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SPORTS PERFORMANCE

Identifying targets for behavior change interventions to integrate biological maturation in German football development programs: A COM-B and Behavior Change Wheel analysis

Lukas Arenas[a], Sabrina Forster[a], Tim Meyer[a], Jamie Salter[b] and Monika Frenger[c]

[a]Institute of Sport and Preventive Medicine, Saarland University, Saarbrücken, Germany; [b]InSPIRe Group, School of Science, Technology & Health, York St John University, York, UK; [c]Department Economics and Sociology of Sport, Saarland University, Saarbrücken, Germany

ABSTRACT

This study examines enablers and barriers to integrating biological maturation into talent identification and development processes within German football academies. Biological maturation significantly influences physical performance, selection decisions, and injury risk in youth football. Early maturing players are often favoured during talent identification, leading to premature deselection of talented late-maturing athletes. Using the COM-B framework (Capability, Opportunity, Motivation – Behaviour), we investigated stakeholders perceived barriers and enablers to implementing maturation strategies. An adapted COM-B-Qv1 questionnaire was distributed to 990 stakeholders across 56 elite academies and 344 regional training centres (June – July 2025), yielding 142 complete responses (14.3% completion rate). Internal consistency of the adapted scales was acceptable to good (Cronbach's $\alpha = 0.67–0.84$). Results showed that 78% of participants conduct maturation assessments, while 24% rarely or never considered it in player development and 51% did so only occasionally. Regional-affiliated stakeholders reported significantly higher barriers than league-affiliated participants ($p < 0.05$). Opportunity, expressed through the perceived lack of tools, time, and incentives, emerged as the strongest barrier (mean = 3.38 ± 1.30). These findings suggest that targeted training, enablement, and environmental restructuring may be particularly effective for improving the systematic integration of biological maturation in German football academies, especially in regional settings.

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Youth football; implementation science; Behavior Change Wheel; bio banding; talent development

Introduction

The German Football Association (DFB) operates a multistage talent development program that identifies and nurtures promising young players through a nationwide network of 339 regional training centers and 56 elite youth academies. Promising players transition from regional training centers to elite youth football academies, which strategically nurture young talents for their first team or aim to generate revenue through player transfers (Balliauw et al., 2022; Reilly et al., 2004). Building on these foundational factors, TID and TD initiatives adopt a multidisciplinary approach, as they periodically assess and track predictor variables, such as technical, psychosocial and physical attributes (Towlson et al., 2018). However, these approaches often favor early maturing players, as stakeholders perceive them as superior across various selection criteria (Konarski et al., 2021; Lüdin et al., 2022; Towlson et al., 2019). In German football academies, however, the systematic integration of biological maturation remains limited. Recent surveys show that only about half of German academies regularly assess maturation status, with even fewer incorporating the results into frequent TID and TD decisions and lacking consistent method for evaluation (Arenas et al., 2023). Despite this well documented bias, stakeholders in European elite youth academies recognize the well documented influence of biological maturation on player characteristics (Arenas et al., 2023; Hill et al., 2021; Hill, Scott, Malina, et al., 2020; Hill, Scott, Mcgee, et al., 2020).

This recognition creates a critical opportunity: Talent development programs can acknowledge the highly individualized timing and rate of biological maturation to retain talented late-developing players and expand the selection pool from which senior football teams can draw (Patel et al., 2019). Without such acknowledgement, programs risk losing potential talent, as late- maturing players are often overlooked in favor of early-maturing peers (Konarski

CONTACT Lukas Arenas Arenas.lukas@gmx.de Institute of Sport and Preventive Medicine, Saarland University, Campus, Geb. B8 2, Saarbrücken 66123, Germany

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et al., 2021). Regular assessments enable the detection of periods of rapid growth, thereby recommending at least quarterly evaluations to support timely adjustments in training and development (Cumming et al., 2017).

To address this variability across multiple domains of player development, talent development programs can apply biological maturation status through a range of maturity-matching strategies, collectively known as bio-banding. Bio-Banding is a general concept whereby academies adjust strategies for individual differences in growth and maturation, whether in player performance and fitness evaluation, training adaptation, or the grouping of players for competition (Malina et al., 2019; Stănilă et al., 2020). In competition context, this approach promotes more equal playing conditions by reducing maturity-related variations in physical dimensions, body composition, and performance metrics (Towlson et al., 2023). Bio-banding can positively impact early- and late- maturing players, by fostering technical and tactical adjustments for on-pitch problem-solving and training load adaptation (Bradley et al., 2019; Lüdin et al., 2021; Towlson, Abt, et al., 2021; Towlson, MacMaster, et al., 2021). It creates a more developmentally informed assessment of players' abilities.

Moreover, a recent study on career trajectories in youth football reveals that early maturation does not guarantee professional success, as late maturing players are more likely to reach professional football, reinforcing the urgency to integrate maturation considerations into the DFB talent development program, particularly given its limited implementation (Aixa-Requena et al., 2025a, 2025b; Arenas et al., 2023; Salter et al., 2021). However, late developers remain proportionally under-represented upon entry into academies; consequently, absolute transition rates to senior professional football are still subject to the base-rate fallacy.

Beyond performance, considering maturation status safeguards adolescent players during periods of rapid growth and increased injury risk by adjusting training loads (Monasterio et al., 2024; Towlson, Salter, et al., 2021; Wik, 2022). Multidisciplinary approaches that incorporate maturity-based load modifications can reduce injury incidence and burden among youth football players (Johnson et al., 2023).

Despite these benefits, key stakeholders in youth football academies acknowledge the advantages of integrating individual biological maturation status into maturity-matching training formats and development processes, but operational challenges hinder widespread adoption. For instance, perceived barriers include limited access to resources and inconsistent evidence-based practices, as identified in surveys of English, German and Spanish elite academies (Aixa-Requena et al., 2025b; Arenas et al., 2023; Towlson et al., 2023). This lack of systematic integration underscores the gap between theoretical awareness and practical implementation within academy settings, making it essential to understand behavioral drivers and determine necessary shifts for a wider integration of biological maturation.

We therefore selected the Behavior Change Wheel (BCW) and its core COM-B model to systematically diagnose behavioral determinants and map targeted interventions (Michie et al., 2011; see Figure 1). Unlike other frameworks that focus mainly on organisational or environmental factors, COM-B explicitly examines capability, opportunity, and motivation at the individual practitioner level, factors that are central to the successful adoption of bio-banding in German academies (Michie et al., 2011).

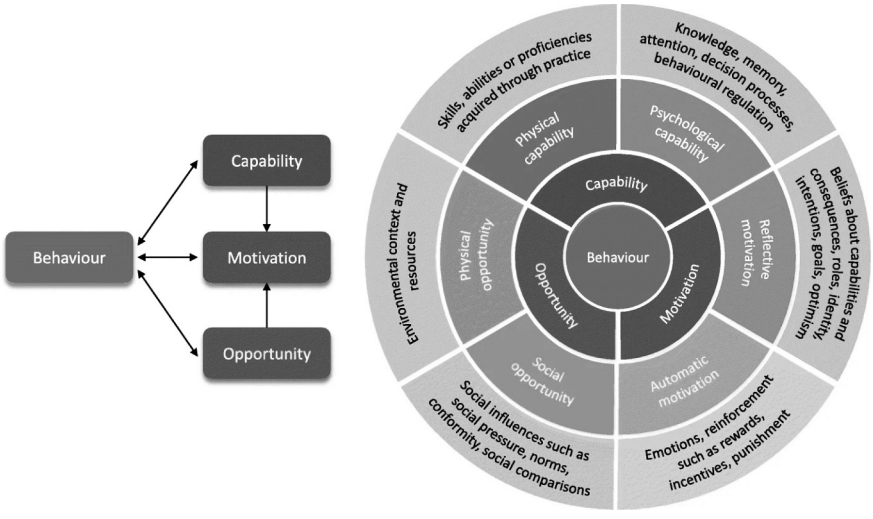

Figure 1. The COM-B model of behavior change (reprinted from Michie et al. (2011) and adapted as presented by McDonagh et al. (2018)).

According to the model, individuals require psychological and physical capabilities (e.g., knowledge and skills), social and physical opportunities (e.g., resources and support), and motivation (e.g., beliefs and incentives) to engage in behaviors like implementing biological maturation strategies (Michie et al., 2011). The COM-B framework enables the diagnosis of behavioral determinants, followed by mapping those to nine targeted interventions by identifying specific areas for improvement, such as education, persuasion, incentivization, coercion, training, restriction, environmental restructuring, modelling and enablement (Chater et al., 2023). Researchers have applied this approach in various contexts, such as barriers to evidence-based practices in healthcare (Gleadhill et al., 2022; Skoien et al., 2016), nutritional adherence in high-performance sports (Bentley et al., 2019) and coaches' perceptions of injury-prevention programs in youth sports (Hawkinson et al., 2022). By adapting a validated COM-B questionnaire that can be customized to specific objectives, contexts, and timeframes, we enhance its applicability to elite youth football (Huijg et al., 2014).

Following BCW guidance, we first specify the target behavior to ensure precise diagnosis: Academy stakeholders (e.g., coaches, medical/performance staff, scouts, and technical leadership) systematically assess and integrate biological maturation status into individual player development and talent identification decisions at least quarterly during performance reviews and pathway planning, in collaboration with multidisciplinary teams (Michie et al., 2014).

This study applies the COM-B model directly to the perspectives of key stakeholders within the DFB talent development program on barriers and enablers to implement biological maturation strategies. This investigation enables us to identify appropriate targets for behavior change interventions, which can be designed to enhance the consideration and integration of biological maturation in player development and talent identification processes. By focusing on the DFB talent development program, we highlight practical implications, such as tailored strategies to overcome resource limitations and foster evidence-based practices for long-term talent retention.

Material and methods

Study design

Researchers conducted a cross-sectional survey to investigate the barriers and enablers influencing the integration of biological maturation into player development processes within German football academies. The study utilized a structured questionnaire distributed between June and July 2025 to capture stakeholder perceptions across 56 elite academies and 344 regional training centers. This design enabled a comprehensive assessment of contextual factors, aligned with the COM-B model's Capability, Opportunity, and Motivation components, while accounting for regional and organizational variability. The survey employed a purposive sampling strategy to ensure representation from league-affiliated and regional settings, with data analyzed to identify actionable targets for behavior change interventions.

Participants

This study collected responses from 142 participants, including staff from league-affiliated elite academies (n = 81) and regional training centers (n = 61), with provisions for multiple submissions per academy or center to reflect varied internal perspectives. Among league-affiliated respondents, affiliations spanned the First League (n = 28, 35%), Second League (n = 34, 42%), Third League (n = 11, 14%), and Fourth League (n = 8, 10%). The sample was predominantly male (n = 136, 96%), with a small proportion of females (n = 6, 4%). Primary roles comprised Coach/Assistant Coach (n = 84, 59%), Medical and Performance Staff (n = 24, 17%), Technical & Strategic Leadership (n = 22, 15%), Analyst/Scout (n = 8, 6%), Support Staff (n = 2, 1%), and Other (n = 2, 1%). Detailed participant characteristics are presented in Table 1.

Survey development

We developed the survey following the BCW framework by Michie et al. (2014). First, we defined the problem by reviewing the literature on barriers to and facilitators of implementing biological maturation strategies, ensuring comprehensive coverage of all factors influencing behavior. Next, we created a cross-sectional survey based on the COM-B model to identify components required for wider biological maturation implementation within the DFB talent development program. To assess stakeholders' self-perceived requirements for behavior change, we adapted the validated self-evaluation COM-B questionnaire (COM-B-Qv1), which comprises statements across the COM-B domains that respondents rate to reveal insights into capability, opportunity and motivation gaps (Michie et al., 2011). This adaptation involved tailoring items to the German football context, such as incorporating DFB-specific terminology (e.g., references to regional training centers and elite academies) and bio-banding strategies relevant to youth player development, while preserving the original

Table 1. Demographic and professional characteristics of survey participants.

Variable	N	All participants (n (%))[1]	League Affiliation (n (%))[1]	Regional Association Affiliation (n (%))[1]
League Affiliation	81			
First league		28 (35%)	28 (35%)	0 (0%)
Second league		34 (42%)	34 (42%)	0 (0%)
Third league		11 (14%)	11 (14%)	0 (0%)
Fourth league		8 (10%)	8 (10%)	0 (0%)
Regional Association Affiliation	61			
DFB regional associations		61 (100%)	0 (0%)	61 (100%)
Gender	142			
Female		6 (4%)	6 (7%)	0 (0%)
Male		136 (96%)	75 (93%)	61 (100%)
Age Group	142			
≤30 years		45 (32%)	38 (47%)	7 (11%)
31–40 years		34 (24%)	21 (26%)	13 (21%)
41–50 years		24 (17%)	12 (15%)	12 (20%)
>60 years		39 (27%)	10 (12%)	29 (48%)
Professional Experience	142			
≤10 years		84 (59%)	55 (68%)	29 (48%)
10–15 years		29 (20%)	12 (15%)	17 (28%)
15–20 years		13 (9%)	5 (6%)	8 (13%)
>20 years		16 (11%)	9 (11%)	7 (11%)
Academic Degree	142			
No Academic Degree		51 (36%)	17 (21%)	34 (56%)
Bachelor/Master/Diplom		78 (55%)	56 (69%)	22 (36%)
Doctorate		3 (2%)	3 (4%)	0 (0%)
Other Degree		8 (6%)	4 (5%)	4 (7%)
Not Reported		2 (1%)	1 (1%)	1 (2%)
Trainer License	142			
No License		20 (14%)	20 (25%)	0 (0%)
DFB C		7 (5%)	6 (7%)	1 (2%)
DFB B		77 (54%)	32 (40%)	45 (74%)
DFB A		26 (18%)	12 (15%)	14 (23%)
DFB Fußballlehrer		10 (7%)	9 (11%)	1 (2%)
Other Licence		2 (1%)	2 (2%)	0 (0%)
Primary Role	142			
Technical & Strategic Leadership		22 (15%)	19 (23%)	3 (5%)
Coach/Assistant Coach		84 (59%)	26 (32%)	58 (95%)
Medical and Performance Staff		23 (16%)	23 (28%)	0 (0%)
Analyst/Scout		3 (2%)	3 (4%)	0 (0%)
Support Staff		8 (6%)	8 (10%)	0 (0%)
Other		2 (1%)	2 (2%)	0 (0%)

[1]n (%)

framework's structure and intent. The survey consisted of four sections, namely: (1) eligibility questions, (2) demographic data, (3) familiarity and consideration of biological maturation in football, (4) and the adopted COM-B-Qv1. We structured questions as either multiple-choice or Likert-scale items, with all scales being unipolar and featuring four to five labeled points (Krosnick & Presser, 2009; Norman, 2010). For the COM-B items, participants rated statements on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree), where higher scores indicate greater perceived need for improvement in that behavioral determinant. To enhance clarity and contextual relevance, we included a definition of biological maturation at the survey's outset, separated the COM-B items into distinct sections (Capability, Opportunity, and Motivation) for improved readability, and added an open-ended question at the end to capture additional stakeholder insights. For content validity, we pilot-tested the survey with an advisory group of five sports scientists from different European clubs, each with experience spanning several years in the assessment and implementation of biological maturation strategies. They provided individual feedback on the alignment of the survey with the study´s purpose, the content of the questions, and the overall structure. Their suggestions informed the adaptations noted above, leading to minor modifications in wording for precision and clarity. We then created a finalized German version of the survey and distributed it using an online survey tool (Soscisurvey). The survey had an estimated completion time of approximately 15 minutes and anonymity of the respondents was preserved to minimize the potential influence of social desirability bias. Internal consistency reliability of the adapted COM-B subcomponents was evaluated using Cronbach's alpha (psych package in R), yielding acceptable to good values for most subscales (psychological capability $\alpha = 0.83$; physical capability $\alpha = 0.74$; physical

opportunity α = 0.84; social opportunity α = 0.78; automatic motivation α = 0.81; reflective motivation α = 0.67). Ethical approval for this research was granted by the University of Saarbrucken Institutional Research Ethics Review Board (22–03). The complete questionnaire appears in the appendix (Supplemental Appendix 1).

Survey distribution

We conducted the study from June to July 2025, distributing the online survey to key stakeholders across all 56 elite male German football academies, the 29 regional coordinators of the 344 regional training centers, and their associated staff. We sourced 990 contacts, through personal networks and publicly accessible forms, contacting them four times via email. In total, 226 individuals responded to the survey, yielding an overall response rate of 24.8%. Of these, 142 participants completed the entire questionnaire, resulting in a complete response rate of 14.3% for the final analysis.

Statistical analysis

In this publication, we analyzed the survey responses by exporting Soscisurvey data into R-Studio (version 2022.07.0) Frequency analysis were conducted following established guidelines (Krosnick & Presser, 2009). Likert scale data were treated as ordinal and analyzed with non-parametric statistics (Norman, 2010). Means and 95% confidence intervals were calculated from COM-B components and subcomponents. Wilcoxon rank-sum tests were used to compare league-affiliated and regional association-affiliation groups, because the data were ordinal (5-point Likert scale). Effect sizes (r) were calculated from the Wilcoxon rank-sum tests and interpreted as small (0.10–0.29), medium (0.30–0.49), or large (≥0.50) to evaluate practical significance. All statistical analyses maintained a significant level of $p < 0.05$ and were performed using the packages tidyverse, gtsummary and gt.

Results

Training status, assessment frequency, familiarity and consideration of biological maturation

Table 2 presents participants' training status, assessment frequency, familiarity, and consideration of biological maturation. Overall, 46% of participants reported receiving training on biological maturation. Regarding assessment practices, 78% conduct biological maturation assessments, with annual assessments being the most common (27% overall). League-affiliated participants demonstrated higher assessment frequency, with 31% conducting quarterly assessments, compared to regional association-affiliated participants, who predominantly conducted annual assessments (51%). Familiarity with biological maturation was moderate overall (mean score: 3.62 ± 0.98), with league-affiliated participants reporting significantly higher familiarity (3.93 ± 0.91) than their regional associated counterparts (3.21 ± 0.93; $p < 0.001$, $r = 0.37$, medium effect). Specifically, 48% of league-affiliated participants rated themselves as 'quite familiar', compared to 30% of regional participants.

Participants assigned high priority to biological maturation, with 55% rating it as high priority or even essential (15%). This emphasis was more pronounced among league-affiliated participants (63%) compared to regional association-affiliated participants (44%). Low to moderate priority (mean score: 2.82 ± 0.70), was reported, whereby league-affiliated participants assigning significantly higher priority (3.02 ± 0.61) than regional affiliates (2.56 ± 0.72; $p < 0.001$, $r = 0.33$, medium effect). In terms of consideration, 24% of participants rarely or never considered biological maturation in player development, while 51% considered it occasionally, and 24% always considered it. Overall, consideration of biological maturation was moderate (mean score: 2.92 ± 0.85), with league-affiliated participants demonstrating significantly greater consideration (3.06 ± 0.93) than regional affiliates (2.72 ± 0.69; $p < 0.002$, $r = 0.25$, small effect).

Perceived barriers to considering biological maturation in player development

Table 3. presents participants barriers to integrating biological maturation in player development, including mean scores, 95% confidence intervals (CI) and results of the group comparison between league-affiliated and regional association participants. All Likert-scale items were rated from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating greater perceived barriers to implementation.

Overall, participants reported moderate barrier perception across domains (mean scores ranging from 2.94–3.38).

Capability

Participants reported moderate perceived barriers in the overall capability component (mean = 2.98 ± 1.29). Within this, the psychological capability subcomponent reported mean = 2.94 ± 1.32, with items focusing on

Table 2. Participants familiarity and consideration of biological maturation in football grouped by affiliation.

Variable	All participants (n (%))[1]	League Affiliation (n (%))[1]	Regional Association Affiliation (n (%))[1]
Training Participation Status			
Yes	66 (46%)	36 (44%)	30 (49%)
No	76 (54%)	45 (56%)	31 (51%)
Assessment Status			
Yes	111 (78%)	65 (80%)	46 (75%)
No	17 (12%)	10 (12%)	7 (11%)
Unsure	11 (8%)	4 (5%)	7 (11%)
Prefer not to say	3 (2%)	2 (2%)	1 (2%)
Assessment Frequency			
Monthly	12 (8%)	11 (14%)	1 (2%)
Quarterly	26 (18%)	25 (31%)	1 (2%)
Semi-annually	27 (19%)	14 (17%)	13 (21%)
Annually	38 (27%)	6 (7%)	32 (52%)
Unsure	10 (7%)	6 (7%)	4 (7%)
Prefer not to say	6 (4%)	4 (5%)	2 (3%)
No assessment	17 (12%)	9 (11%)	8 (13%)
Other	6 (4%)	6 (7%)	0 (0%)
Familiarity Level			
Not at all familiar	1 (1%)	0 (0%)	1 (2%)
Slightly familiar	21 (15%)	8 (10%)	13 (21%)
Somewhat familiar	36 (25%)	12 (15%)	24 (39%)
Quite familiar	57 (40%)	39 (48%)	18 (30%)
Very familiar	27 (19%)	22 (27%)	5 (8%)
Priority Level			
No priority	3 (2%)	0 (0%)	3 (5%)
Low priority	40 (28%)	14 (17%)	26 (43%)
High priority	78 (55%)	51 (63%)	27 (44%)
Essential	21 (15%)	16 (20%)	5 (8%)
Consideration Level			
Not considered at all	11 (8%)	8 (10%)	3 (5%)
Rarely considered	24 (17%)	8 (10%)	16 (26%)
Sometimes considered	73 (51%)	36 (44%)	37 (61%)
Almost always considered	34 (24%)	29 (36%)	5 (8%)

[1] n (%)

understanding, practical knowledge and reducing biases regarding biological maturation's relevance. League-affiliated participants reported significantly lower perceived barriers in psychological capability than regional association-affiliated counterparts ($p < 0.001$, $r = 0.13$), with significant differences in reducing biases regarding biological maturation's relevance ($p = 0.005$, $r = 0.23$). In contrast, the physical capability subcomponent reported mean = 3.05 ± 1.25, with items on technological barriers and maturation process understanding. A small group disparity emerged in maturation process understanding ($p = 0.046$, $r = 0.17$), with regional affiliates reporting higher perceived barriers than league-affiliated stakeholders. Overall, regional affiliates reported significantly higher capability barriers than league-affiliated counterparts (mean = 3.13 ± 1.35 vs. 2.78 ± 1.16 (2.78 ± 1.16 vs. 3.13 ± 1.35); $p < 0.001$, $r = 0.19$).

Opportunity

Participants reported moderate perceived barriers in the overall opportunity component (mean = 3.27 ± 1.27). Within this, the physical opportunity subcomponent reported mean = 3.38 ± 1.30, highlighting the need for access to better measurement tools and for incentives. Regional association-affiliated participants reported significantly higher barriers than league affiliates ($p < 0.001$, $r = 0.18$), with notable differences in tool access, incentives, and information availability ($p = 0.008$–0.017, $r = 0.20$–0.22). In contrast, the social opportunity subcomponent reported mean = 3.12 ± 1.22, with items on expert support and reminders, with higher barriers in regional affiliates ($p < 0.001$, $r = 0.19$).

Motivation

Participants reported moderate barriers in the overall motivation component (mean = 3.04 ± 1.26). Within this, the automatic motivation subcomponent reported mean = 3.04 ± 1.26, with a prominent need to automatically integrate biological maturation into player decision-making processes and to develop stronger awareness of its benefits and its necessity. Regional association affiliates reported higher barriers ($p < 0.001$, $r = 0.17$), especially in benefit awareness ($p < 0.001$, $r = 0.34$) and necessity ($p = 0.012$, $r = 0.21$) Likewise, the reflective motivation subcomponent mean = 3.04 ± 1.27, with key barriers in developing effective implementation strategies, and significant group differences ($p < 0.001$, $r = 0.22$).

Table 3. COM-B framework analysis: barriers to biological maturation in player development.

To consider the biological maturation of players in player development and talent identification, I would need to . . . [1]	Overall (N = 142) Mean (SD)	95% CI	League Affiliation (N = 81) Mean (SD)	95% CI	League Affiliation (N = 81) Mean (SD)	95% CI	p-value[2]	Effect Size (r; interpretation)
CAPABILITY								
1. Develop a better understanding of its significance, e.g., gain a more precise knowledge of why accounting for biological maturation is important for player development and talent promotion.	3.08 (1.41)	2.85–3.32	2.79 (1.46)	2.47–3.11	3.48 (1.26)	3.15–3.80	**0.005***	0.24 (small)
2. Acquire more practical knowledge for its implementation, e.g., learn how biological maturation can be reliably measured and interpreted.	3.32 (1.34)	3.10–3.55	3.15 (1.43)	2.83–3.46	3.56 (1.18)	3.26–3.86	0.114	0.13 (small)
3. Overcome technological barriers, e.g., improve my proficiency with software and other tools to efficiently assess and evaluate biological maturation.	3.16 (1.24)	2.96–3.37	3.17 (1.33)	2.88–3.47	3.15 (1.12)	2.86–3.44	0.786	0.02 (small)
4. Enhance my communication skills, e.g., adopt a clearer and more structured approach to effectively communicate information about biological maturation to club management, coaches, parents, players, and other relevant stakeholders.	3.06 (1.20)	2.86–3.26	2.91 (1.24)	2.64–3.19	3.26 (1.12)	2.97–3.55	0.088	0.14 (small)
5. Gain a deeper understanding of the biological development process, e.g., to make maturity-specific adjustments in training and competition and adapt player evaluations accordingly.	3.15 (1.24)	2.94–3.35	2.96 (1.28)	2.68–3.25	3.39 (1.16)	3.10–3.69	**0.046***	0.17 (small)
6. Build greater confidence in my assessment competence, e.g., become more assured in contextualizing biological maturity within a TID and TD context.	2.85 (1.21)	2.65–3.05	2.77 (1.25)	2.49–3.04	2.97 (1.17)	2.67–3.27	0.329	0.08 (small)
7. Address methodological limitations, e.g., be able to utilize alternative methods when direct measurement techniques are unavailable.	3.23 (1.22)	3.03–3.43	3.20 (1.28)	2.91–3.48	3.28 (1.14)	2.99–3.57	0.780	0.02 (small)
8. Reduce my biases regarding biological maturation, e.g., reflect on and diminish doubts about its relevance.	2.15 (1.20)	1.96–2.35	1.95 (1.21)	1.68–2.22	2.43 (1.13)	2.14–2.72	**0.005***	0.23 (small)
9. Strengthen my organizational skills, e.g., develop efficient processes to ensure the regular collection and integration of biological maturation data, even under time constraints.	2.67 (1.24)	2.46–2.88	2.59 (1.24)	2.32–2.87	2.77 (1.24)	2.45–3.09	0.400	0.07 (small)
10. Cultivate greater perseverance in its long-term implementation, e.g., consistently integrate biological maturation data into workflows and decision-making processes despite initial challenges.	3.15 (1.24)	2.94–3.35	3.16 (1.34)	2.86–3.46	3.13 (1.10)	2.85–3.41	0.614	0.04 (small)
Mean score: *Psychological capability component (statements 1, 2, 4, 6, 8, 10)*	2.94 (1.32)	2.85–3.03	2.79 (1.38)	2.67–2.91	3.14 (1.21)	3.01–3.26	**<0.001***	0.13 (small)
Mean score: *Physical capability component (statements 3, 5, 7, 9)*	3.05 (1.25)	2.95–3.16	2.98 (1.30)	2.84–3.12	3.15 (1.18)	3.00–3.30	0.141	0.06 (small)
OPPORTUNITY								
11. Have more time for it, e.g., through designated time slots.	3.37 (1.26)	3.16–3.58	3.26 (1.39)	2.95–3.57	3.52 (1.04)	3.26–3.79	0.377	0.07 (small)
12. Receive greater incentives from the Academy/DFB regional training center to encourage its implementation.	3.29 (1.33)	3.07–3.51	3.04 (1.43)	2.72–3.35	3.62 (1.11)	3.34–3.91	**0.017***	0.20 (small)
13. Gain access to better measurement tools or technologies to assess biological maturation more accurately.	3.65 (1.34)	3.43–3.87	3.37 (1.47)	3.05–3.70	4.02 (1.04)	3.75–4.28	**0.014***	0.21 (small)
14. Have easier access to relevant information and resources, e.g., through guidelines or informational materials.	3.23 (1.26)	3.02–3.43	2.98 (1.34)	2.68–3.27	3.56 (1.06)	3.29–3.83	**0.008***	0.22 (small)
15. Be supported by experts in my environment, e.g., be part of a group that already systematically implement it.	3.38 (1.25)	3.17–3.59	3.19 (1.37)	2.88–3.49	3.64 (1.03)	3.37–3.90	0.061	0.16 (small)
16. Be reminded more frequently to implement it, e.g., through automated notifications or scheduled follow-up discussions integrated into daily routine.	2.69 (1.11)	2.51–2.87	2.42 (1.13)	2.17–2.67	3.05 (0.97)	2.80–3.30	**<0.001***	0.28 (small)
17. Receive more support from colleagues, coaches, or other professionals, e.g., through active assistance from the team or management.	3.29 (1.19)	3.09–3.49	3.12 (1.29)	2.84–3.41	3.51 (1.01)	3.25–3.77	0.091	0.14 (small)
Mean score: *Physical opportunity component (statements 11, 12, 13, 14)*	3.38 (1.30)	3.28–3.49	3.16 (1.41)	3.01–3.31	3.68 (1.08)	3.54–3.82	**<0.001***	0.17 (small)
Mean score: *Social opportunity component (statements 15, 16, 17)*	3.12 (1.22)	3.00–3.24	2.91 (1.31)	2.74–3.07	3.40 (1.03)	3.25–3.55	**<0.001***	0.19 (small)

(*Continued*)

Table 3. (Continued).

To consider the biological maturation of players in player development and talent identification, I would need to . . . [1]	Overall (N = 142) Mean (SD)	95% CI	League Affiliation (N = 81) Mean (SD)	95% CI	League Affiliation (N = 81) Mean (SD)	95% CI	p-value[2]	Effect Size (r; interpretation)
MOTIVATION								
18. Feel that I really want to do it, e.g., perceive a greater necessity or satisfaction in considering biological maturation.	2.79 (1.24)	2.58–2.99	2.56 (1.25)	2.28–2.83	3.10 (1.16)	2.80–3.40	**0.012***	0.21 (small)
19. Experience a stronger desire to want to do it, e.g., become more aware of the negative consequences of not incorporating biological maturation.	2.78 (1.22)	2.58–2.98	2.60 (1.28)	2.32–2.89	3.02 (1.09)	2.74–3.29	0.052	0.16 (small)
20. Be more firmly convinced of its importance, e.g., develop a stronger awareness of its benefits and necessity.	2.63 (1.30)	2.42–2.85	2.26 (1.26)	1.98–2.54	3.13 (1.19)	2.83–3.44	**<0.001***	0.34 (medium)
21. Develop more effective implementation strategies, e.g., create a structured plan to regularly assess and account for biological maturation.	3.44 (1.11)	3.25–3.62	3.31 (1.27)	3.03–3.59	3.61 (0.82)	3.40–3.82	0.332	0.08 (small)
22. Make it a habit, e.g., automatically integrate the biological maturity of players into decision-making processes without needing to consciously consider it.	3.54 (1.18)	3.35–3.74	3.36 (1.37)	3.05–3.66	3.79 (0.80)	3.58–3.99	0.213	0.10 (small)
Mean score: *Automatic motivation component (statements 18, 19, 22)*	3.04 (1.26)	2.92–3.16	2.84 (1.35)	2.67–3.01	3.30 (1.08)	3.14–3.46	**<0.001***	0.17 (small)
Mean score: *Reflective motivation component (statements 20, 21)*	3.04 (1.27)	2.89–3.18	2.78 (1.37)	2.57–3.00	3.37 (1.05)	3.18–3.56	**<0.001***	0.22 (small)

[1]*Participants responded on a scale of 1 (strongly disagree) to 5 (strongly agree).
[2]*$p < 0.05$.

Discussion

This study investigated barriers and enablers to integrating biological maturation in German football academies using the COM-B framework, with 142 stakeholders from league-affiliated (n = 81) and regional (n = 61) settings contributing complete responses. Key results revealed 78% assessment rates but only 46% specialized training, with moderate familiarity (mean 3.62) and consideration (mean 2.92), whereby both significantly lower in regional affiliates. COM-B analysis revealed moderate barriers across domains, with physical opportunity the highest (mean 3.38), driven by needs for better tools and incentives. Regional-affiliated participants reported higher barriers in all subcomponents ($p < 0.05$, small to medium effects), highlighting systemic disparities.

This methodology adheres to established protocols for employing the BCW to identify implementation challenges and design targeted interventions. Compared to a prior German survey where only half of respondents conducted biological maturation assessments (Arenas et al., 2023), the current findings indicate increased assessment and consideration of biological maturation. This progress contrasts with more advanced integration in English academies under the Elite Player Performance Plan (EPPP), where maturation data is mandatorily collected and centrally stored to mitigate maturation biases (Cumming et al., 2017; Towlson et al., 2023). However, surveys from Germany, Spain, and England highlight high variability in methods and frequency, with a tendency toward non-invasive somatic equations such as predicted adult height or maturity offset. Over half (54%) of participants reported a lack of systematic training in biological maturation, indicating a gap in the capability-building aspect of the COM-B model, which likely amplifies barriers to its widespread adoption.

League-affiliated participants reported significant greater familiarity and consideration compared to regional affiliates, highlighting disparities in capability and opportunity aspects of the COM-B model. This variability by academy type echoes findings from European surveys, where barriers to biological maturation implementation are lower in first-tier academies due to better resources and staffing, but higher in lower-tier settings (Towlson et al., 2023), highlighting a systematic disparity across European clubs that underscores the need for focused interventions such as educational programs for lower-tier academies and grassroots clubs.

Broader survey outcomes, informed by the COM-B framework, revealed moderate barriers across capability (psychological; physical), opportunity (physical; social), and motivation (automatic; reflective). Although these group differences were statistically significant, the effect sizes remained generally small, suggesting modest practical impact and the need for larger-scale validation to guide further interventions in systems like the DFB. Nevertheless, these group differences highlight the importance of addressing specific disparities, as regional participants reporting systematicallyhigher barriers than league-affiliated participants across all COM-B subcomponents. This consistent pattern underscores the need for targeted interventions to bridge these gaps and support more equitable and widespread integration of biological maturation within the DFB talent development system.

This study represents, to our knowledge, the first application of the COM-B model and Behaviour Change Wheel framework to systematically diagnose barriers and enablers to the integration of biological maturation assessment and consideration in German football academies. By doing so, the present work provides a theoretically grounded pathway from diagnosis to prioritised, context-specific recommendations.

To drive behavioral change, we mapped our findings to intervention functions. This mapping suggests guided interventions that could aim at enhancing adherence and supporting the implementation of biological maturation-based strategies. In line with BCW guidelines, we identified seven intervention functions: education, modelling, persuasion, incentivization, training, environmental restructuring, and enablement. We prioritized these functions using the APEASE framework (Affordability, Practicability, Effectiveness, Acceptability, Side-effects, Equity) to ensure real-world applicability through a targeted hierarchy that tackles the most pressing barriers while accounting for operational restrictions (McQuinn et al., 2022; Michie et al., 2014). This mapping translates these functions into actionable steps that academies and regional training centers can implement as tailored recommendations based on current evidence. Based on carryover effects and cost efficiency, we propose prioritizing enablement and training intervention functions, which could emphasize workshops and skill-building sessions to improve capability, particularly in anthropometric assessment techniques and interpretation of maturation data.

We recommend environmental restructuring as the next priority to address physical opportunity barriers, focusing on enhancing access to measurement tools and streamlining assessment processes to alleviate practitioners' time constraints. Furthermore, persuasion, modelling, and incentivisation could target automatic motivation, with strategies including targeted campaigns to increase awareness of the benefits of implementing biological maturation. Modelling could involve case studies of successful academies,

while incentivisation might include DFB funding grants for academies achieving regular assessments, encouraging implementation despite physical opportunity. For instance, rewarding centres that implement biological maturation could motivate stakeholders to address methodological challenges, such as adopting efficient anthropometric protocols during periods of rapid growth. This approach could foster habitual integration of biological maturation strategies into routine decision-making processes for analysing and developing youth players.

To enhance practicality, sports organizations can adopt the following COM-B-structured recommendations for implementing biological maturation strategies, informed by BCW applications in sports and biological maturation research. These prioritize evidence-based, user-centered strategies to overcome identified barriers.

Capability (Psychological and Physical): Enhance stakeholders' knowledge and skills to interpret maturation data effectively.

- Deliver mandatory workshops on biological maturation assessment methods, drawing from validated protocols in youth football. These workshops should incorporate bias-reduction modules to challenge perceptions favouring early maturers.
- Provide hands-on training with accessible tools for anthropometric measurements and biological maturation assessment, prioritizing non-invasive methods like percentage of predicted adult height, which require less expertise than skeletal age assessments.

Opportunity (Physical and Social): Address resource limitations and support networks for effective implementation.

- Invest in centralized digital platforms for growth and maturation tracking, reducing time constraints and improving accessibility to relevant information.
- Establish peer networks where league-affiliated experts mentor support staff from regional training centers and incentivize collaboration through joint seminars to promote collective buy-in.

Motivation (Automatic and Reflective): Increase perceived necessity and desire for sustained adoption.

- Launch awareness campaigns highlighting long-term benefits, such as reduced injury rates, using insights from case studies of bio-banding competitions and their effects on early and late maturers.
- Promote biological maturation status checks into routine workflows for player evaluations and player development purposes.

While these recommendations provide a framework for addressing identified barriers, researchers must acknowledge limitations. The 142 responses, while robust, may reflect a selection bias toward capturing perspectives of practitioners already engaged in biological maturation assessments, thereby potentially overrepresenting favourable attitudes toward its implementation and underestimating broader barriers in the German talent development system. Limited representation from lower divisions and regional associations may skew results, portraying a more positive picture of integration. Moreover, the low complete response rate (14.3%) could limit generalizability, as non-respondents might hold different views. The underrepresentation of analysts and scouts may limit perspectives on talent identification and development, a known bias in player evaluation. Consequently, the small effect sizes observed suggest further validation through additional research to confirm the practical significance of these disparities and to better inform the design of effective behavior change strategies. Moreover, self-reported data could be influenced by social desirability bias, potentially skewing the reported perceptions of barriers and enablers. To address these limitations, future research should adopt longitudinal designs to monitor integration of biological maturation over time, conduct randomized controlled trials to assess the efficacy of interventions across diverse football ecosystems, and incorporate objective metrics (e.g., academy performance data) to validate self-reports. Building on this, mixed-methods approaches could combine surveys with qualitative interviews to uncover nuanced stakeholder experiences, while international comparisons might assess how cultural or systemic factors influence adoption in other national programs. These steps will strengthen the evidence base for implementing biological maturation strategies in the German talent development system.

Conclusion

While the adoption of biological maturation assessments is increasing within German elite football academies, a significant gap remains in the systematic implementation across all talent development levels, particularly within regional associations. Our behavioral analysis reveals that the primary obstacles are not a lack of interest, but rather a deficit in access to efficient measurement tools and a lack of specialized training among staff.

To bridge this gap, organizations should prioritize practical applications such as the implementation of mandatory, bias-reduction workshops and the adoption of non-invasive somatic assessment methods, like percentage of predicted adult height, which require less specialized expertise. Furthermore, investing in centralized digital platforms to track growth and establishing peer-mentorship networks between elite academies and regional centers will alleviate resource constraints and foster a more equitable development environment.

In conclusion, shifting the focus from mere theoretical awareness to habit-based integration is essential. By addressing structural barriers through targeted environmental restructuring and skill-building, the German talent development system can move beyond selection biases toward a truly individualized and developmentally informed pathway for every young player.

Author contributions

CRediT: **Lukas Arenas:** Conceptualization, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing; **Sabrina Forster:** Supervision; **Tim Meyer:** Supervision; **Jamie Salter:** Supervision, Writing – review & editing; **Monika Frenger:** Supervision, Writing – review & editing.

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ORCID

Lukas Arenas http://orcid.org/0009-0006-5995-0619

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