

Review article

## The Effect of Bio-Banding On Talent Identification in Youth Soccer: A Systematic Review

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### Abstract

Maturity-related selection bias is prevalent in youth soccer, and bio-banding has been proposed as a practical approach to promote fairer competition and support talent identification. This systematic review aimed to synthesize the evidence base and describe the characteristics of bio-banding competition formats used in youth soccer for talent identification and player development. Systematic searches were conducted in PubMed, Web of Science, SPORTDiscus, Scopus, and China National Knowledge Infrastructure (CNKI) in accordance with PRISMA 2020 guidelines. Studies were eligible if they examined bio-banding competition formats and reported outcomes related to talent identification or player development. Study quality was assessed using the QualSyst checklist. Thirteen studies involving 861 youth players met the eligibility criteria. While all studies were rated as having good overall methodological quality (mean QualSyst score = 0.85), common limitations included lack of randomization, blinding, and control for confounding variables. Across studies, bio-banding was associated with a range of reported effects spanning physiological, psychological, technical, and tactical performance outcomes. The included literature was predominantly characterized by small-sided games compared against chronological-age or mixed-maturity groupings. A broad set of implementation characteristics was identified, providing an initial basis to inform future refinement and optimization of bio-banding formats. However, substantial inconsistency was evident in maturation assessment approaches, banding thresholds, competition rules, and outcome reporting, which limited cross-study comparability. Bio-banding can serve as a supplementary method to alter the competitive environment and reveal different player behaviors in youth soccer. However, the current evidence base relies heavily on short-term match responses and proxy outcomes rather than direct evidence of improved selection accuracy or long-term development. Heterogeneity in assessment methods and reporting currently constrains the strength and comparability of the evidence. Further high-quality research using more consistent maturation assessment, banding criteria, competition rules, and standardized outcome reporting is needed to strengthen the evidence base and guide implementation. The protocol for this systematic review was prospectively registered in PROSPERO (CRD420251231375).

**Key words:** Bio-banding, Youth Soccer, Performance, Biological Maturation, Talent Identification.

### Introduction

Fairness in opportunity, validity in evaluation, and the accurate prediction of long-term potential are central challenges in youth sport development. While professional

football clubs prioritize the identification and development of talented young players (Sullivan et al., 2023), the prevailing practice of grouping by chronological age (CA) often conflates biological maturity with talent, potentially compromising these three distinct but linked goals. In practice, youth soccer academies typically group players by chronological age for competition and talent identification. However, the timing of the adolescent growth spurt (i.e. peak height velocity [PHV]) is highly individualised (Philippaerts et al., 2006), which may contribute to selection bias. Worldwide prevalence of these selection biases is difficult to estimate, but illustrative cases suggest significant skewing; for instance, one study found that 54.8% of selected youth players in an English academy were born in the first quarter, and no players in the U15 and U16 groups were classified as late maturing (Hill et al., 2020). If left to persist, maturity-related bias can have an ongoing negative impact on talent identification and development, as early-maturing players may be favoured due to temporary physical advantages while later-maturing players face reduced match involvement or premature deselection. This compromises fairness of opportunity (limited playing time), fairness of evaluation (confounding physical size with skill), and the prediction of long-term potential (overlooking late developers who may possess superior technical or cognitive traits) (Deprez et al., 2015; Sweeney and Lundberg, 2025; Towlson et al., 2017).

Given the asynchronous relationship between children's growth rates and decimal age (Philippaerts et al., 2006; Towlson et al., 2018), accounting for biological maturation in selection is essential to avoid conflating maturity-related advantages with talent. To mitigate maturity-related selection bias, existing literature recommends adopting a comprehensive approach to talent identification (Sweeney et al., 2023; Williams et al., 2020), including longitudinal and multidimensional testing and delayed selection (Tribolet et al., 2018; Williams and Reilly, 2000). However, despite the availability of evidence-informed strategies to reduce this bias, coaches and practitioners often struggle to implement them, citing the substantial time and effort involved as key barriers (Sieghartsleitner et al., 2019).

One practical method to overcome these barriers and provide a fair gaming environment is 'bio-banding' (Abbott et al., 2019; Cumming et al., 2017; Malina et al., 2019). Bio-banding categorizes adolescent players according to indicators of biological maturation, typically derived from assessments such as the percentage of predicted adult

height, skeletal age, and estimates of age at PHV (Lloyd et al., 2014; Malina et al., 2019). It is important to acknowledge that these non-invasive estimation methods carry inherent uncertainty and the possibility of misclassification, which must be considered when interpreting results. Theoretically, maturity-matched competition reduces the physical dominance of early matures, thereby forcing all players to rely more heavily on technical proficiency, tactical awareness, and psychological resilience to succeed. This shift in competitive constraints may reveal qualities that are otherwise masked in age-based groups. Bio-banding programmes have been positively received by both early- and late-maturing players during bio-banded tournaments (Cumming et al., 2018). Researchers have suggested that bio-banding might reduce injury incidence (Baxter-Jones et al., 1995; Towlson et al., 2023), improve the validity and fairness of talent identification processes (Flores et al., 2025), and enhance athletes' perceptions of maturity-matched competition formats (Cumming et al., 2018).

To date, there has been limited synthesis of the design and delivery features of bio-banding competitions for talent identification in youth soccer. A focus on adolescence is warranted because chronological age does not align closely with biological maturation, and same-age players can differ markedly in growth and development (Towlson et al., 2018). This review specifically targets players aged  $\leq 18$  years, encompassing the critical window of the adolescent growth spurt where the discrepancy between CA and biological age is most pronounced, making bio-banding particularly relevant for distinguishing early, on-time, and late maturers. Greater clarity on how bio-banding competitions are designed and delivered is therefore needed to inform the refinement of competition formats, should the evidence base support their use. Existing reviews have outlined the rationale and potential applications of bio-banding across youth sport (Chimera et al., 2024; Cumming et al., 2017; Malina et al., 2019). In contrast, a soccer-focused review synthesized bio-banding effects primarily across physiological, physical, technical, and tactical parameters, emphasizing short-term match and performance responses (Jäger et al., 2025). Although one helpful recent review considered bio-banding alongside other approaches to reduce selection bias across multiple sports, its broader scope limited soccer-specific conclusions (Butcher et al., 2024). Unlike recent reviews that synthesized general performance responses (Jäger et al., 2025) or covered multiple sports (Butcher et al., 2024), this review specifically targets outcomes directly relevant to talent identification processes in soccer, distinguishing between immediate performance proxies and indicators of underlying potential, with a specific focus on psychological and behavioral dimensions often overlooked in purely physiological analyses.

To our knowledge, there are currently few systematic reviews that focus specifically on the effects of bio-

banding competitions on talent identification in youth soccer. Moreover, there is a lack of knowledge regarding the extent to which bio-banding influences different performance dimensions, such as physiological, psychological, and technical–tactical outcomes. Conceptually, this review operates on a framework linking competition format (e.g., small-sided vs. full-sided) and match context (e.g., maturity-matched vs. mixed) to observable behaviors (e.g., decision-making, workload), which in turn offer implications for talent identification by revealing player attributes under altered constraints. Given the need for fairness in talent selection, a review of the available interventions targeted at this specific age range is warranted to drive future research and practice. Specifically, this review sought to address the following questions:

1. What evidence exists on the effects of bio-banded competitions on outcomes relevant to talent identification in youth soccer, across physiological, psychological, and technical–tactical domains?
2. What are the key design and delivery characteristics of bio-banded competition formats used in youth soccer?

## Methods

### Registration and search process

This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The study protocol has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) with the reference number CRD420251231375. Literature searches were conducted in the following electronic databases from inception to November 2025 without any restriction to language or publication status: PubMed, Web of Science, SPORTDiscus, Scopus, and China National Knowledge Infrastructure (CNKI). Non-English records identified through CNKI were screened by native speakers among the author team, and relevant data were translated into English for extraction to ensure comprehensive coverage. Keywords were collected through consultation with three experts in youth soccer talent identification and biological maturation, whose domain expertise guided the selection of controlled vocabulary and free-text terms (see Table 1). A Boolean search was conducted in each database using terms with the following keywords: (“bio-banding” OR “bio-banded” OR “bio-band” OR “bio band”) AND (youth OR teenager OR teen OR adolescen\* OR pubert\*) AND (soccer OR football). Full search strings, including field tags for each database, are provided in Table 2. Reference lists of all included articles were manually reviewed to identify other pertinent studies.

### Eligibility criteria

A PICOS (Population, Intervention, Comparison, Outcome, and Study design) approach framework was employed to assess the eligibility of studies (see Table 3).

**Table 1.** Examples of terms used in the database searches.

Search builder	Examples of search terms
Bio-banding	“Bio-banding” or “bio-banded” or “bio-band” or “bio band”
Youth	Youth or teenager or teen or adolescen* or pubert*
Soccer	Soccer or football

**Table 2. Detailed search strategy.**

Database	Strategy	Result
PubMed (Nov. 2025)	(bio-banding[All Fields] OR bio-banded[All Fields] OR bio-band[All Fields] OR bio band[All Fields]) AND (adolescen*[All Fields] OR pubert*[All Fields] OR teenager[All Fields] OR teen[All Fields] OR youth[All Fields]) AND (soccer[All Fields] OR football[All Fields])	21
Scopus (Nov. 2025)	( ALL ( bio-banding OR bio-banded OR bio-band OR bio band) AND ALL ( adolescen* OR pubert* OR teenager OR teen OR youth ) AND ALL ( soccer OR football ) )	471
SPORTDiscus (Nov. 2025)	TX (bio-banding OR bio-banded OR bio-band OR bio band) AND (adolescen* OR pubert* OR teenager OR teen OR youth) AND (soccer OR football)	254
Web of Science (Nov. 2025)	((TS=(bio-banding OR bio-banded OR bio-band OR bio band)) AND TS=(adolescen* OR pubert* OR teenager OR teen OR youth)) AND TS=(soccer OR football)	41
CNKI (Nov. 2025)	SU=bio-banding OR bio-banded OR bio-band OR bio band AND SU=adolescen* OR pubert* OR teenager OR teen OR youth AND SU=soccer OR football	4
Total	791	

**Table 3. PICOS criteria for inclusion and exclusion.**

Items	Inclusion criteria	Exclusion criteria
<b>Population</b>	Male and/or female youth soccer players aged ≤18 years	Participants aged >18 years
<b>Intervention</b>	Bio-banding competition formats	Not involving bio-banding competition formats
<b>Comparison</b>	Chronological age-based groupings or mixed-maturity groupings	No eligible comparator reported
<b>Outcome</b>	Outcomes relate to task performance or talent identification	Outcomes not related to task performance or talent identification
<b>Study designs</b>	Non-randomized controlled trials, randomized controlled trials, and non-randomized non-controlled trials	Review articles, book chapters, and conference proceedings

The studies incorporated in this review were required to fulfill the following eligibility criteria: (i) participants were male and/or female youth aged ≤18 years; (ii) the intervention involved bio-banding in competition or game-based formats; (iii) the comparison involved either chronological age-based groupings or mixed-maturity groupings (these comparator types were analyzed separately given their distinct implications for practice); (iv) outcomes included at least one measure of task performance or athlete selection; and (v) the study involved empirical experiments, including randomized controlled trials (RCT), non-randomized controlled trials (nRCT), and controlled non-randomized trials (nCT). Studies without a comparator condition were excluded.

Research was excluded if it met any of the following criteria: (i) participants over the age of 18; (ii) the intervention did not incorporate bio-banding within competitive or game-based settings; (iii) no eligible comparison condition was reported; (iv) outcomes were not relevant to task performance or talent identification; or (v) the article was not original research (e.g. reviews, book chapters, conference proceedings).

### Data extraction and synthesis

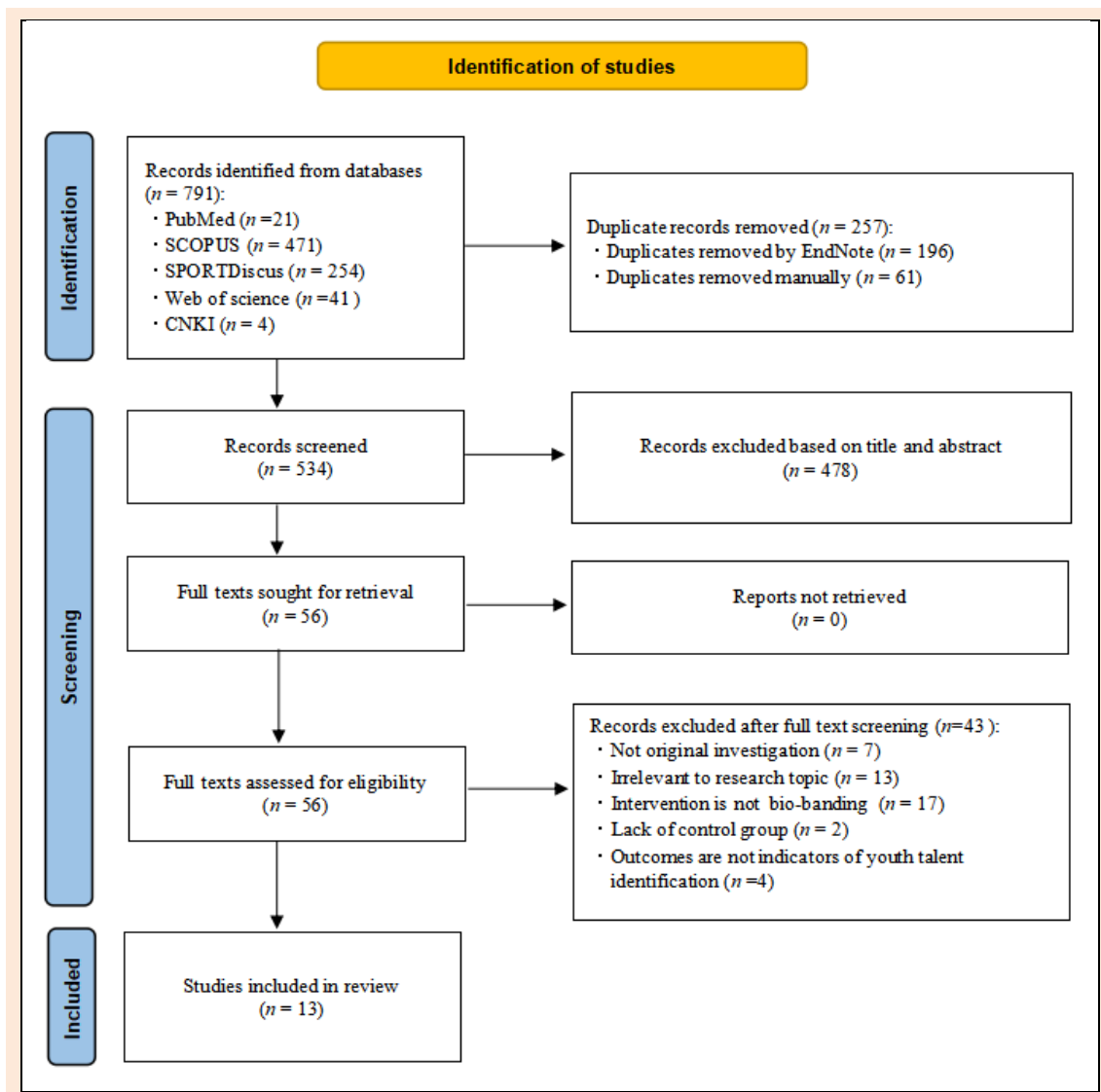
Results from the searches conducted across all five databases were exported to EndNote (Version 21; Clarivate, Philadelphia, PA, USA). After the removal of duplicates, two reviewers (C.H. and N.L.) independently implemented a three-step study selection process: (1) title screening, (2) abstract screening, and (3) full-text screening. During each step, all articles that could not be definitively excluded were retained for further evaluation in the subsequent stage. The researchers remained blinded to each other's decisions throughout this process. Disagreements regarding final inclusion were resolved through discussions with a third researcher (Z.Z.).

Following selection, two reviewers independently

extracted data using a standardized piloted form. Extracted items included: (i) study design and risk of bias indicators; (ii) participant demographics (age, sex, maturity status, playing level); (iii) intervention specifics (bio-banding method, thresholds, game format, duration, bout structure); (iv) comparator type (CA-based vs. mixed-maturity); and (v) outcomes, which were categorized a priori into three groups: direct selection outcomes (e.g., selection/deselection decisions), proximal performance indicators (physiological, technical-tactical metrics), and contextual or process measures (psycho-social behaviors, perceived exertion). For studies contributing multiple formats, multiple outcomes, or utilizing multiple maturity assessment methods, each distinct comparison was treated as a separate data point for synthesis where appropriate to ensure granular analysis.

### Quality assessment

The evaluation of the methodological quality of the articles included in this literature review was conducted utilizing the Standard Quality Assessment Criteria for Evaluating Primary Research (Kmet et al., 2004). QualSyst was selected due to its applicability for both randomized and non-randomized studies. It comprises a 14-item checklist, with each item being scored based on its adherence to specific criteria ("yes" = 2, "partial" = 1, "no" = 0, and "N/A" = not applicable). Included articles were independently assessed by two reviewers (C.H. and N.L.). Discrepancies were discussed with an additional reviewer (Z.Z.). Quality scores for the included studies were calculated by summing the total score across relevant items and dividing it by the total possible score, yielding a value ranging from 0 to 1. Higher scores indicate superior methodological quality. It is acknowledged that while QualSyst provides a broad overview, it is a relatively blunt tool for intervention-focused evidence compared to design-specific risk-of-bias frameworks. Furthermore, reliance on a single composite score



**Figure 1.** Flow of selection and exclusion of studies.

can conceal important weaknesses in specific domains such as randomization, assessor blinding, or confounding control; therefore, domain-specific deductions are reported alongside aggregate scores.

## Results

### Search Results

Figure 1 shows the process of study selection, detailing the progression from initial search to final inclusion in the review. The systematic database searches resulted in 791 studies, including PubMed ( $n = 21$ ), Scopus ( $n = 471$ ), SPORTDiscus ( $n = 254$ ), Web of Science ( $n = 41$ ), and CNKI ( $n = 4$ ). After the removal of duplicates ( $n = 257$ ), a total of 534 articles remained for screening. At the initial screening (phase 1), 478 records were excluded based on title and abstract, leaving 56 reports sought for retrieval. Following this, an additional 43 articles were excluded during the full-text screening phase (phase 2) for not meeting the inclusion criteria. The reasons for exclusion in this phase included studies that were not original investigations, were not relevant to the review question, did not use bio-banding as the intervention, lacked an appropriate con-

trol group, and failed to report outcomes related to youth talent identification. Ultimately, a total of 13 articles were included in the review.

### Study characteristics

Table 4 presents the characteristics of 13 articles that fulfilled the inclusion criteria. All the articles were published during or after 2019 ( $n = 13$ ), with the majority since 2020 ( $n = 12$ ). Based on the institutional affiliation of the corresponding authors, twelve articles were from European continent, specifically from the United Kingdom ( $n = 9$ ), Switzerland ( $n = 2$ ), and Portugal ( $n = 1$ ). The remaining study was conducted in Brazil ( $n = 1$ ). With respect to methodology, all studies adopted quasi-experimental designs. While one study utilized a randomized cross-over repeated design, the majority ( $n = 12$ ) employed non-randomized repeated-measures designs, including crossover formats (Abbott et al., 2019; Arede et al., 2024; Barrett et al., 2022; Lüdin et al., 2022; de Macedo et al., 2025; Romann et al., 2020; Salter et al., 2023; Salter et al., 2025; Towlson et al., 2021a; Towlson et al., 2021b; Towlson et al., 2022) and cross-sectional repeated-measures designs (King et al., 2025; Robinson et al., 2025).

**Table 4. QualSyst results for the studies.**

No	Item	Detailed quality assessment: Yes = 2; Particular = 1; No = 0; Not applicable = NA												
		Abbott et al (2019)	Arede et al (2024)	Lüdin et al (2022)	Romann et al (2020)	Towlson et al (2021a)	Towlson et al (2021b)	Salter et al (2023)	King et al (2025)	Salter et al (2025)	Towlson et al (2022)	Robinson et al (2025)	De Macedo et al (2025)	Barrett et al (2022)
1	Question /objective is sufficiently described?	2	2	2	2	2	2	2	2	2	2	2	2	2
2	Study design is evident and appropriate?	2	2	2	2	2	2	2	2	2	2	2	2	2
3	Method of subject/comparison group selection or source of information/input variables is described and appropriate?	2	2	2	2	2	2	2	2	2	2	2	2	2
4	Subject (and comparison group, if applicable) characteristics are sufficiently described?	2	2	2	2	2	2	2	2	2	2	2	2	2
5	If interventional and random allocation was possible, was it described?	0	0	2	0	0	1	0	1	2	1	0	2	2
6	If interventional and blinding of investigators was possible, was it reported?	0	0	0	0	0	1	0	1	0	1	1	0	1
7	If interventional and blinding of subjects was possible, was it reported?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	Outcome(s) and (if applicable) exposure measure(s) is/are well defined and robust to measurement/misclassification bias? Means of assessment are reported?	2	2	2	2	2	2	2	2	2	2	2	2	2
9	Sample size is appropriate?	1	2	2	2	2	2	2	2	2	2	2	1	2
10	Analytic methods are described/justified and appropriate?	2	2	2	2	2	2	2	2	2	2	2	2	2
11	Some estimate of variance is reported for the main results?	2	2	2	2	2	2	2	2	2	2	2	2	2
12	Controlled for confounding?	1	1	2	1	1	1	2	1	1	1	1	2	1
13	Results reported in sufficient detail?	2	2	2	2	2	2	2	2	2	2	2	2	2
14	Conclusions supported by the results?	2	2	2	2	2	2	2	2	2	2	2	2	2
<b>Summary score (total sum / total possible sum)</b>		<b>0.77</b>	<b>0.81</b>	<b>0.92</b>	<b>0.81</b>	<b>0.81</b>	<b>0.88</b>	<b>0.85</b>	<b>0.88</b>	<b>0.81</b>	<b>0.88</b>	<b>0.88</b>	<b>0.88</b>	<b>0.92</b>

### Participant characteristics

Table 4 presents the specific details of the participants from the 13 included studies. There were 861 participants across all the studies. Ninety-nine point eight percent of the participants were male (n = 859), while only 0.2% were female (n = 2). Across studies, participants were typically in early to mid-adolescence, with ages ranging from approximately 11 to 16 years, and sample sizes varying between 20 and 139 players. In terms of skill levels of recruited participants, nine studies examined players from academy-based development programmes (Abbott et al., 2019; Arede et al., 2024; Barrett et al., 2022; de

Macedo et al., 2025; King et al., 2025; Salter et al., 2023; Towlson et al., 2021a; Towlson et al., 2021b; Towlson et al., 2022), two studies focused on players from elite youth clubs (Lüdin et al., 2022; Romann et al., 2020), and the remaining two studies included players competing in the Junior Premier League (Salter et al., 2025; Robinson et al., 2025).

### Intervention characteristics

A total of six different bio-banding competition formats were implemented across the 13 included studies. As can be seen in Table 4, ten studies employed reduced-player games.

Across these studies, reduced-player formats included 4v4 ( $n = 4$ ), 5v5 ( $n = 1$ ), 6v6 ( $n = 1$ ), 7v7 ( $n = 1$ ), and 9v9 ( $n = 2$ ), with one study incorporating multiple formats (4v4, 5v5, and 6v6) within the same intervention (King et al., 2025). In contrast, three studies used full-field 11v11 matches (Abbott et al., 2019; Robinson et al., 2025; Salter et al., 2025). Intervention delivery also varied in match structure and exposure. The number of bouts ranged from 1 to 4, and period length ranged from 5 to 35 minutes. Seven studies reported 5-min periods (Barrett et al., 2022; de Macedo et al., 2025; King et al., 2025; Salter et al., 2023; Towlson et al., 2021a; Towlson et al., 2021b; Towlson et al., 2022), five reported 20-min periods (Abbott et al., 2019; Arede et al., 2024; Romann et al., 2020; Salter et al., 2025), and one reported 35-min periods (Lüdin et al., 2022). Notably, eight studies used chronological age groups as the comparator condition for the intervention (Abbott et al., 2019; Arede et al., 2024; Lüdin et al., 2022; de Macedo et al., 2025; Robinson et al., 2025; Romann et al., 2020; Salter et al., 2023; Salter et al., 2025), while five studies used maturity-mixed teams as the comparator (Barrett et al., 2022; King et al., 2025; Towlson et al., 2021a; Towlson et al., 2021b; Towlson et al., 2022).

#### Assessment methods for maturity status

Three different methods were used to estimate maturity status. The predicted adult height (PAH) method by Khamis and Roche (1994) was most frequently reported ( $n = 9$ ), while the Mirwald et al. (2002) and Fransen et al. (2018) methods were each used in three studies. Because two studies applied more than one method (Towlson et al., 2021b; Towlson et al., 2022), these frequencies are not mutually exclusive. All approaches provide indirect maturity estimates derived from somatic measures. However, the cut-off criteria used to classify athletes as pre-, circa-, or post-PHV varied across studies, indicating inconsistent thresholds for maturity grouping.

#### Quality assessment results

Table 5 shows the results of the methodological quality assessment for the studies. After evaluating the 13 studies included in this review using the QualSyst tool (Kmet et al., 2004), all were rated as good quality (mean = 0.85, SD = 0.047, range = 0.77–0.92) and exceeded the 0.75 threshold proposed by Kmet et al. (2004). However, it is crucial to note that this aggregate score masks specific methodological weaknesses. Table 5 reveals repeated deductions across studies for random allocation procedures, investigator blinding, control for confounding variables, and adequate sample sizes. While the nature of bio-banding interventions makes participant blinding impossible (Item 7 marked 'NA'), the lack of randomization and blinding of outcome assessors in many studies introduces potential bias that tempers the strength of the evidence. In particular, we considered that all studies employed appropriate methodologies and drew justified conclusions from their findings, yet these limitations must be acknowledged when interpreting the synthesis.

#### Key outcome

Results were synthesized according to outcome domains

relevant to talent identification in youth soccer, with a summary of the evidence provided in Table 6. To enhance interpretability, results are stratified by game format (small-sided vs. full-sided) and comparator type (CA-based vs. mixed-maturity) where data permitted.

#### Effect of Bio-Banding on physiological performance

In total, 8 of the 13 articles included in this review examined the effects of bio-banding on physiological performance. Among these articles, four employed global or local positioning systems (GPS/LPM) to capture running activity and overall physical workload (Arede et al., 2024; Lüdin et al., 2022; Romann et al., 2020; Towlson et al., 2021b), while four used wearable inertial sensors (e.g., foot-mounted IMUs or waist-worn accelerometers) (King et al., 2025; de Macedo et al., 2025; Salter et al., 2023; Salter et al., 2025).

Overall, the findings indicate that the physiological effects of bio-banding are highly context-dependent and not uniformly positive or negative. Several studies reported no consistent whole-group differences in traditional physical performance indicators such as total distance, running intensity, or heart-rate responses when bio-banded conditions were compared with chronological age-based grouping (Romann et al., 2020; Salter et al., 2025; Towlson et al., 2021b). In contrast, when maturity status was considered, bio-banding appeared to modify the distribution of physiological demands between players at different stages of maturation though the direction of this effect varied by game format.

In match-play contexts, small-sided bio-banding tended to attenuate overall physical load or peak physiological strain, as demonstrated by reduced external and peak internal loads in bio-banded competition (Arede et al., 2024), as well as smaller acute neuromuscular fatigue responses during training sessions (Salter et al., 2023). However, studies using larger game formats or full-sized matches reported greater high-intensity demands for more mature players, with little change in less mature players (King et al., 2025; Lüdin et al., 2022). Supporting this pattern, De Macedo et al. (2025) reported higher external workload for less mature players under bio-banding without a corresponding increase in perceived or internal strain. These divergent findings suggest that the ecological meaning of bio-banding differs substantially between small-sided and full-sided contexts.

#### Effect of Bio-Banding on psychological performance

A total of 7 studies involved psychological outcomes: four assessed perceived effort using session rating of perceived exertion (sRPE) or differential rating of perceived exertion (dRPE) (Abbott et al., 2019; Barrett et al., 2022; de Macedo et al., 2025; Salter et al., 2023), whereas three evaluated psycho-social behaviors via expert ratings using the Hull Soccer Behavioral Scoring Tool (HSBST) or equivalent behavioral scoring charts (King et al., 2025; Robinson et al., 2025; Towlson et al., 2021b). It is important to distinguish between these self-reported internal states (RPE) and observer-rated external behaviors, as they represent different psychological signals.

**Table 5.** Study design and sample characteristics.

Author (date)	Country	Study design	Participants		Competitive Level	Compared groups	Intervention		Maturity assessment
			N (sex)	Age (years)			Type	Duration	
Abbott et al. (2019)	UK	Repeated-measures crossover	25 M	12.7 ± 1.0	Soccer academy players	BB vs. CA	11v11	4 x 20 min 2 matches (1 CA + 1 BB)	Khamis–Roche (1994) method
Arede et al. (2024)	Portugal	Repeated-measures crossover	116 M	U13: 12.2±0.3 U14:13.2±0.4	Soccer academy players	BB vs. CA	7v7	20 min 8 matches (4 CA + 4 BB)	Khamis–Roche (1994) method
Lüdin et al. (2022)	Switzerland	Randomized cross-over repeated	65 M	11.7-13.7	Elite youth soccer clubs players	BB vs. CA	9v9	2 x 35 min 2 matches (1 CA + 1 BB)	Mirwald et al. (2002) method
Romann et al. (2020)	Switzerland	Repeated-measures crossover	60 M, 2 F	U13: 12.2±0.3 U14: 13.2±0.4	Elite youth soccer clubs players	BB vs. CA	9v9	20 min 8 matches (4 CA + 4 BB)	Mirwald et al. (2002) method
Towilson et al. (2021a)	UK	Repeated measures	32 M	12.9 ± 0.9	Soccer academy players	BB vs. MM	4v4 SSGs	5 min, 96 matches (48 MM + 48 BB)	Khamis–Roche (1994) method
Towilson et al. (2021b)	UK	Repeated measures	72 M	11-14	Soccer academy players	BB vs. MM	4v4 SSGs	5 min, 15 matches (5 MM + 10 BB)	Khamis–Roche (1994) method; Fransen et al. (2018) method
Towilson et al. (2022)	UK	Repeated measures	72 M	11-14	Soccer academy players	BB vs. MM	4v4 SSGs	5 min 15 matches (5 MM + 10 BB)	Khamis–Roche (1994) method; Fransen et al. (2018) method
Salter et al. (2023)	UK	Repeated measures	55 M	13.8 ± 1.4	Soccer academy players	BB vs. CA	6v6 SSGs,	5 min 30 matches (15 CA + 15 BB)	Khamis–Roche (1994) method
Salter et al. (2025)	UK	Repeated-measures crossover	139 M	12-16	Junior Premier League players	BB vs. CA	11v11	20 min 6 matches (3 CA + 3 BB)	Khamis–Roche (1994) method
King et al. (2025)	UK	Cross-sectional repeated-measures	53 M	13.4 ± 0.9	Soccer academy players	BB vs. MM	4v4, 5v5, and 6v6 SSGs	5 min 72 matches (36 MM + 36 BB)	Fransen et al. (2018) method
Robinson et al. (2025)	UK	Cross-sectional repeated-measures	118 M	13.7 ± 0.8	Junior Premier League players	BB vs. CA	11v11	20 min 6 matches (3 CA + 3 BB)	Khamis–Roche (1994) method
De Macedo et al. (2025)	Brazil	Repeated measures	20 M	11.8 ± 1.15	Soccer academy players	BB vs. CA	5v5 SSGs	4 x 5 min 6 matches (2 CA + 4 BB)	Mirwald et al. (2002) method
Barrett et al. (2022)	UK	Repeated measures	32 M	12.9 ± 0.9	Soccer academy players	BB vs. MM	4v4 SSGs	5 min 12 matches (6 CA + 6 BB)	Khamis–Roche (1994) method

Abbreviations: N, number; M, male; F, female; BB, Bio-banded; CA, chronological age; MM, Mixed-maturity (surrogate control); SSGs, small-sided games.

Regarding subjective perceptual responses, findings were inconsistent. One study reported significantly higher RPE for early developers in bio-banded compared with chronological-age competition (Abbott et al., 2019). In contrast, another study observed no significant differences in sRPE between bio-banding and chronological-age game formats (de Macedo et al., 2025). Salter et al (2023) observed post-PHV players showing a significant decrease in RPE-T compared with chronological-age game formats. Additionally, Barrett et al. (2022) reported higher dRPE in pre-PHV than post-PHV players and greater overall dRPE outputs in mixed-maturity games.

For psycho-social behaviors, most studies showed significant improvements in most psycho-social attributes during bio-banded games. Pre-PHV players displayed

enhanced psychological characteristics relative to post-PHV players in maturity-mismatched bio-banded small-sided games (Towilson et al., 2021b), whereas more mature players showed small-to-moderate increases in psychological characteristics in 4v4 formats across maturity-matched and mixed-maturity conditions (King et al., 2025). Expert ratings using the HSBST indicated small or significant improvements in most psycho-social attributes under bio-banded (except communication), with pre-PHV players rated higher for composure and decision-making and on-time developers showing the greatest gains in confidence, competitiveness, and X-factor (Robinson et al., 2025). However, these "improvements" are context-specific and depend heavily on the scoring method and maturity group, cautioning against overgeneralization.

### Effect of Bio-Banding on technical-tactical performance

Seven studies focused on technical–tactical performance: four employed video-based match analysis to quantify technical–tactical performance indicators, using notational analysis software (e.g., Dartfish, SportsCode) and estab-

lished coding frameworks (e.g., the Team Sport Assessment Procedure) (Abbott et al., 2019; Lüdin et al., 2022; Romann et al., 2020; Towlson et al., 2022), whereas three used foot-mounted inertial measurement units (F-IMUs) to assess technical characteristics (King et al., 2025; Salter et al., 2025; Towlson et al., 2021a).

**Table 6.** Key outcomes of included studies.

Author (Year)	Compared groups	Key Outcomes for BB Intervention			Tactical performance
		Physiological performance	Psychological performance	Technical performance	
Abbott et al. (2019)	Chronological age	None	Early developers: ↑ RPE	Early developers: ↑ Short pass, ↓ Dribbles On-time developers: ↑ Short pass, ↑ Dribbles ↓ Long pass, Late developers: ↑ Tackles, ↓ Long pass	None
Arede et al. (2024)	Chronological age	↓ Distance covered ↓ Decelerations ↓ Average speed ↓ Body impacts ↓ Peak heart rate	None	None	None
Lüdin et al. (2022)	Chronological age	U13 MO Low: ↓ High Accelerations U13 MO High: ↑ High accelerations U14 MO Low: ↓ High accelerations	None	U13 MO Low: ↑ Conquered balls U13 MO High: ↓ Conquered balls U14 MO Low: ↑ Conquered balls, ↑ Attacked balls	None
Romann et al. (2020)	Chronological age	↓ Jogging distance, ↓ Running distance ↓ High speed running	None	↑ Duels ↑ Unsuccessful passes	↑ Set Pieces ↓ Mean possession time
Towlson et al. (2021a)	Mixed-maturity	None	None	No consistent differences	Early developers: ↓ Degree centrality
Towlson et al. (2021b)	Mixed-maturity	No consistent differences	Pre-PHV vs Post-PHV: ↑ Positive attitude, ↑ Confidence ↑ Competitiveness ↑ Total psychological score ↑ sRPE-TL	None	None
Towlson et al. (2022)	Mixed-maturity	None	None	No consistent differences	No consistent differences
Salter et al. (2023)	Chronological age	Attenuated pre-post changes: ↓ Absolute stiffness ↓ Stride length, ↓ Cadence	Post-PHV: ↓ RPE-T	None	None
Salter et al. (2025)	Chronological age	Post-PHV: ↑ High-intensity distance	None	↓ One-touch actions Post-PHV: ↓ Total touches, ↓ Total possessions	↑ Time per possession
Robinson et al. (2025)	Chronological age	None	↑ Competitiveness, ↑ Confidence ↑ Decision making ↑ Composure, ↑ X-factor	None	None
de Macedo et al. (2025)	Chronological age	Pre-PHV: ↑ ETL PHV: ↓ ETL	↔ ITL	None	None
Barrett et al. (2022)	Mixed-maturity	None	↓ dRPE	None	None

Abbreviations: PHV, peak height velocity; RPE-T, technical/cognitive exertion; ETL, external load; ITL, internal load.

Overall, most studies indicated that bio-banding influences technical–tactical behaviors and may redistribute match involvement according to maturity status. For example, bio-banding increased the frequency of duels and set pieces, while reducing the average duration of ball possession per action (Romann et al., 2020). Furthermore, the success rate of passes decreased and the rate of unsuccessful passes increased under bio-banding, although the total number of passes remained unchanged (Romann et al., 2020). In parallel, late developers exhibited greater engagement in defensive and ball-winning actions (e.g., more tackles, recoveries, and attacking-ball actions) (Lüdin et al., 2022), while action profiles shifted toward shorter passing and fewer long passes, with dribbling patterns differing across maturity groups (Abbott et al., 2019).

In particular, one study using network approaches suggested that early developers displayed more effective collective behaviors and became more integral to team dynamics when playing in mixed-maturity teams, whereas smaller pitch areas tended to elicit more tactical behaviors and subsequent technical actions (Towlson et al., 2021a). However, one study reported minimal and inconsistent technical–tactical changes across most maturity-matched and maturity-mismatched fixtures, with differences mainly evident in post-PHV maturity-matched small-sided games (Towlson et al., 2022). These inconsistencies highlight that technical-tactical changes are not uniform and are likely moderated by the specific constraints of the bio-banded environment.

## Discussion

### Effect of Bio-Banding on physiological performance

Bio-banding did not produce uniform changes in physiological demands across studies, suggesting that its primary influence lies in reshaping competitive balance rather than systematically increasing or decreasing match intensity. At the group level, the absence of consistent differences between bio-banded and age-based formats indicates that overall physical demands may remain broadly comparable when all players are considered together (Romann et al., 2020; Salter et al., 2025; Towlson et al., 2021b). However, the more consistent pattern emerged when biological maturity was taken into account: bio-banding appeared to redistribute demanding actions between less and more mature players, with effects varying by game format and competitive context (King et al., 2025; Lüdin et al., 2022; Salter et al., 2025).

One plausible explanation is that bio-banding reduces the physical advantage typically held by more mature players in age-based competition. When players are matched more closely by maturity, more mature players may be required to perform a greater share of high-intensity actions to influence the game, while less mature players may gain more opportunities to participate without being physically overmatched. This interpretation is consistent with the observation that some studies reported lower peak strain or reduced short-term declines in movement-related performance under bio-banding (Arede et al., 2024; Salter et al., 2023), whereas larger formats and full-

sized matches sometimes elicited greater high-intensity demands for more mature players (King et al., 2025; Lüdin et al., 2022; Salter et al., 2025). Together, these findings suggest that bio-banding can shift where the most demanding physical actions occur, depending on the competitive structure.

From a talent identification perspective, these maturity-specific effects are important because physical outputs in youth soccer are strongly influenced by biological development. If bio-banding reduces the extent to which early physical development dominates match involvement, it may help practitioners observe players' contributions under conditions that place less mature players in a more comparable physical environment (King et al., 2025; Lüdin et al., 2022; Salter et al., 2025). At the same time, the variability across contexts indicates that bio-banding should not be treated as a single, fixed “load” intervention. Instead, the choice of game format and grouping approach is likely to determine whether bio-banding primarily moderates peak strain (Arede et al., 2024; Salter et al., 2023), increases demands on more mature players (King et al., 2025; Lüdin et al., 2022; Salter et al., 2025), or increases workload opportunities for less mature players (de Macedo et al., 2025).

### Effect of Bio-Banding on psychological performance

The evidence on psychological outcomes suggests a clear contrast between perceived effort and observed behavioural responses under bio-banding. Perceived effort responses were inconsistent across studies, with some reporting higher exertion ratings in bio-banded formats for certain maturity groups, others reporting no meaningful differences compared with age-based competition, and at least one reporting lower perceived effort in more mature players under bio-banding (Abbott et al., 2019; de Macedo et al., 2025; Salter et al., 2023). This variability likely reflects differences in how bio-banding was implemented (e.g., matched, mismatched, or mixed-maturity formats), the type of game played, and the extent to which bio-banding changed players' roles and responsibilities during competition. For example, when less mature players gain greater involvement, their perceived effort may increase, whereas more mature players may experience reduced dominance and a shift toward more demanding or less comfortable roles, producing different subjective responses.

In contrast, expert-rated psycho-social behaviors showed more consistent improvements under bio-banded conditions. Studies using structured behavioral scoring tools generally reported enhanced psycho-social attributes during bio-banded games, including better composure and decision-making in less mature players, and improvements in confidence- and competitiveness-related behaviors in players of average maturity (Robinson et al., 2025; Towlson et al., 2021b). Improvements were also reported for more mature players in certain formats, particularly small-sided conditions that increase the frequency of involvement and decision-making opportunities (King et al., 2025). These patterns suggest that bio-banding may create competitive environments that encourage adaptive

behaviors—such as persistence, confidence, and decision-making—by altering the social and physical balance of play.

From a talent identification perspective, this distinction is important. If bio-banding can elicit more favourable behavioral responses, it may provide practitioners with an additional observation context to evaluate psychological qualities that are relevant to long-term development but can be difficult to detect in age-based competition dominated by physical maturity advantages. However, it must be acknowledged that favorable behavior in a specific bio-banded context is not necessarily equivalent to stable talent. Context sensitivity is part of the phenomenon, and behaviors observed here may not automatically transfer to other settings. Furthermore, the inconsistent perceived effort findings caution against assuming a uniform psychological experience for all players (Abbott et al., 2019; de Macedo et al., 2025; King et al., 2025; Robinson et al., 2025).

### **Effect of Bio-Banding on technical-tactical performance**

Overall, the available evidence suggests that bio-banding can influence technical–tactical behaviors primarily by changing how players become involved in match play, rather than producing uniform improvements across settings. By reducing maturity-related physical imbalances, bio-banding may redistribute opportunities to contest possession and make decisions, which in turn can alter observable match behaviors. This is consistent with reported changes in match events and possession characteristics under bio-banding, including more duels and set pieces, shorter possession sequences, and less efficient passing outcomes in some contexts (Romann et al., 2020).

The direction and size of these effects appear to depend on maturity status and game constraints. Less mature players may gain greater involvement in ball-winning and attacking actions, while action profiles may shift (e.g., more short passing, fewer long passes) and dribbling patterns may differ across maturity groups (Abbott et al., 2019; Lüdin et al., 2022). Evidence also indicates that team interaction structure and pitch size can shape technical–tactical expression under bio-banding, with mixed-maturity conditions and smaller pitch areas influencing collective behaviors and subsequent technical actions (Towlson et al., 2021a).

Importantly, technical–tactical changes are not always consistent. One study reported few tactical differences and no consistent technical differences across conditions (Towlson et al., 2022). From a talent identification perspective, bio-banding may therefore be most useful as a complementary assessment condition alongside age-based competition, with careful selection of game formats and constraints to elicit the behaviors of interest.

### **Implications for talent identification**

A critical distinction must be made between "creating better observation conditions" and "improving identification accuracy." The current evidence speaks more directly to the former: bio-banding successfully alters the competitive landscape, allowing late-matures to demonstrate technical

and tactical skills that might be suppressed in age-based groups. However, whether these observed behaviors reliably predict long-term progression, selection, or career success remains unproven. Future work must clarify if the qualities revealed in bio-banded settings (e.g., enhanced decision-making under pressure for late maturers) are indeed the predictors of long-term potential they are hypothesized to be, and over what developmental time horizon these qualities matter most.

### **Strengths and limitations**

The primary advantage of this review lies in its inclusion of studies that utilize age-based and mixed maturity groupings as control groups, thereby enabling a comprehensive examination of the various grouping patterns and their variations. Furthermore, a systematic literature search was conducted utilizing several electronic databases along with a comprehensive array of search strings. Additionally, reference lists of all included articles were manually reviewed to identify other pertinent studies, a procedure now explicitly noted in the Methods section. The search strategy was sufficiently broad to encompass relevant research, including those that did not explicitly prioritize talent identification as their primary focus.

Regarding limitations, this review focuses exclusively on soccer players, and the existing studies primarily concentrate on male samples from European soccer academies. Consequently, it is not possible to draw conclusions about the impact of bio-banding competition formats on other sports, genders, cultural backgrounds, or levels of competitiveness. Furthermore, the meaning of bio-banding effects may itself be context-dependent rather than universally transferable. Academy structures, coaching cultures, and selection systems differ significantly across countries and levels, suggesting that findings from UK academies may not apply directly to other environments. Additionally, there is a lack of uniformity in the methods used for measuring maturity across the included studies, which may affect the research outcomes. We also acknowledge the likelihood of partial sample or cohort dependence across multiple publications from the same research groups and developmental settings, which could make the evidence base appear broader than it really is. Therefore, future research should further explore the effects of bio-banding competition formats on different athletic populations and address issues related to the selection of maturity measurement methods.

### **Future directions**

Future studies should strengthen study design and reporting so that findings can be compared across settings with greater confidence. Where feasible, researchers should use randomized, counterbalanced, or other controlled designs when comparing bio-banded and age-based competition, and clearly describe how maturity was assessed and how groups were formed. More generally, studies should justify sample size, describe the competition format, and standardize how exposure to bio-banding is delivered. Player characteristics should be reported in a consistent way, including age, sex, playing level, and maturity distribution, and assessors should be blinded when outcomes rely on subject-

tive ratings. In addition, clear reporting of intervention adherence, such as the proportion of participants who completed the scheduled bio-banded matches, is critical, as is improving diversity in participant sex, cultural background, and competitive level, and exploring the effects of bio-banding in other sports.

Beyond improving study quality, future work should clarify whether bio-banding improves talent identification over time rather than only altering short-term match responses. Longitudinal studies are needed to examine whether behaviors observed in bio-banded competition predict later progression, selection, and performance. To support this aim, researchers should agree on a small set of shared outcomes that capture “how players contribute” rather than only how much they run, and should combine match analysis with simple, repeatable indicators of involvement and decision-making. Studies should also directly compare different bio-banding models (such as maturity-matched, mismatched, and mixed-maturity teams) and game constraints to identify which conditions best reveal the qualities of interest. Specifically, future research should define what successful bio-banding is expected to reveal about players (e.g., resilience, tactical adaptability, technical consistency under pressure) and establish the developmental time horizons over which these revealed qualities should matter for long-term success. Finally, future studies should also consider how acceptable and practical bio-banding is for players and coaches in real development pathways.

## Conclusion

Whilst more robust controlled studies and implementation research are required, overall, bio-banding appears to be a potential solution to address maturation bias in youth soccer performance and selection, but the lack of long-term follow-up data and variable outcome measures needs to be addressed. This review has given an overview across physiological, psychological, and technical–tactical domains to inform the design and refinement of bio-banding competition formats, but future research is needed to identify which bio-banding models and game constraints are most informative and acceptable for players and coaches. It is imperative to delimit the represented context of these findings: the current evidence is dominated by short-term quasi-experimental studies involving predominantly male players in academy or Junior Premier League contexts. Consequently, claims that bio-banding is a definitive solution to maturation bias in selection are premature. Instead, it should be viewed as a valuable tool for enriching observational data and creating fairer short-term competitive environments, pending further validation of its long-term impact on talent identification accuracy.

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### Key points

- Bio-banding is a promising approach to address maturity-related selection bias in youth soccer, and the current evidence base suggests it can alter the competitive environment in ways that support talent identification and player development across maturational stages.
- Reported effects of bio-banding span multiple performance domains, with technical-related outcomes frequently showing favourable changes, although the direction and magnitude of effects vary between studies and may depend on players' maturation status, context, and the specific competition format applied.
- Large variation in maturation assessment, banding thresholds, game rules, and outcome reporting limits comparability; standardized protocols and higher-quality research are needed to clarify effects on performance.

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