias for the randomised control trials, neither study provided clear information on the method of randomisation used to assign participants to groups [24,25]. Only one of the included RCT articles reported the blinding of participants to their treatment assignment, although no information was provided for the blinding of those delivering the treatment or the outcome assessors in this study [24]. Regarding the quasi-experimental articles (O2), the 'cause' and 'effect' of the studies were made clear, however they did not provide clear information regarding the similarity of participants used in comparisons, with limited information on positional breakdowns of bio-banded or player labelled groups and the breakdown of groups in the comparator conditions [20,31–38]. Six of the eleven included articles were not clear on follow up of unused participants or the analysis of female participants [25,31,34–37], while the follow up of participants was determined to be non-applicable for the other five articles due to there being no indication of any loss of participants [20,24,32,33,38]. Seven of the eleven articles did not provide reliability data for their outcome measurements [24,25,31,33,35,36,38]. Two articles had limitations regarding the choice of statistical analyses in relation to their sample size and study design [33,37]. Additionally, two included articles [20,24] required more information on the statistical analysis that was implemented.

3.6 Quality of reporting

The quality of reporting tables can be found in the supplementary files using the following link https://osf.io/2fb8p/?view_only=4ca30312d9384bbd97d2d4b05a3f2054. The CONSORT checklist for the two RCT articles is presented in online resource table 3 (O3) and online resource table 4 (O4), while the TREND statement for the nine quasi-experimental articles is presented in online resource table 5 (O5) and online resource table 6 (O6). According to the tables O3 and O5, the majority of included articles had limitations in the reporting of the background section with no hypothesis being stated [25,32–37]. The majority of included articles also had limitations in the reporting of the recruitment method of participants [31,34–38], while three articles did not provide clear information on the biological sex of the participants recruited, which required email confirmation from the leading author [25,32,33]. Eight articles had limitations in the reporting of their interventions, as they had missing information on equipment size and the method of assigning participants into teams [25,31–37]. Seven articles did not indicate how their sample size was determined [24,25,31–33,37,38], while the other four required more information on how players were assigned to be reserve participants [20,34–36]. Only one of the included articles appropriately reported baseline data [31], while four articles were given 'yes with limitations' as there was missing information on the positional breakdowns of maturity teams [20,24,25,32].

4. Discussion

The primary purpose of this review was to identify, synthesise and critically appraise research studies that have investigated potential strategies aimed at reducing biological maturation biases on performance and selection in youth team sports. This review has identified bio-banding and player labelling as interventions that have been investigated with the majority focusing on bio-banding. Moreover, interventions such as implementing longitudinal and multi-dimensional testing, and delayed selection were suggested as potential strategies that could also be considered for reducing maturation bias in youth sport [25]. While the use of different tools (depending on the research design) makes it difficult to compare the quality of articles as these tools include different questions, some key trends were identified across the articles included in this review. Most notably, this study revealed a general lack of information on blinding, which may present potential risks of bias that need to be considered when interpreting these articles. In terms of the quality of reporting, a general lack of information on participant assignment and recruitment was identified, which may also present issues when understanding and/or replicating the interventions used in these articles.

4.1 Bio-banding:

Bio-banding is the process of grouping youth athletes based on their estimated biological maturity status as opposed to their chronological age [42]. The aim of bio-banding is to reduce the variance in maturity between individuals within teams that train with or compete against one another [4]. All included articles utilised estimation equations [39–41] to provide an indication of an individual's Age at Peak height Velocity [40,41] or percentage of predicted adult stature at a particular age [39]. In this context it is important to note that these estimation equations have been associated with significant measurement errors [3]. For example, Mirwald et al., [41] reported that the maturity offset could be estimated within an error of one year 95% of the time, although these errors could be much greater in samples with diverse ethnic or sociocultural backgrounds that don't resemble the original reference data [3]. Whilst these estimation equations are less accurate than the gold standard estimation of maturity status through skeletal age based on wrist x-rays, they are considered sufficiently sensitive to assign players to categories including "pre", "circum", and "post" puberty [3]. This was the case for the majority of included articles that used a within-sample criterion to assign participants into early or late maturing groups, relative to where their estimated maturity status fell within the sample. For example, the least mature half of the sample were placed into the late maturing group and vice versa for the most mature participants. However, four articles grouped participants using pre-determined percentages of adult height or maturity Z scores to classify participants as "early", "on-time", or "late" maturers. [20,31–33]. This often led to uneven numbers of participants within maturity groups and given the measurement error that exists when using estimation equations, it is possible that some participants may be incorrectly classified when using these methods. Additionally, it is likely that the maturation bias that already exists within the samples recruited in these articles may explain some of the inequities in group numbers. For example, Walters et al., [20] report that only one of their 57 cricket players who were invited by their club coaches to participate in a regional talent development camp were classified as a "late" maturer based on their pre-determined Z scores of percentage of predicted adult stature. Therefore, the most practical way to conduct bio-banding may be to evenly split participants into "early" or "late" maturing groups based on their relative estimated maturity status within the sample.

Interestingly, only four of the included articles compared performance during bio-banded games to chronological age groups [25,31,37,38]. Alternative comparator conditions included un-matched games where early, on-time and late maturing teams competed against each other e.g., team of early vs team of late maturers [32,33] or mixed maturity games e.g., two early and two late maturers grouped together [34–36]. The use of un-matched and mixed maturity games may not be representative of the conditions that youth athletes typically experience during their normal chronological age groups. For example, in the Arede, Cumming, Johnson, et al., [32] study, the basketball players in the pre-PHV (later maturing) group were an average of 2 years younger, 22cm shorter and 21kg lighter than those in the post-PHV (earlier maturing) group. When competing in un-matched bio-banded games between the pre-PHV and post-PHV groups, the differences between these groups are likely more exaggerated than those they would be exposed to during their normal chronological age groups. Whilst the use of mixed maturity games may even out the physical differences between teams, the team dynamics may not be comparable to those exhibited during their normal chronological age groups, particularly when players from different age groups are assigned to play together. Thus, the differences observed when comparing bio-banding to mixed maturity or un-matched games may not be applicable to the changes that may be present when applying bio-banding in practical settings.

The logistical challenges of implementing bio-banded games in terms of equipment size and positional preferences may also be an important consideration when interpreting the results of the included articles. Indeed, equipment sizes are typically scaled based on the age of players as equipment size in youth sport has been reported to have significant effects on player behaviours and performance [43]. None of the articles that investigated bio-banding in soccer reported the size of the ball used during bio-banded games despite recruiting participants from multiple age groups ranging from the under 12's to under 16's. Thus, it is not clear if alterations in the equipment size might have influenced participants' performance, which may warrant further research investigating how equipment size should be considered in bio-banded games. For example, should early maturing players be given a larger sized ball during bio-banding and vice-versa for late maturing players regardless of the age makeup of these groups? In terms of playing position, only one included article [31] reported the playing positions of participants within bio-banded groups. Abbott et al., [31] reported a relatively even split of defenders and attackers amongst the "early", "on-time" and "late" maturing groups during bio-banded soccer games. This is important to consider as Towlson et al., [44] report that maturity status can play a role in the position that players are assigned to, with more mature players predominantly being selected as goal keepers and central defenders in elite youth soccer teams. Given that the majority of included articles did not report the positional breakdowns of bio-banded groups, it is unclear if any changes in positional preferences may be attributed to significant differences in performance variables. This should also be considered in future research when forming bio-banded groups to ensure that differences in performance can't be attributed to significant changes in the role players are given within their teams.

The majority of articles included in this review investigated the effect of bio-banding on performance in both small-sided and full field games. There were many significant differences (Table 2) in the reported variables between bio-banding and the comparator conditions for each study. Authors of the included articles posited that the differences in the variables they measured may provide an indication that bio-banding could be used to create different challenges and opportunities for early and late maturers to be able to showcase and develop important skills and attributes needed in their development. Similar themes were reported by Cumming et al., [45] when interviewing premier league academy players on their experiences of competing in bio-banded soccer tournaments. Some of their key themes included greater competitive equity, reduced injury risk, increased opportunity to use, develop and demonstrate technique, providing challenge and adaptation, and created pressure [45]. Despite some of the limitations with the articles included in this review, bio-banding seems to be a promising method of reducing maturation bias to create a more even playing field for youth athletes. Furthermore, as highlighted by Cumming et al., [45], methods of bio-banding as an adjunct to chronological age groups are now being used by practitioners in youth soccer academies to provide athletes with a diverse set of challenges for enhancing development. Nevertheless, it is crucial to emphasize that employing bio-banded tournaments for the development of previously selected players does not alleviate the existing maturation bias within youth academies. This raises the question whether the differences in performance reported during bio-banding have a meaningful impact on the selection process of youth athletes? Thus, highlighting the need for future high-quality research to investigate the potential for bio-banding to reduce maturation bias in the performance and selection of youth athletes.

4.2 Player labelling

Only one included article [24] investigated the use of player labelling as a potential solution for reducing maturation bias during the ranking of youth soccer players. Player labelling highlights the maturity status of youth athletes using a visual cue to allow coaches and selectors to take maturity status into account during selections. In this study, participants were provided numbered shirts based on their estimated maturity status with number 1 representing the most mature participant while number 12 represented the least mature participant. This is similar to the process used in the age ordered shirt numbering study by Mann & van Ginneken, [46] where players were provided with numbered shirts that indicated their relative chronological age within the sample to reduce the relative age effect. In the player labelling study, Lüdin et al., [24] recruited scouts and randomly assigned them into groups with the informed scouts being given information on the meaning of the numbered shirts players wore before conducting player rankings, while the uninformed scouts were simply asked to rank players based on their performance during small-sided soccer games. Player labelling was reported to cause a reverse selection bias in which later maturing players were ranked higher than the early maturing players by the informed scouts [24]. Similarly, Mann & van Ginneken, [46] reported that age ordered shirt numbering reduced the selection bias towards relatively older youth athletes. Thus, player labelling could provide a practical solution to the issue of maturation bias during the selection of talented youth athletes [24].

Although, as was the case for the bio-banding articles, methodological issues warrant caution to be taken when interpreting these results. In the sample of under 11 male youth soccer players recruited by Lüdin et al., [24], no maturation bias was observed. Despite the smaller sample size, this contrasts with previous research where maturation selection biases were found in similar age groups to those recruited [16,17,47]. The majority of the sample recruited are unlikely to have reached peak height velocity given the mean age of European and North American children reaching this maturation milestone has been reported to occur between 13.4-14.2 years of age

[6]. As such these researchers may have in fact observed a fairly homogeneous group of individuals who had not yet commenced a period of increased growth velocity. Thus, future research investigating the effect of player labelling on the rankings of older youth athletes that are more likely to have reached their peak height velocity may be warranted.

Additionally, the method of labelling players in order to reduce maturation bias may need to be considered when conducting future research. The Khamis & Roche, [39] equation was utilised to estimate the percentage of adult height attained by participants before providing them with numbered shirts to individually label players from most mature to least mature. However, it is important to note that Khamis & Roche, [39] reported a general estimating error (at the 90% error bound) of 5.3 ± 1.4 cm in males. Given that estimation equations are most accurate around the key event that is being estimated and the majority of the sample recruited by Lüdin et al., [24] were yet to reach their peak height velocity, it is likely that some players were incorrectly labelled. Given that estimation equations are sufficiently sensitive to assign players into groups such as "pre", "circum" and "post" puberty [3], it would perhaps be more appropriate to provide labels to groups of youth athletes based on their estimated maturity status instead of the shirt numbers representing individual differences. For example, numbers 1-10 could be allocated to players estimated to be an most mature players while numbers 11-20 could be allocated to the less mature players within the sample.

4.3 Quality assessment

When assessing the risk of bias for all included articles using the JBI RCT and JBI Quasi experimental checklists in tables O1 and O2 respectively, some important trends were highlighted. Interestingly, none of the included articles investigating bio-banding provided information on blinding practices of participants or outcome assessors. Only Lüdin et al., [24] reported the blinding of the uninformed scouts in their player labelling study. However, there was no information on the blinding of outcome assessors and those delivering the treatment. This is important as participants' and those delivering the interventions' knowledge of the true purpose of these studies may alter their performance in the study [48]. For example, during a bio-banding study, participants may not perform to the best of their ability when grouped into chronological age groups or mixed maturity/un-matched games as they know that the researchers are most interested in the bio-banded games. Alternatively, the knowledge of relatively older participants being grouped with relatively younger participants based on their estimated maturity may reduce their buy-in to the study as they might wonder why they are not grouped with their older peers. While it is true that participants may recognise that they are being grouped into teams with players of similar maturity, it is important for researchers to do everything in their power to ensure that the changes in the variables measured are not impacted by such biases. In the case of comparing performance in bio-banding to chronological age groups, researchers may blind participants by concealing their assignment to a certain team or by proposing that they are competing in randomised teams [49]. Regardless, it is important that authors disclose blinding practises to ensure that blinding was appropriately conducted based on the study design, and to encourage transparent scientific practices [48]. Furthermore, the blinding of outcome assessors and those delivering the interventions is also important to ensure that all conditions are treated equally to reduce the chance of the intervention of interest being over analysed compared to the control condition.

Additionally, the information available in the different studies retained in this review about the assignment of participants to groups was generally poor. Question one in the JBI RCT checklist (O1) revealed that both studies [24,25] did not report on the method of randomisation used to assign participants into teams or assign interventions to the different clubs involved in the study. A similar issue was also present in question four of the TREND statement (O5) with studies not reporting the method of assignment for players into maturity teams when there were multiple teams per maturity band. This makes it difficult to attribute changes in performance across conditions to the intervention itself, or potential differences between maturity teams. Furthermore, accurately reporting the method of group assignment and baseline group characteristics is important for the replication of these studies and to ensure the researchers attempted to limit the risk of bias when grouping participants.

In terms of the quality of reporting, question 11 of the TREND checklist (O5) highlighted that three of the included articles did not provide information on the effect sizes or the assumptions of the statistical analysis used to analyse their data. This not only effects the potential reproducibility of these articles but also impacts the interpretation of their results. The majority of the included articles also reported that small sample sizes were a limitation of their studies. Question 7 in the TREND checklist (O5) revealed that only four articles utilised convenience sampling [20,34–36], while the rest provided no information on how their sample size was determined. Future researchers should consider the use of sample size estimations to ensure they recruit an appropriate number of participants to be able to detect an effect size of interest. As such, it is important that readers seriously consider how the risk of bias and quality of reporting of the included articles could affect their results (table 2) and any inferences that can be drawn from them.

4.4 Additional suggested solutions

Aside from the potential solutions of bio-banding and player labelling there are several other potential solutions that were suggested by Lüdin et al., [25], despite not being directly implemented in their study design. It is important to note that some articles investigating these potential solutions were identified using the search query in this review. However, these studies were subsequently omitted from the review because they did not meet all of the inclusion criteria for this systematic review. These suggested solutions include longitudinal and multi-dimensional testing, and delayed selection [25]. Longitudinal and multi-dimensional testing involves creating testing protocols that allow selectors to assess key attributes that contribute to performance in a particular sport across a sustained period through multiple testing periods [50,51]. This could be used to mitigate the risk of selecting athletes based on biased testing protocols that favour early maturing youth athletes. Deliberately delaying selection until after the adolescent growth spurt may also allow selectors to gain a more holistic perspective of athletes' abilities over a longer period of time [51,52]. This could potentially reduce the likelihood of an athlete being selected or deselected based on maturational advantages alone. Additionally, using longitudinal assessments allows practitioners to recognise periods of peak growth (e.g. through the longitudinal measurement of stature at regular time intervals) instead of relying on estimation equations with the potential for significant error [3,39,41]. Although, it should be noted this may not actually reveal peak growth periods until they have passed if the peak height velocity occurs between testing periods. While the use of longitudinal and multi-dimensional testing protocols may require a large amount of time and effort, they have demonstrated superiority in regards to the selection of talented athletes compared to less complex selection strategies [53].

4.5 Limitations

While this review provides a valuable summation, synthesis, and appraisal of the available literature regarding potential solutions that have been investigated to reduce maturation biases in performance and selection, there are some limitations that should be recognised. First, it should be noted that this review only examined team sport athletes and as such its findings are not generalisable to other athletic populations, such as individual sports where athletes still compete in chronological age groups like track and field or gymnastics. It may be that in these sports, other strategies to mitigate maturation biases are used (or considered for use) which were not included in this review. Additionally, this study did not include articles that examined the effects of strategies used to mitigate maturity biases on other relevant aspects of athlete development, like athletes' perspectives on the use of bio-banding (e.g. Cumming et al., [45] investigating premier league academy soccer players perspectives of competing in bio-banded tournaments).

4.6 **Future recommendations**

Given the evidence presented in this review, it is currently difficult to confidently recommend any of the proposed solutions used in the literature to be used in practical settings. In particular, the use of maturity un-matched or mixed maturity games as comparator conditions to bio-banding makes it difficult to apply any differences in the reported performance outcomes to the constraints related to participating in chronological age groups directly. Additionally, the potential risks of bias in regard to lack of blinding practises as well as poor reporting of the assignment process of participants into groups and sample size estimations warrants caution when interpreting the results of the included articles. Therefore, future research investigating any potential solutions aiming to reduce maturation bias in youth sport should include chronological age groups as a comparator condition to ensure that any changes in performance or selection are applicable to conditions experienced in practical settings.

This review also identified some potential gaps in the literature that should be considered by future researchers. Of the six included articles investigating bio-banding in soccer athletes, none reported on the size of the ball used during bio-banded games [25,31,34–37]. This is an important consideration for any future researchers or practitioners given the significant effects that equipment scaling has on performance during youth sport [43]. At this stage it is unclear if early maturing players should be competing with a larger sized ball or vice-versa for late maturing players. Thus, future researchers should aim to assess the impact of different ball sizes on performance when mixing participants from different age groups during bio-banded games to provide practitioners with the knowledge they need to make informed decisions. Additionally, player labelling and it's close counterpart age ordered shirt numbering have limited information available in the current literature [24,46]. It is important that future research is conducted to determine the appropriate method of "labelling" youth athletes considering the potential limitations when utilising maturity estimation equations where it may be more appropriate to provide labels for a subgroup of players within a cohort. Finally, it may be important to consider potential solutions which are not reported on in the studies included in this review, including those aiming to reduce the relative age effect. While it is true that the relative age effect is significantly independent of maturation bias, there is a large amount of research available on this issue [54–56] that could be adapted to reduce the issues presented when youth athletes begin to reach their peak height velocity, as was the case for player labelling and age ordered shirt numbering [24,46].

5 Conclusion

This review highlights bio-banding and player labelling as potential solutions explored in the current literature to address maturation bias in youth team sports performance and selection. Both approaches show potential in creating a more even playing field for youth athletes in their performance and selection during team sports, however potential risk of bias and issues in the quality of reporting make it difficult to provide recommendations on the use of these solutions in practical settings at this stage. Recognizing that no single solution exists for maturation bias in youth sports, future researchers can use the insights from this review to conduct high-quality studies, addressing gaps in bio-banding, player labelling, and other suggested solutions, contributing to the ongoing efforts to reduce maturation bias.

Conflicts of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this article.

Contributions

Substantial contributions to conception and design: CB, MS, JF

Acquisition of data: CB, JO

Analysis and interpretation of data: CB, JO

Drafting the article or revising it critically for important intellectual content: CB, JO, MS, JF

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