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The influence of biological maturity status on the German talent pathway in youth elite soccer: Insights into selection biases, differences in playing positions and team performance within national selection tournaments

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ABSTRACT

Differences in biological maturity status (BMS) during puberty may advantage biologically older players within selection processes. This study examined maturity-related differences across multi-stage selection procedures, playing positions, and the relationship between BMS and team performance within the German Football Association's U15 national selection tournaments. Anthropometric measurements were collected from $N = 695$ male regional association team players ($M = 14.1 \pm 0.3$ years), and BMS was assessed via skeletal age using the BAUSport™ ultra-sound device. When compared to players' expected BMS, a significant large pre-selection bias was observed favouring players with higher BMS to get selected for a regional association team ($M = 15.1 \pm 1.0$, $d = 1.19$, $p < .001$). Positional analyses revealed significant differences in BMS ($\eta^2 = .14$, $p < .001$) with goalkeepers, defenders, and forwards being biologically older than midfielders. Team performance (points achieved) showed a strong positive correlation with BMS ($r_s = .71$, $p < .001$). Significant small advantages in maturity-related variables were found for players selected for the extended U15 youth national team squad ($0.17 \le d \le 0.23$; $p < .05$). Position-specific analysis of selection status revealed medium-to-large effects in forwards and goalkeepers with respect to BMS. The findings highlight the critical influence of BMS in multi-stage selection processes and underscore the need for position-specific considerations to ensure fair and developmentally appropriate talent promotion.

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Introduction

An ongoing challenge in competitive youth elite soccer is the identification, development, and selection of young talented players (Höner et al., 2023; Williams et al., 2020). Decision-makers in clubs or national federations (e.g., coaches and scouts) must consider multiple factors (e.g., anthropometric, physiological, psychological, sociological, technical, and tactical) when evaluating players' potential (Baker et al., 2022). Based on these evaluations, players are identified for talent promotion programs. Within such programs, further selection processes are conducted at various stages – either for progression to the next age category or to a higher performance level (Votteler & Höner, 2017). As a result, selection measures (e.g., selection tournaments) within talent promotion programs are inherently shaped by preceding selection stages. These critical multi-stage selection processes in male youth football, particularly between the U13 and U16 age groups, coincide with the pubertal phase (Cumming et al., 2017). Players' biological maturation therefore constitutes a key factor that can significantly influence talent selection processes (Carvalho & Gonçalves, 2023).

Biological maturation refers to the progression towards the adult state and can be defined in terms of status, tempo and timing. While biological maturity status (BMS) describes the current stage of maturation that an individual has reached, tempo refers to the rate at which the maturation process is progressing with timing referring to the age at which specific maturation events occur (Malina et al., 2019). In practice, however, maturity-related parameters are often not taken into account, resulting in highly talented players being overlooked or deselected due to their delayed biological maturation. Thus, an over-representation of early maturing players is apparent in nationwide talent identification and development programs or youth elite soccer academies (Hill et al., 2020; Johnson et al., 2017; Leyhr et al., 2020, 2023).

Building on these findings, Sweeney and Lundberg (2024) recently explored whether selection biases based

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on biological maturation vary according to competition level (regional, national, international) among U15 male soccer players in Sweden. Their research revealed a significant bias favouring early maturing players, with the bias increasing at higher competition levels. Notably, the most significant maturity-related differences were found in BMS and body mass, with players of higher BMS and body mass more likely to be selected for national and international teams. A reason for this seems to be temporally occurring anthropometric and physiological advantages of those who enter puberty early and develop at high tempo (i.e., 11–16 years of age; Meylan et al., 2010). Supporting this notion, a study by Sweeney et al. (2022) confirmed the existence of a maturation-related selection bias in youth soccer, though the extent of this bias varied depending on playing position. The study, which looked at 159 Irish youth national soccer players from the U13 to U16 age groups, found that central defenders were significantly more biologically mature than players in other positions, such as full-backs and attacking midfielders. The studies confirm that BMS influences player selection at different levels and, by extension, the composition of a team's squad in terms of playing positions. However, in particular the results about differences in playing positions are based on one single study which highlights the need for further investigations in this direction.

Further, it remains essential to examine the effects of BMS on both individual player and team performance. These effects may manifest, for example, in superior (physical) performance capacities or increased match playing time among biologically older players. Building on this, several studies have examined the relationship between biological maturity and individual performance diagnostics, particularly during the adolescent growth spurt, which typically occurs at an average age of 13.8 ± 1.0 years in boys (Philippaerts et al., 2006). Early maturing players have consistently demonstrated superior performance in physiological attributes such as sprinting and agility (Grendstad et al.; Gundersen et al., 2022; Rommers et al., 2019; Towlson, MacMaster, Parr, et al., 2021). A study by Eskandarifard et al. (2022) further indicated that a combination of BMS, physical fitness, and hormonal levels plays a significant role in determining match participation (i.e., minutes played) among youth soccer players.

Moreover, a more advanced BMS may provide advantages in match-related performance outcomes at both the individual and team levels. For instance, Goto et al. (2019) reported that U13/U14 Premier League academy players with advanced maturity exhibited superior high-speed running performance during matches. Similarly, Hill et al. (2021) found that players with advanced biological maturity received higher coach ratings for individual match performance in certain age groups (U10, U14, and U15), although this trend was not observed consistently across all cohorts (e.g., U9, U11–U13, and U16). However, research exploring the influence of maturation-related variables on actual match performance remains limited. To the best of the author's knowledge, there is no study that considered match performance on a team level so far.

In summary, further research is warranted to examine biological maturation as a key factor in talent identification and development with a special focus on its impact on playing-positions and team-level performance. While several findings parallel those in the well-established body of literature on the Relative Age Effect (RAE) – such as the overrepresentation of relatively older players in talent promotion programs (Kelly et al., 2021; Leyhr et al., 2021; Romann et al., 2020) and their tendency to occupy more physically demanding positions (Peña-González et al., 2021, 2025) – these patterns cannot be directly extrapolated to biological maturation. Indeed, although often associated with early biological development, recent research suggests that relative age and maturation are distinct constructs (Parr et al., 2020). Consequently, despite increasing recognition of biological maturation in youth soccer talent development, its role in multi-stage selection processes, playing position differences, and team-level performance outcomes remains inadequately understood.

The present study

The purpose of the present study was to examine the influence of maturity-related variables on different stages of the selection process within the German talent development pathway. Specifically, two progressive stages (i.e., talent development, and elite promotion) were investigated with regard to their role in the progression of youth soccer players towards potential selection for the national youth teams. Within the DFB's youth development structure, the talent development stage typically occurs during early adolescence (i.e., U12–U15) and takes place across various regional institutions (e.g., competence centres, youth academies, regional associations). This stage is followed by the elite promotion stage at the national level, which involves national youth academies, regional associations, and youth national teams (Wachsmuth et al., 2024).

A key transition point between these two stages is the two annual DFB national selection tournaments for the U15 youth national team. These tournaments for which approximately 0.3% of actively playing male youth footballers in the respective age group are selected represent the first selection event within the elite promotion stage at the national level. Prior to participating in the national selection tournament (i.e., during the talent development stage) players typically undergo multiple selection procedures within their respective clubs and regional associations. As previous research has shown that players with advanced maturity-related characteristics are often favoured throughout various selection stages in male youth soccer (Hill et al., 2020; Sweeney et al., 2023), the following directed hypotheses were tested:

H1: There is a pre-selection bias towards players of higher BMS within the national selection tournament.

Second, differences in maturity-related variables (i.e., body mass, height, and BMS) across playing positions (i.e., goalkeepers, defenders, midfielders, and forwards) were analysed. Due to the different requirement profiles of the various playing positions, the following was assumed:

H2: There are differences in maturity-related variables across playing positions.

Third, the impact of BMS on team performance at the tournament was considered (i.e., points won during the tournament). As advantages in this variable might align with performance advantages, the following directed hypothesis was tested:

H3: Regional association teams of higher BMS show higher team performances.

While *H1-H3* address the selection process at the regional level, a further aim of this study was to examine differences in maturity-related variables between players who were selected for further promotion following the tournament and those who were not. *H4* specifically addresses potential selection biases at the second stage of selection (i.e., the national level). This hypothesis was tested in a directed manner:

H4: Players selected for the extended squad of the U15 national team are advanced with respect to maturity-related variables when compared to their non-selected counterparts within the tournament.

In line with *H2*, playing position may act as a moderating variable in this context. Therefore, in addition to analysing the overall sample, differences in maturity-related variables between selected and non-selected players were also examined separately for each playing position.

Materials and methods

Sample

The study sample consisted of $N = 695$ male youth soccer players (14.1 ± 0.3 years old, birth cohorts 2010 and 2011) participating in the U14 national selection tournaments of the German Football Association (Deutscher Fußball-Bund, DFB) in 2023 or 2024 (i.e., one tournament in May and one in June each year). Coaches of 22 regional association teams nominate players at the regional level to compete in one of the two separate nationwide tournaments where each regional association team plays four competition games. Youth national team coaches determined playing positions based on the starting 11 formations resulting in the categories goalkeepers (GK, $n = 87$), defenders (DF, $n = 230$), midfielders (MF, $n = 300$), and forwards (FW, $n = 78$). Furthermore, the same coaches evaluated players based on their playing performance and selected ($n = 126$) or not selected ($n = 569$) them for the extended squad of the U15 youth national team just after the end of the tournament. Players from this extended squad will be invited to additional elite promotion camps throughout the season, where they will be promoted and re-evaluated by the German youth national team coaches.

Procedures

All data were collected at the respective tournaments within 3 days. Participation in the study was voluntary and could be declined to every time point. Players' legal guardian/next of kin provided written informed consent for the collection and scientific use of the data. The research was approved by the ethics committee of the first author's institution.

Measures

To determine anthropometric characteristics and BMS, established measures commonly applied in research were used (Cumming et al., 2024; Lloyd et al., 2014; Rachmiel et al., 2017). Test-retest reliabilities for all anthropometric measurements ($r_{tt} \geq 0.99$) and BMS assessment ($r_{tt} = .98$) were excellent and have already been reported in a former study (Leyhr et al., 2020). Inter-rater reliability of the BMS assessments was found to be excellent ($r = .95$) in a pilot study with 71 U14 regional association team players on the selection tournament 2022.

Anthropometric data of the players were gathered before breakfast time. Body mass was measured with calibrated scales (seca 813 electronic flat scale) to the nearest 0.1 kg. Height was determined to the nearest 0.1

cm with a fixed stadiometer (seca 213 portable stadiometer). Players had to stand with feet together and arms relaxed while having their head aligned with the Frankfurt horizontal plane (Malina & Koziel, 2014). Two measurements were taken for each anthropometric variable by the same trained research assistant. If the results differed by more than 0.4 kg for body mass, or 0.4 cm for height a third measurement was conducted. Finally, the values for each anthropometric measurement were averaged.

To determine players' *BMS* via skeletal age (SA), the BAUSport™ ultrasound device (SonicBone, Rishon Lezion, Israel; Rachmiel et al., 2017) was used as a non-invasive alternative to X-ray assessment, which is not permitted in Germany for children without a medical indication due to ethical considerations. Reflecting an alternative, and practical and methods for the estimation of SA in young athletes (Cumming et al., 2024), the portable bone sonometer analyzes three sites of the left hand: (1) the distal radius and ulna's secondary ossification centres of the epiphyses at the wrist; (2) the growth plate of the third metacarpal and the shaft of the proximal phalange; and (3) the distal metacarpal epiphysis at the metacarpals. The device measures the speed of propagation through bone of inaudible high-frequency waves of a short ultrasound pulse (m/s) and the distance attenuation factor (decay rate). With the use of these parameters and the averaged anthropometric data, SA was calculated (to the nearest 0.01 years) by an algorithm integrated into the software of BAUSport™ using the scoring method designed by Tanner and Whitehouse (TW2 method; Morris, 2003; Rachmiel et al., 2017). All ultrasound examinations were conducted once per player by the same trained person according to the BAUSport™ user manual's instructions.

Data analysis

Data were analysed utilizing IBM SPSS version 29.0 (IBM Corporation, Armonk, NY, USA). The significance level was set to $\alpha = .05$. Effect sizes were classified in accordance with Cohen (1992). Prior to the data analysis, one player's data on SA was adjusted. For this player, initially, a SA of 18.8 years was recorded which indicates full maturity. According to the TW2 protocol for SA assessment, full maturity is defined as being reached at 18.2 years (Tanner, 1983). This discrepancy has been previously reported and extensively discussed in the literature (e.g., Lolli, 2024a, 2024b; Ruf et al., 2024). While the applied method is widely used and evaluated (e.g., Cumming et al., 2024; Leyhr et al., 2020) SA in this specific case was corrected to 18.2 years to account for the observed discrepancy. This procedure provides a more realistic analytical framework compared to excluding the player as a missing value, as it permits the inclusion of the individual as fully matured within the dataset.

To check whether the aggregation of two seasons confounded the analysis, two-way ANOVAs for each of the variables were conducted: differences regarding the *season* as well as potential interaction effects between *playing positions* or *selection status* and the *season* of data collection were examined. Neither significant differences regarding the *season* ($F(1; 691/687) \leq 3.20$, $p \geq .07$) nor significant interaction effects were found for any of the variables (*playing position* × *season:* $F(3; 687) \leq 0.77$, $p \geq .51$; *selection status* × *season:* $F(1; 691) \leq 0.66$, $p \geq .42$). Thus, data from both seasons were accumulated.

For a descriptive overview of the total sample, body mass, height, and SA were considered. A one-sample *t*-test was conducted to assess pre-selection biases concerning SA (*H1*). Specifically, players' mean SA was compared to the expected SA of an average player of the age group born in mid-year. It was hypothesized, from a theoretical perspective, that individuals in the population are assumed to have their SA aligned with their chronological age (CA), i.e., that SA equals CA (Lloyd et al., 2014). Thus, players expected SA to be 13.9 years at the time of the measurement when using June 1 as the average date of the tournament's two measurement slots. Therefore, the reference value for the one-sample *t*-test was set to $M_{SA} = 13.9$. Additionally, Cohen's *d* (including 90% confidence intervals) was calculated as effect size. Mean differences in maturity-related outcomes between playing positions (*H2*) were examined via one-way ANOVAs (including Bonferroni-corrected post-hoc tests for multiple group comparisons) and partial η^2 served as effect size. To examine the impact of SA on team performance during the tournament (*H3*), Spearman rank correlations were conducted to assess the relationship between the regional association teams' mean SA and the total points accumulated across their four matches (i.e., a possible range of 0 to 12 points). Independent samples *t*-tests were conducted to examine differences in maturity-related parameters between selected and non-selected players for the overall sample and for each playing position separately (*H4*). Cohen's *d* served as effect size.

Sample size estimation and justification

The sample consisted of players who had been nominated for the regional association squads. As such, the sampling procedure followed a non-probability approach, resulting in a convenience sample based on prior selection decisions. Thus, in line with Ditroilo et al.

(2025), sensitivity was calculated by post hoc power analyses using G*Power version 3.1.9.7 ($\alpha = 0.05$, $1 - \beta = 0.80$, two-tailed) to determine the size of a potentially detectable population effect. The analyses determined the sensitivity for discovering at least small-to-medium effects for all hypotheses (i.e., Cohen's $d > 0.2$, partial $\eta^2 > 0.01$, $r > 0.3$) depending on the respective hypothesis).

Results

Players' anthropometric data indicated a mean body mass of 59.2 ± 8.4 kg and a mean height of 172.8 ± 7.6 cm. Players' mean SA was 15.1 ± 1.0 years. Within the considered U14 age group, the difference between the player with the lowest (11.5 ys.) and highest SA (18.2 ys.) resulted in more than 6 years (Table 1).

Examining *H1* the one-sample t-test revealed a significant pre-selection bias of the sample towards biologically older players in terms of SA when compared to $M_{SA} = 13.9$ including a large effect size ($t(694) = 31.41$, $p < .001$, $d = 1.19$). Table 1 further shows the results for all assessed variables in relation to differences in playing positions (*H2*). One-way ANOVAs revealed significant mean differences between playing positions for all relevant variables, with large effect sizes ($37.38 \le F(3, 691) \le 37.67$, each $p < .001$, each $\eta^2 = .14$). Post-hoc multiple group comparisons showed significant differences between GK and field positions in body mass for DF ($d = 0.62$, $p < .001$) and MF ($d = 1.19$, $p < .001$), and in SA for DF ($d = 0.63$, $p < .001$) and MF ($d = 1.15$, $p < .001$), but not for FW. GK were significantly taller than all other (field) positions (each $p < .001$) with medium effect sizes when compared to DF ($d = 0.64$) and FW ($d = 0.63$) and large effect sizes for MF ($d = 1.21$). The group of MF players were the smallest, lightest and biologically youngest players across field positions. They differed significantly from DF (height: $d = 0.58$; body mass $d = 0.52$; SA: $d = 0.54$, each $p < .001$), and FW (height: $d = 0.57$; body mass $d = 0.82$; SA: $d = 0.75$, each $p < .001$). In contrast, no significant differences were found between DF and FW for any of the variables (each $p > .13$).

The relationship between regional association teams' SA and team performance (*H3*) is displayed in Figure 1. Spearman rank correlations showed a strong association between SA and team performance ($r_s = .71$, $p < .001$; see Figure 1).

When comparing players selected for the extended youth national team after the tournament to their non-selected counterparts (*H4*) significant differences were observed in body mass, height, and SA across the total sample ($1.77 \le t(693) \le 2.29$, each $p < .05$). These differences, favouring the selected players, yielded small effect sizes ($0.17 \le d \le 0.23$; see Table 2). Position-specific analyses revealed that the GK group exhibited the most pronounced differences between selected and non-selected players, with large and statistically significant effect sizes across all variables ($2.98 \le t(85) \le 3.80$, each $p < .01$; $0.90 \le d \le 1.14$), consistently favouring the selected group. Selected players were significantly taller and biologically older than their non-selected peers with small effect sizes among DF ($1.66 \le t(228) \le 1.94$, each $p < .05$; $0.31 \le d \le 0.36$) and medium effect sizes for FW ($1.94 \le t(76) \le 2.25$, each $p < .05$; $0.57 \le d \le 0.66$). In contrast, a significant difference for MF was found only in body mass, with selected players being slightly heavier than non-selected ones, resulting in a small effect size ($t(119.69) = 1.77$, $p < .05$; $d = 0.23$).

Discussion

This study utilized a large sample of elite male youth soccer players to examine maturity-related differences in selection and playing position, as well as the relationship between BMS and team performance in U15 youth national team selection tournaments. The fact that the study covers almost the entire sample of players participating in the tournaments (695 of potentially 704 players [98.7%]), makes their results particularly

Table 1. Descriptive and inference statistics of maturity-related characteristics of regional association team players competing at the tournament for total sample as well as separated by playing positions (*H1-H2*).

	Descriptive statistics						Inference statistics		
	Total ($N = 695$)		GK ($n = 87$)	DF ($n = 230$)	MF ($n = 300$)	FW (n = 78)	ANOVA		Post-hoc analyses
	M ± *SD*	*Min – Max*	*M* ± *SD*				η^2	F(3, 691)	
Body Mass (kg)	59.17 ± 8.42	37.40 – 91.80	64.93 ± 7.11	60.05 ± 8.09	56.00 ± 7.65	62.41 ± 8.45	.14***	37.58	GK = FW; GK > DF, MF; FW = DF > MF
Height (cm)	172.79 ± 7.60	146.80 – 194.00	178.30 ± 5.67	174.05 ± 7.05	169.90 ± 7.28	174.10 ± 7.72	.14***	37.67	GK > FW = DF > MF
SA (years)	15.13 ± 1.01	11.49 – 18.20	15.82 ± 0.83	15.25 ± 0.93	14.74 ± 0.97	15.47 ± 0.98	.14***	37.38	GK = FW; GK > DF, MF; FW = DF > MF

Note. SA = skeletal age; GK = goalkeepers; DF = defenders; MF = midfielders; FW = forwards; *$p < .05$, **$p < .01$, ***$p < .001$; ">" and "<" = Bonferroni-corrected $p < .05$; "=" = non-significant.

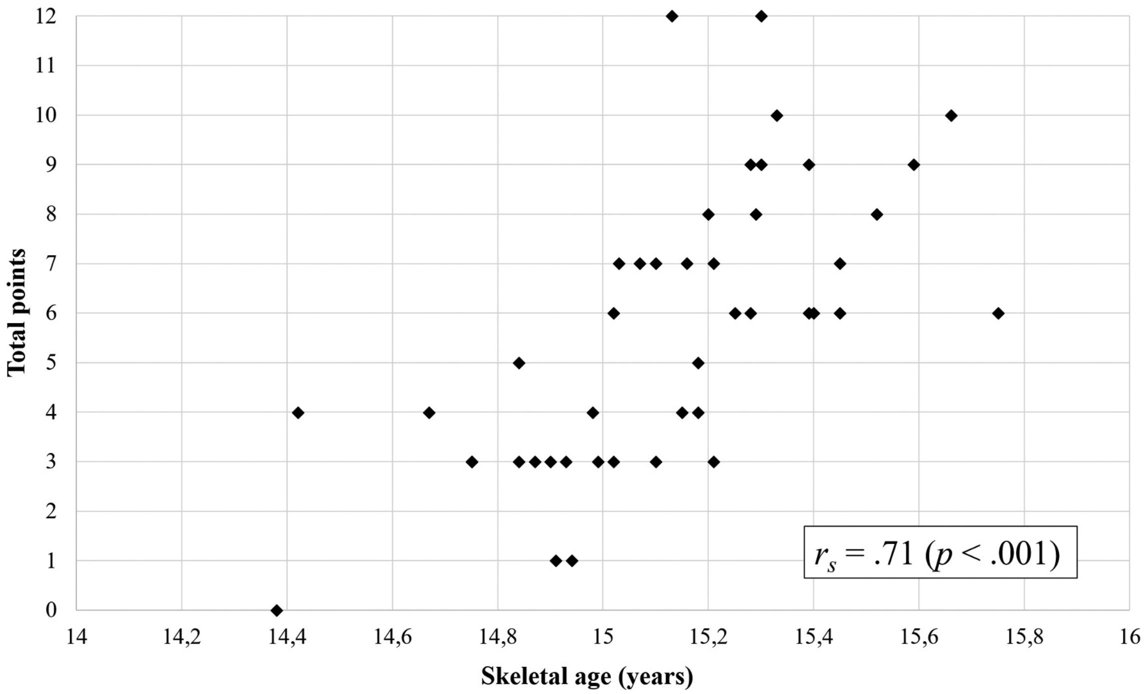

Figure 1. Scatter plot of the relationship between regional association teams' mean skeletal age and team performance (i.e., total points accumulated across each teams' four matches at the tournament; $r_s = .71$, $p < .001$). Note. *$p < .05$, **$p < .01$, ***$p < .001$.

valuable. The study offers various insight into the influence of maturity-related information with the selection process with the German talent identification and development program. By analysing positional differences in relation to BMS and its association with team performance, the study expands the current state of research within the field of talent development. First, the study found a significant pre-selection bias favouring players with higher BMS to get selected for a regional association team competing at the tournament (*H1*). Second, significant positional differences in maturity-related variables indicate the necessity to differentiate across positions within the selection process, with GK, DF, and FW being biologically older than MF (*H2*). Third, a significant relationship of BMS with the team performance on the tournament was revealed (*H3*). Lastly, small, but still significant differences in maturity-related variables were found between players who were selected for the extended U15 youth national team squad and their non-selected counterparts (*H4*).

The discovered pre-selection bias, which was characterized by a large effect ($d = 1.19$) aligns with previous research demonstrating a consistent preference for early maturing players in youth soccer (Hill et al., 2020; Sweeney et al., 2023). This selection bias, driven by short-term physical advantages, raises concerns about the fairness of talent identification systems that might overlook late-maturing players who possess equal technical and tactical potential but lack early physical development (Cumming et al., 2018). Consistent with the underdog hypothesis, it may be assumed that only those late developers tend to remain within the system who possess or develop exceptional technical or tactical skills – enabling them to offset their temporary biological disadvantages and to compete with their more advanced peers (Kelly et al., 2020). The extent of the significant pre-selection bias underscores that it must have developed over several selection decisions at the regional level. This highlights the need to raise awareness of this issue within talent identification procedures at regional stages, prior to the first selection at the national level. The first selection decisions at the national level are often made during the pubertal age (O'Connor et al., 2016), as is the case in the present study. The large bias, however, indicates that biologically older players already have higher chances of promotion or longer playing times in competitions at the regional level, even before the national selection process. Already within the highly selective sample investigated, differences in BMS were as much as 7 years. It is likely that many biologically younger players had dropped out of the promotion before and were no longer part of this cohort. It is thus crucial to raise coaches' and involved stakeholders' awareness of biological maturation processes and their impact on (athletic) performance in the context of selection decisions. Further, measures should be implemented, for example, to better support the development of biologically younger players for players in order to

Table 2. Descriptive and inference statistics of players selected for the extended U15 youth national team after the tournament and their non-selected counterparts for total sample as well as separated by playing positions (*H4*).

	Total (N = 695)			GK (n = 87)			DF (n = 230)			MF (n = 300)			FW (n = 78)		
	Selected (n = 126)	Non-selected (n = 569)		Selected (n = 13)	Non-selected (n = 74)		Selected (n = 33)	Non-selected (n = 197)		Selected (n = 66)	Non-selected (n = 234)		Selected (n = 14)	Non-selected (n = 64)	
	$M \pm SD$		d	$M \pm SD$		d	$M \pm SD$		d	$M \pm SD$		d	$M \pm SD$		d
Body mass (kg)	60.72 ± 8.21	58.83 ± 8.44	.23*	70.13 ± 7.90	64.3 ± 6.61	.90**	62.08 ± 8.02	59.71 ± 8.08	.29	57.34 ± 6.73	55.62 ± 7.87	.23*	64.74 ± 6.10	61.90 ± 8.84	.34
Height (cm)	173.88 ± 7.90	172.56 ± 7.52	.17*	183.20 ± 4.51	177.44 ± 5.31	1.11***	176.23 ± 7.58	173.68 ± 6.91	.36*	170.06 ± 6.18	169.86 ± 7.57	.03	177.66 ± 7.60	173.32 ± 7.58	.57*
SA (years)	15.30 ± 1.09	15.09 ± 0.99	.21*	16.57 ± 0.91	15.69 ± 0.75	1.14***	15.50 ± 0.90	15.21 ± 0.93	.31*	14.81 ± 0.91	14.72 ± 0.99	.09	15.99 ± 1.02	15.36 ± 0.94	.66*

Note. SA = skeletal age; GK = goalkeepers; DF = defenders; MF = midfielders; FW = forwards; *p < .05, **p < .01, ***p < .001.

reduce dropout rates from selection squads as well as from the sport of soccer itself. Such measures could include approaches like playing down – regulations (i.e., participation of late maturing players lower chronological age levels; Kelly et al., 2023). Further, bio-banding tournaments are certainly a potential approach to broadening coaches' perspectives and insights (Cumming et al., 2018).

Significant differences in body mass, height, and BMS were found across playing positions, with GK, DF, and FW being more biologically mature than MF. Indeed, this aligns with the findings of a recent systematic review analysing differences in body composition in male professional soccer where MF were characterized by lower values in height and body mass when compared to GK or the other field positions (Sebastiá-Rico et al., 2023). The results are further confirmed by earlier findings showing that certain positions in soccer favour early-maturing players due to physical demands, particularly in defence and goalkeeping, where height and strength are critical (Meylan et al., 2010). The question arises regarding whether biologically older players in physically demanding positions sustain and capitalize on their advantages into adulthood. Alternatively, it is possible that players who were biologically younger at the time of selection, yet demonstrated superior qualities such as game intelligence and passing abilities, may have been better suited for these positions after compensating for their initial disadvantages (Kelly et al., 2021). Those often called 'underdogs' present a significant area for future research.

The study found a strong positive correlation between the mean skeletal age of regional teams and their performance in the tournament (r_s = .71). Confirming *H3*, this suggests that teams characterized by higher BMS performed better in terms of match results. This study represents a preliminary initiative to investigate the relationship between BMS and match performance at the team level and may serve as an example for future research. From the authors' perspective, there are currently no studies available for comparison with these findings. Nevertheless, existing literature that examines match performance in relation to individual performance parameters (e.g., running performance) suggests a similar trend, with biologically older players demonstrating superior performances.

The present study revealed that maturity-related outcomes confer a selection advantage (0.17 ≤ d ≤ 0.23) also at elite level. Specifically, players selected for the extended U15 national squad were biologically older than their non-selected counterparts. Since there was already a strong pre-selection bias before being selected for the youth national team (Sweeney & Lundberg, 2024) the effect sizes were comparably low. To better contextualize the observed effects, it is essential to consider the selection criterion applied and the corresponding selection rates (Bergkamp et al., 2019). That said, the utilized criterion – drafted for the extended U15 national team squad – represents a relatively lenient (selection rate: 126 out of 695 players; 18.1%). Employing a more selective criterion, such as inclusion in the final national team squad, might yield stronger discriminatory effects, given the lower selection rate associated with this group (estimated at 44 out of 695; 6.3%, assuming a 22-player squad per cohort). However, the existence of small differences suggests that maturity-related attributes remain important at an already very high level of competition but are no longer essential to performance assessment. Indeed, the varying extent of the influence of BMS on pre-selection and selection was similarly observed in a study with German basketball players of the same age group at a comparable level (Leyhr et al., 2024). When analysing selection differences across playing positions, the GK position stands out with particularly large effects between selected and non-selected players across all maturity-related variables. This aligns with the position-specific performance profile of GK, where physical attributes are considered critical performance factors (Otte et al., 2022). These trends are evident throughout the multi-stage selection process – both during the talent development stage (e.g., GK exhibited the highest values for body mass, height, and skeletal age; see *H2*) and during the elite promotion stage (*H4*), where further selected GK were the heaviest, tallest, and biologically oldest players within an already maturity-advanced group.

Limitations

The study provides valuable insights into the biological maturity and performance of elite youth soccer players in Germany, but there are notable limitations that should be addressed to improve the generalizability of the findings. Although the sample size of 695 players is substantial, the study is restricted to a highly selective sample of elite youth players within Germany. Thus, the transferability of its conclusions to youth soccer players in talent promotion programs in other countries should be reflected cautiously. Further, expanding future research by considering further age groups may be beneficial. Younger age groups such as U12/U13 might be included in order to derive conclusions on the critical age at which early selection begins, while the consideration of older age groups (i.e., U15) might identify differences in the influence of BMS in selection in that age. That said, this cross-sectional study offers only a snapshot of players' BMS and performance at a specific point in time as data was collected during a single tournament. This design limits the ability to predict long-term player development, suggesting a need for future studies to incorporate longitudinal data to better capture performance trajectories over time. An additional limitation is the restriction on the four general playing positions in soccer (i.e., GK, DF, MF, and FW). Although this approach yielded valuable insights into differences in maturity-related characteristics future research would benefit from more refined or alternative positional groupings (e.g., box-to-box vs. defensive MF, central vs. wide positions). Finally, team performance was evaluated based on points that a team achieved during the tournament, which reflects a pragmatic method of team performance assessment solely based on match results. However, this points-based evaluation could be complemented by additional individual performance indicators (e.g., goals scored, assists, playing time) as well as further team-based characteristics (e.g., quality of coaching, level of teamwork) to provide a more comprehensive assessment of factors impacting team performance and their correlation with BMS.

Practical implications

The findings raise important questions about whether the current talent selection process is too focused on biological maturity and physical attributes, potentially neglecting other critical factors like technical skills, tactical awareness, and psychological resilience (Towlson, MacMaster, Gonçalves, et al., 2021). A more balanced approach to talent selection can prevent the over-representation of early maturing players and ensure that late developers are given the opportunity to succeed. In practice, this could be implemented by bio-banding approaches in training and competition (i.e., grouping players by BMS rather than CA) or by providing late developers with special playing down regulations (i.e., permitting them to compete temporarily in younger CA groups, when their BMS falls below a predetermined threshold; Kelly et al., 2023).

Future research could assess whether these early advantages in physical maturity translate into long-term success by examining whether biologically advanced players selected at U15 continue to perform better at later stages (e.g., U18/U19) or at senior professional level. Therefore, mixed-methods studies could investigate whether late-maturing players develop compensatory skills (e.g., technical or tactical) that enable them to overcome early physical disadvantages. This could be achieved through longitudinal monitoring of their skill development, as well as interviews with coaches experienced in working with successful late-maturing players or with the players themselves. In addition, longitudinal studies could follow the progress of both early- and late-maturing players over several years to determine whether early selection based on biological maturity accurately predicts long-term success.

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Author contributions

Conceptualization: DL, DM, OH; Data curation: DL; Formal analysis: DL; Funding acquisition: OH; Investigation: DL, DM; Methodology: DL, DM, OH; Project administration: DL, OH; Resources: DL, DM, MH, OH; Software: DL; Supervision: OH; Validation: DL, DM, OH; Visualization: DL, DM; Writing – original draft: DL, DM; Writing – review & editing: DL, DM, MH, OH.

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Data availability statement

De-identified versions of the datasets used in this study will be provided upon reasonable request.

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