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Effect of bio-banding on physiological and technical-tactical key performance indicators in youth elite soccer

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ABSTRACT

Bio-banding has been introduced to reduce the impact of inter-individual differences due to biological maturation among youth athletes. Existing studies in youth soccer have generally examined the pilot-testing application of bio-banding. This is the first study that investigated whether bio-banded (BB) versus chronological age (CA) competition affects reliable physiological and technical-tactical in-game key performance indicators (KPIs) using a randomized cross-over repeated measures design. Sixty-five youth elite soccer players from the under-13 (U_{13}) and under-14 (U_{14}) age category and with maturity offsets (MO) between −2.5 and 0.5 years, competed in both a BB and CA game. For statistical analysis, players were divided into four sub-groups according to CA and MO: $U_{13}MO_{low}$ ($CA \leq 12.7$, $MO \leq -1.4$), $U_{13}MO_{high}$ ($CA \leq 12.7$, $MO > -1.4$), $U_{14}MO_{low}$ ($CA > 12.7$, $MO \leq -1.4$), $U_{14}MO_{high}$ ($CA > 12.7$, $MO > -1.4$). The two-factor mixed ANOVA revealed significant ($p < .05$) interactions between competition format and sub-group for the KPIs high accelerations ($\eta_p^2 = .176$), conquered balls ($\eta_p^2 = .227$) and attack balls ($\eta_p^2 = .146$). Especially, $U_{13}MO_{high}$ (i.e. early maturing players) faced a higher physiological challenge by having more high accelerations ($|d| = 0.6$) in BB games. Notably, $U_{14}MO_{low}$ (i.e. late maturing players) had more opportunities to show their technical-tactical abilities during BB games with more conquered balls ($|d| = 1.1$) and attack balls ($|d| = 1.6$). Affected KPIs indicate new challenges and learning opportunities during BB competition depending on a player's individual maturity status. Bio-banding can beneficially be applied to enhance the talent development of youth elite soccer players.

KEYWORDS

Talent development; talent identification; maturation; relative age; football

Introduction

Successful talent development and identification are of utmost importance for sports federations and clubs (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). In the context of high-performance soccer, the systematic development and promotion of promising athletes is the foundation for financial sustainability and success for many elite soccer clubs (Ford et al., 2020; Williams & Reilly, 2000). It is, therefore, necessary to have an effective process of talent development and identification in place, if youth athlete potential is to successfully transfer into the elite level. However, this process appears challenging as maturity-related individual differences affect a youth's performance and evaluation of their potential (Guellich & Cobley, 2017; Unnithan, White, Georgiou, Iga, & Drust, 2012).

Young athletes are commonly grouped into Chronological Age (CA) groups based on their age relative to cut-off dates. Annual-age categories, predominantly used in youth sport (including soccer), are meant to help provide a more appropriate developmentally matched environment for participation, promoting equal opportunity and fair competition (Musch & Grondin, 2001). Young athletes pursue sports to progress and in turn expect a fair and supportive environment (Vaeyens et al., 2008). However, the CA of players can still differ by up to one year within the same CA category. Thus, on average, relatively older players born earlier in a CA group are more advanced in their physical and cognitive development compared to their relatively younger counterparts born at the end of the same CA group (Musch & Grondin, 2001). These CA related differences manifest in terms of Relative Age Effects (RAEs), where an overrepresentation of relatively older players is apparent across youth sport and athlete development programmes (Cobley, Baker, Wattie, & McKenna, 2009; Smith, Weir, Till, Romann, & Cobley, 2018). Further, large inter-individual variations in the process of

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maturation around the age of puberty (i.e. 11–16 years) can both substantiate CA difference, or mitigate against them depending on the individuals maturity (Malina, Bouchard, & Bar-Or, 2004). Earlier maturing athletes exhibit anthropometric and physiological advantages, which provide performance advantages within respective CA categories. For instance, earlier maturing players show superior physical strength (Lefevre, Beunen, Steens, Claessens, & Renson, 1990; Till, Cobley S, Cooke, & Chapman, 2014), speed (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004), agility (Towlson, Cobley, Parkin, & Lovell, 2018) and aerobic capabilities (Malina, Beunen, Lefevre, & Woynarowska, 1997; Towlson et al., 2018) compared to CA group matched later maturing peers. Thus, if talent identification and development programmes do not carefully consider these inter-individual developmental differences within organized CA groups, they are likely vulnerable to overlooking and excluding late maturing, but potentially talented players (Unnithan et al., 2012).

To address the problem of developmental differences within talent identification and development, research has identified several approaches, for example adopting a broad longitudinal and multi-dimensional perspective on athlete development (Sarmento, Anguera, Pereira, & Araujo, 2018; Vaeyens et al., 2008) as well as delaying selection and differentiation until beyond maturation (Cobley, Till, O'Hara, Cooke, & Chapman, 2014).

In this line of reasoning, bio-banding has been introduced in order to account for maturity-associated variation (Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017). The aim of bio-banding is to reduce the impact of inter-individual maturational differences by helping both late and early-maturing youth to potentially participate and compete on a more developmentally matched basis (Malina et al., 2019). This is achieved via the process of banding youth athletes according to other maturity-related characteristics than just CA.

Existing studies in youth soccer have generally examined pilot-testing application and effects of bio-banding from a predominantly qualitative perspective (Bradley et al., 2019; Cumming et al., 2018; Reeves, Enright, Dowling, & Roberts, 2018; Towlson et al., 2020). Reflecting across these studies, player interviews of those who experienced a bio-banded (BB) soccer tournament provided positive evaluative assessments. Early maturing players perceived bio-banding as providing more of a physical challenge, indicating they had to adapt their game toward greater technical and tactical skill use. Late maturing players highlighted they had more opportunities to use their technical, physical and psychological competencies, due to less physiological demands.

To date, only pilot data on the quantitative evaluation of bio-banding in soccer are available. Over a small, hence practically applicable age range (12–14 years) the effect of bio-banding on the overall game play indicated a reduced physical demand while the number of duels and set-piece situations increased compared to the traditional CA competition format. Ball possession analysis revealed a more equal game between the teams with a quicker change of match play situations when playing with BB teams (Romann, Lüdin, & Born, 2020). It is assumed that these results can be explained through a higher involvement of late maturing players in the BB competition format. A preliminary analysis of the effects of a BB competition format on the physical and technical performance of youth elite soccer players dependent on their maturity status showed that early maturing players had a higher rate of perceived exertion (RPE), more short passes and less dribbles during bio-banding, whereas late maturing players had more tackles and less long passes (Abbott, Williams, Brickley, & Smeeton, 2019). But not only late or early maturing players adapt their game play: Average maturing players had more short passes, less long passes and dribbled more often in BB games. Unfortunately, these two existing studies did not consistently analysed Key Performance Indicators (KPIs) – referring to players' physiological and technical-tactical in-game conditioning relevant to talent development. Further, neither study provided reliability assessments for their technical-tactical indices applies.

Given the broader research and practical need to improve the efficacy and effectiveness of talent development and identification processes, and the more specific need to address the influence of inter-individual maturational associated developmental differences within youth sport competition and athlete evaluation, the present study had two main purposes. Firstly, using a randomized cross-over repeated measures design, the present study aimed to examine bio-banding effects relative to normative (CA group based) youth soccer competition more extensively and reliably by assessing multiple physiological, as well as technical-tactical player's in-game KPIs in a sample of elite Swiss youth soccer players. The second purpose was to provide practitioners and talent development systems alike with information about how and when bio-banding could be effectively applied based on a player's individual developmental need. We considered that such a study would help provide a more substantive quantitative evaluation of BB games, as well as help anticipate the impact upon individual talent development.

Methods

Participants

The study was conducted in accordance with the guidelines of the Declaration of Helsinki. Following institutional ethical approval (Swiss Federal Institute of Sport; Nr. 2019/079), eighty-one youth elite soccer players between 11.7 and 13.7 years of age from either the Under-13 (U_{13}) or the Under-14 (U_{14}) age category who played at one of four Swiss elite youth soccer clubs participated. Clubs were part of the national youth development programme of the Swiss Football Association. The programme promotes the "Top 2000" U_{13} and "Top 1300" U_{14} players respectively (Knäbel, 2020). At the time of participation, players had been officially licensed at a soccer club for 4.2 ± 0.7 years. All Goalkeepers and eight injured players at the time of data-collection were excluded, resulting in sixty-five players being taken forward for data-analysis.

Study design

A randomized cross-over repeated measures design was applied. Each participant played two games of 9v9 on a natural grass pitch (56 × 67 m). The 9v9 game is the traditional format in Switzerland for the U_{13} and U_{14} age-groups (Bruggmann & Moulin, 2020). A game consisted of two 35-minutes halves separated by 10 min for half-time. One game was played adhering to a BB competition format and the other adhering to the CA competition format. Games were played on two match days separated by one week. Each match day, two clubs with their respective two teams each played their games against each other. To control for familiarization effects, the first pair of clubs played their first game under the CA format, while the second club pair played their first games in the BB format. Playing positions were fixed and matched across games for each player to ensure paired comparisons.

Maturity assessment

Maturity was assessed by anthropometric measurements using the equation for predicting maturity offset (MO) (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). MO is defined as years between the age at the point in time of the measurement and the predicted age at peak height velocity. The equation required body weight, standing height and sitting height, which were measured using a body scale (Seca 876, Seca, Hamburg, Germany) and a stadiometer (Seca 217, Seca, Hamburg, Germany). The measurements were standardized, and measured according to protocol by the same trained sport scientist two weeks prior to the first games. Although some limitations of the method exist, it is known to be especially accurate the closer subjects are estimated to their MO (Malina & Koziel, 2014). The participating soccer players between 11.7 and 13.7 years of age in this study are very close to the most accurate time in point for the application of the equation.

Bio-banding procedure

The bio-banding procedure was based on the players MO. Players with an individual MO lower than the MO median were assigned to the lower bio-band (MO_{low}). Players with an individual MO higher than the MO median were assigned to the higher bio-band (MO_{high}). Players in the MO_{low} had an individual MO ≤ -1.4 years. Players in the MO_{high} had an individual MO > −1.4 years. The clubs played the BB games with their players categorized based on the MO (i.e. MO_{low} and MO_{high}). For the CA games, the players were grouped according to their CA (U_{13}; CA ≤ 12.7 and U_{14}; CA > 12.7). For the statistical analysis, players were divided into four sub-groups, taking into account CA and MO: U_{13} aged players in the lower bio-band ($U_{13}MO_{low}$), U_{13} aged players in the higher bio-band ($U_{13}MO_{high}$), U_{14} aged players in the lower bio-band ($U_{14}MO_{low}$) and U_{14} aged players in the higher bio-band ($U_{14}MO_{high}$). Descriptive statistics on maturity-related characteristics for the four sub-groups are summarized in Table 1.

Key performance indicators (KPIs)

Table 2 provides a summary list and definitions of KPIs. The list of KPIs was identified based on a combination of previous bio-banding studies (Abbott et al., 2019;

Table 1. Descriptive maturity-related participants' characteristics for the four sub-groups.

	Sub-group			
	$U_{13}MO_{low}$ (*n* = 20)	$U_{13}MO_{high}$ (*n* = 12)	$U_{14}MO_{low}$ (*n* = 11)	$U_{14}MO_{high}$ (*n* = 22)
Variable				
Chronological age [yr]	12.2 ± 0.2	12.4 ± 0.2	13.0 ± 0.2	13.3 ± 0.3
Maturity offset [yr]	−1.9 ± 0.3	−1.1 ± 0.2	−1.7 ± 0.3	−0.9 ± 0.4
Stature [cm]	147.9 ± 3.7	158.1 ± 5.5	147.4 ± 3.6	157.4 ± 6.9
Sitting height [cm]	76.3 ± 2.4	81.6 ± 1.7	75.3 ± 2.1	80.5 ± 3.4
Body mass [kg]	38.7 ± 4.5	45.9 ± 4.2	37.3 ± 3.0	44.4 ± 6.3

Notes: Values are Mean ± Standard Deviation. $U_{13}MO_{low}$ = Under-13 players in the lower bio-band; $U_{13}MO_{high}$ = Under-13 players in the higher bio-band; $U_{14}MO_{low}$ = Under-14 players in the lower bio-band; $U_{14}MO_{high}$ = Under-14 players in the higher bio-band.

Table 2. Definition and description of KPIs.

KPIs	Description
Physiological KPIs	
Total distance [m]	Total distance covered
High-speed running [m]	Distance covered ≥15.8 km·h^{-1}
High accelerations [n]	Number of accelerations ≥2.4 m·s^{-2}
Technical-Tactical KPIs	
Conquered balls [n] (ICC = .805)	Intercepting a pass from an opponent or Stealing the ball form an opponent or Causing a missed pass from an opponent
Attack balls [n] (ICC = .789)	Passing the ball to a teammate in direction of the opponent's goal or Taking the ball to a free space in direction of the opponent's goal or Protecting the ball in a small space or Taking the ball past an opponent or Shooting the ball on the opponent's goal
Neutral balls [n] (ICC = .598)	Passing the ball to a teammate across or in direction of the own goal or Taking the ball across or in direction of the own goal
Lost balls [n] (ICC = .859)	Losing the ball without having scored a goal (shots on the opponent's goal excluded)
Volume of play on the ball [n] (ICC = .713)	Receiving the ball from a teammate or Intercepting a pass from an opponent or Stealing the ball from an opponent
Volume of play off the ball [n] (ICC = .551)	Putting the opponent under pressure
Efficiency on the ball [%]	Share of conquered and attack balls on the total number of conquered, attack, neutral and lost balls

Notes: KPIs = Key Performance Indicators; ICC = Intra-class correlation coefficient.

Bradley et al., 2019; Cumming et al., 2018; Romann et al., 2020; Towlson et al., 2020) and a group of soccer experts with 24.3 ± 9.5 years of experience in Swiss youth elite soccer. KPIs were divided into *Physiological* and *Technical-Tactical* KPI types.

In-game player positional data were measured using a Local Position Measurement system (LPM; inmotiotec GmBH, Regau, Austria) with 24 Hz (Frencken, Lemmink, & Delleman, 2010; Stevens et al., 2014). Using the LPM, the following physiological indicators were determined: Total distance covered, High-speed running (≥15.8 km·h^{-1}) distance covered, and the Number of high accelerations (≥2.4 m·s^{-2}). Commonly applied speed zones and thresholds for acceleration were used and adjusted for age (Bradley et al., 2009; Harley et al., 2010). Due to the failure of the connection of transponders to the base station during the matches, data from 12 players could not be integrated into the data set.

For technical-tactical KPIs, all player data were derived from game video-recording and coded based on the Team Sports Assessment Procedure (TSAP) (Gréhaigne, Godbout, & Bouthier, 1997). Each game was filmed using two mounted video cameras placed on the side line of each pitch half, guaranteeing full area and match play coverage. The game recording was oriented toward ball-following without zoom. These recordings were used to manually code all technical-tactical KPIs by one of three experts using an iPad with the application Dartfish Note (Dartfish, Fribourg, Switzerland). Intra-class correlation coefficient (ICC) analysis identified good (.75 ≤ ICC < .90) to excellent (ICC ≥ .90) intra-rater reliability of the three experts (two-way mixed effects, absolute agreement, single measurement) (Koo & Li, 2016): .825, .902, and .900, respectively. Inter-rater reliability of the collection of technical-tactical indicators was moderate (.50 ≤ ICC < .75) to good (.75 ≤ ICC < .90) (two-way mixed effects, absolute agreement, single rater) (Koo & Li, 2016).

Statistical analysis

The collected KPIs were checked for homogeneity of the error variances and the covariances using Levene's test ($p > .05$) and Box's test ($p > .05$), respectively. For all KPIs except "attack balls", there were homogeneity of the error variance and covariances, respectively. The assumption of homogeneity of the error variances and covariances was met after the KPI "attack balls" was box–cox transformed (Box & Cox, 1964). KPIs were analysed using two-factor mixed analysis of variance (ANOVA). Competition format (BB, CA) served as within-subject factor and sub-group ($U_{13}MO_{low}$, $U_{13}MO_{high}$, $U_{14}MO_{low}$, $U_{14}MO_{high}$) as the between-subjects factor. Partial eta squared (η_p^2) were calculated to analyse the effect size (ES) of the interactions. η_p^2 was regarded as a trivial ($\eta_p^2 < .01$), small ($.01 \le \eta_p^2 < .06$), medium ($.06 \le \eta_p^2 < .14$) or large ($\eta_p^2 \ge .14$) ES (Cohen, 1988). Bonferroni post-hoc tests for pairwise comparisons within competition formats. Statistical significant α-level was set at a p-value < .05. Additionally, to support the interpretations of detected interactions, mean ± standard deviation for sub-groups separated by competition format, as well as Cohen's d ES and corresponding 95% confidence intervals for the differences between the competition formats within each sub-group were calculated. Cohen's d was regarded as a trivial ($|d| < 0.2$), small ($0.2 \le |d| < 0.5$), medium ($0.5 \le |d| < 0.8$) or large ($|d| \ge 0.8$) ES (Cohen, 1988). Main effects for sub-group were excluded from statistical analysis as they were not subject to the purpose of the study. Statistical calculations were conducted using a statistic software (IBM SPSS Statistics, Version 25.0, Armonk, NY, United States).

Results

No significant main effects were identified for the competition format. A summary of the results of the interactions between competition format and sub-group of the two-factor mixed ANOVA on Key Performance Indicators (KPIs) are presented in Table 3. Mean ± standard deviation for the sub-groups depending on the competition format, as well as Cohen's *d* ES and corresponding 95% confidence intervals for the differences between the competition formats within each sub-group are presented in Table 4.

Physiological KPIs

The two-factor mixed ANOVA revealed a statistically significant interaction between competition format and sub-group for high accelerations ($F_{(3,49)} = 3.495$, $p = .022$, $\eta_p^2 = .176$). Pairwise post-hoc tests showed significantly more high accelerations for $U_{14}MO_{high}$ compared to $U_{13}MO_{high}$ only in the CA competition format ($p = .016$). Cohen's *d* ES indicated a higher number of high accelerations for $U_{13}MO_{high}$ during BB games with a medium ES ($|d| = 0.6$). Other sub-groups showed a lower number of high accelerations with small or medium ES during BB games compared to the CA competition format ($U_{13}MO_{low}$: $|d| = 0.4$, $U_{14}MO_{low}$: $|d| = 0.6$, $U_{14}MO_{high}$: $|d| = 0.5$). No significant interactions between competition format and sub-group for the total distance and high-speed running were present. Related to these indicators, trivial or small ES were evident for the difference between competition formats within all sub-groups.

Technical-tactical KPIs

The two-factor mixed ANOVA revealed statistically significant interactions between competition format and sub-group for conquered balls ($F_{(3,61)} = 5.964$, $p = .001$, $\eta_p^2 = .227$) and attack balls ($F_{(3,61)} = 3.466$, $p = .022$, $\eta_p^2 = .146$). Pairwise post-hoc tests for conquered balls revealed no significant differences between the sub-groups in any competition format. Cohen's *d* ES however indicated a higher number of conquered balls specifically for $U_{14}MO_{low}$ during BB games with a large ES ($|d| = 1.1$). $U_{13}MO_{high}$ had less conquered balls with a medium ES ($|d| = 0.6$), whereas $U_{13}MO_{low}$ and $U_{14}MO_{high}$ showed more conquered balls in BB games compared to the CA competition format with a small and a trivial ES, respectively. Pairwise post-hoc tests showed significantly more attack balls for $U_{14}MO_{high}$ compared to $U_{14}MO_{low}$ ($p = .034$) and $U_{13}MO_{high}$ ($p = .043$) only in the CA competition format. A higher number of attack balls was specifically evident for $U_{14}MO_{low}$ during BB games with a large ES ($|d| = 1.6$). Additionally, medium η_p^2 ES demonstrated a trend towards interactions between competition format and sub-group for volume of play on the ball ($F_{(3,61)} = 2.513$, $p = .067$, $\eta_p^2 = .110$) and efficiency on the ball ($F_{(3,61)} = 2.646$, $p = .057$, $\eta_p^2 = .115$). No significant post-hoc tests were evident for these two KPI. However, a higher volume of play on the ball, specifically for $U_{14}MO_{low}$ during BB games, was showed with a large ES ($|d| = 0.8$). Further, only $U_{14}MO_{low}$ showed a higher efficiency on the ball compared to the CA competition format with a large ES ($|d| = 0.9$). No significant interactions between competition format and sub-group for neutral balls, lost balls and volume of play off the ball were revealed. Related to these indicators, trivial or small ES were evident for the difference between competition formats within all sub-groups.

Table 3. Summary of interactions between competition format and sub-group of the ANOVA on KPIs.

KPIs	df_{Num}	df_{Den}	F	η_p^2	p-value
Physiological KPIs					
Total distance	3	49	0.579	.034	.632
High speed running	3	49	0.998	.058	.402
High accelerations	3	49	3.495	.176†	**.022***
Technical-tactical KPIs					
Conquered balls	3	61	5.964	.227†	**.001***
Attack balls	3	61	3.466	.146†	**.022***
Neutral balls	3	61	0.088	.004	.966
Lost balls	3	61	0.286	.014	.835
Volume of play on the ball	3	61	2.513	.110††	.067
Volume of play off the ball	3	61	0.119	.006	.948
Efficiency on the ball	3	61	2.646	.115††	.057

Notes: KPIs = Key performance indicators; df_{Num} = Degrees of freedom for the numerator; df_{Den} = Degrees of freedom for the denominator; F = F statistic; η_p^2 = partial eta squared; † indicates $\eta_p^2 \geq .14$; †† indicates $.06 \leq \eta_p^2 < .14$; * indicates $p < .05$.

Discussion

To the best of our knowledge, this is the first study that systematically examined bio-banding in elite youth soccer players based on quantitative data. A randomized crossover trial was applied to analyse the effects of bio-banding on participating sub-groups depending on maturity status and CA. The data mainly showed significant interactions between competition format and sub-group for the KPI high accelerations, conquered balls and attack balls. Specifically, $U_{13}MO_{high}$ showed more high accelerations with a medium ES in their BB compared to their CA game. In addition, in their BB game $U_{14}MO_{low}$ had more conquered balls and attack balls with a large ES compared to their CA game.

Physiological KPIs

Previous qualitative studies on bio-banding effects based on player's perceptions indicated a greater physiological challenge during BB format for early maturing players compared to the traditional CA competition format (Bradley et al., 2019; Cumming et al., 2018). The

Table 4. Descriptive results of KPIs and Cohen's *d* ES of the difference between competition formats within sub-groups.

	Sub-group															
	$U_{13}MO_{low}$				$U_{13}MO_{high}$				$U_{14}MO_{low}$				$U_{14}MO_{high}$			
KPIs	CA	BB	ES	95% CI Lower; Upper	CA	BB	ES	95% CI Lower; Upper	CA	BB	ES	95% CI Lower; Upper	CA	BB	ES	95% CI Lower; Upper
Physiological KPIs																
Total distance [m]	3983 ± 316	4074 ± 320	−0.3	−0.8; 0.1	3910 ± 266	4005 ± 279	−0.4	−1.1; 0.3	4119 ± 404	4018 ± 478	0.2	−0.5; 0.9	4245 ± 386	4324 ± 565	−0.1	−0.7; 0.5
High speed running [m]	501 ± 141	452 ± 133	0.4	0.0; 0.9	498 ± 111	471 ± 93	0.2	−0.5; 0.9	515 ± 200	524 ± 179	−0.1	−0.8; 0.6	571 ± 163	604 ± 249	−0.2	−0.8; 0.4
High accelerations [n]	62 ± 23	50 ± 17	0.4	0.0; 0.9	**47 ± 13***	64 ± 25	−0.6	−1.3; 0.1	57 ± 17	48 ± 13	0.6	−0.1; 1.3	75 ± 24	62 ± 19	0.5	−0.1; 1.1
Technical-Tactical KPIs																
Conquered balls [n]	7.7 ± 3.8	8.4 ± 2.6	−0.3	−0.7; 0.2	9.0 ± 4.3	7.1 ± 3.2	0.6	−0.1; 1.2	5.8 ± 2.1	9.3 ± 2.7	−1.1	−1.8; −0.4	9.4 ± 4.0	9.5 ± 3.5	0.0	−0.5; 0.4
Attack balls [n]	**10.4 ± 5.2***	10.7 ± 3.6	−0.1	−0.5; 0.4	13.5 ± 6.7	12.3 ± 4.8	0.3	−0.4; 0.9	**9.1 ± 3.2***	14.4 ± 4.4	−1.6	−2.3; −1.0	15.3 ± 6.3	15.3 ± 6.6	0.0	−0.5; 0.4
Neutral balls [n]	9.7 ± 4.1	10.7 ± 4.8	−0.2	−0.6; 0.3	8.6 ± 3.0	9.3 ± 2.7	−0.3	−0.9; 0.3	11.7 ± 5.9	12.2 ± 4.7	−0.1	−0.8; 0.6	12.5 ± 4.7	12.7 ± 4.6	0.0	−0.5;0.4
Lost balls [n]	7.5 ± 2.6	7.3 ± 2.5	0.0	−0.4; 0.5	7.8 ± 2.1	7.3 ± 2.3	0.2	−0.5; 0.8	6.6 ± 2.6	7.4 ± 1.8	−0.3	−0.9; 0.4	7.4 ± 3.2	7.3 ± 2.9	0.0	−0.4; 0.5
Volume of play on the ball [n]	23.3 ± 7.8	25.5 ± 7.3	−0.2	−0.7; 0.2	25.3 ± 7.4	23.6 ± 5.7	0.4	−0.2; 1.0	22.5 ± 5.8	28.0 ± 6.9	−0.8	−1.5; −0.1	27.4 ± 8.2	27.1 ± 6.6	0.0	−0.4; 0.5
Volume of play off the ball [n]	13.1 ± 4.1	14.0 ± 5.7	−0.2	−0.6; 0.3	12.2 ± 5.1	12.6 ± 4.0	−0.1	−0.7; 0.5	12.6 ± 5.0	12.3 ± 5.7	0.0	−0.6; 0.7	12.7 ± 4.0	12.8 ± 5.2	0.0	−0.5; 0.4
Efficiency on the ball [%]	50.4 ± 8.8	51.6 ± 8.1	−0.1	−0.6; 0.4	55.9 ± 8.8	53.5 ± 9.5	0.3	−0.4; 0.9	45.9 ± 8.9	55.1 ± 9.5	−0.9	−1.5; −0.2	54.3 ± 9.1	54.4 ± 10.3	0.0	−0.5; 0.4

Notes: Values are Mean ± Standard Deviation per 35 min; KPIs = Key performance indicators; $U_{13}MO_{low}$ = Under-13 players in the lower bio-band; $U_{13}MO_{high}$ = Under-13 players in the higher bio-band; $U_{14}MO_{low}$ = Under-14 players in the lower bio-band; $U_{14}MO_{high}$ = Under-14 players in the higher bio-band; CA = Chronological age competition format; BB = Bio-banded competition format; ES = Effect size (Cohen's *d*); 95% CI = 95% Confidence interval, *indicates significantly lower values than $U_{14}MO_{high}$ ($p < .05$).

player's perceived higher physiological demands were underlined by a preliminary analysis of bio-banding during youth soccer competition, where only early maturing players produced higher rates of perceived exertion (RPE) in BB games compared to CA games (Abbott et al., 2019). Still, the same study did not show a simultaneous significant increase in any of the other measured quantitative physiological indicators that could have mediated the higher RPE (i.e. total distance covered, high-speed running distance covered and explosive distance covered). In line with those findings, the present study only revealed trivial or small ES of bio-banding on the total or the high-speed running distance covered for any sub-group. However, a significant interaction between competition format and sub-group for the number of high accelerations was evident with a large ES. Specifically, $U_{13}MO_{high}$ had more high accelerations with a medium ES. Throughout the other sub-groups, lower numbers of high accelerations were found in their BB game compared to their CA game. This finding provides a mediation for the higher perceived physiological demand of early maturing players when playing BB matches and hence confirms observations in previous studies (Abbott et al., 2019; Bradley et al., 2019; Cumming et al., 2018). The higher physiological challenge for players who are relatively advanced in maturation is seen as a positive influence on their development, as it prepares them for future adult age competitions against physically more equal opponents (Cumming et al., 2018).

Technical-tactical KPIs

Regarding current studies analysing the effects of bio-banding on technical-tactical indicators, affected players reported different experiences depending on their maturity status in interviews (Bradley et al., 2019; Cumming et al., 2018). On the one hand, early maturing players pointed out that they can no longer solely rely on their physical strength during BB games, but more often have to resort to their technical-tactical abilities to compete. On the other hand, late maturing players enjoyed a greater opportunity to prove their technical-tactical skills in BB compared to CA games. Overall, it can be assumed that bio-banding leads to a more balanced and technically-tactically challenging game with more duels and unsuccessful passes (Romann et al., 2020). Indeed, previous results showed significant interactions between competition format and maturity group on certain technical-tactical indicators (Abbott et al., 2019). Less dribbles of early maturing players confirm the reduced physical advantage during BB matches. Late maturing players were able to successfully conduct a tackle more often during BB compared to CA games. Present findings showed significant interactions between competition format and sub-group for conquered balls and attack balls. In addition, for volume of play on the ball and efficiency on the ball, moderate η_p^2 ES demonstrated a trend towards interactions between competition format and sub-group. Specifically, during BB games only $U_{14}MO_{low}$ had more conquered and attack balls, as well as a higher volume of play and efficiency on the ball compared to their CA game, with a large ES. Thus, new learning stimuli with more opportunities to show technical-tactical abilities during bio-banding were evident, especially for $U_{14}MO_{low}$. Also, it is assumed that a higher technical-tactical involvement and the associated greater influence on the match play supports the psychological development of players playing in a lower CA category (e.g. taking on more responsibility and leadership or increasing confidence) (Cumming et al., 2018). Further, in BB games $U_{13}MO_{high}$ had less conquered balls and volume of play on the ball compared to their CA game, with medium ES. While they were physically rather superior in the CA competition format, they were provided with a challenging environment and had to adapt their style of play to more equal opponents in the BB game. A variety of challenges has been indicated to impact the psychological development of athletes and help them reach their potential (e.g. developing mental toughness and resilience) (Collins & MacNamara, 2012). For completeness, not all collected technical-tactical KPI were affected by bio-banding. For the KPI neutral balls, lost balls and volume/time of play off the ball, there were only trivial or small ES in differences between competition formats within sub-groups with no significant interaction between competition format and sub-group.

Limitations

The study has some limitations that need to be addressed. The application of bio-banding in the current study includes the U_{13} and U_{14} age categories only. As such, findings are based on study participants between 11.7 and 13.7 years of age. Applying the results to other or wider age ranges should be used with caution. Playing positions were fixed and matched across games for each player. However, the sample size did not allow an analysis specified for playing positions. Future studies should therefore try to evaluate the effects of bio-banding specified for each playing position, as it would provide a more detailed understanding of bio-banding. The individual and short-term variability is a feature of youth soccer matches. Hence, more studies, especially longitudinal studies, would be desirable and valuable to evaluate the effects of bio-banding even more thoroughly and precisely.

Practical implications

Practitioners such as coaches and staff should consider and be aware of the effects bio-banding can have on different sub-groups involved. The present study allows estimation of the effects and their extent on technical-tactical and physiological KPIs when implementing bio-banding for U_{13} and U_{14} youth elite soccer players and the corresponding four sub-groups. According to the KPIs measured, players who did not change their traditional CA category (i.e. $U_{13}MO_{low}$ and $U_{14}MO_{high}$) experienced trivial to small changes due to bio-banding compared to CA competition. However, players changing their usual CA category (i.e. $U_{13}MO_{high}$ and $U_{14}MO_{low}$) encountered more substantial effects. On the one hand, players from $U_{13}MO_{high}$ face a higher physiological challenge and can no longer rely solely on their physical advantage. Whereas players from $U_{14}MO_{low}$ had more opportunities to use and demonstrate their technical-tactical skills. Thus, by providing participating players with a new learning environment and considering their individual developmental needs, bio-banding has the potential to enhance the process of talent development. Bio-banding can be applied to modify the competition environment to benefit the development for both types of players, offering them new stimuli for technical-tactical skill acquisition and maturity-adjusted physical challenges. Further, coaches and staff are given the chance to minimize the loss of potential talents by evaluating player's potential in an environment adapted to their maturational development.

Conclusion

Practitioners within talent development systems should be aware of the revealed effects of bio-banding and consider them when implementing bio-banded (BB) competition. In summary, present results showed that bio-banding affects in-game Key Performance Indicators of youth elite soccer players, depending on individual maturity status. Compared to chronological age (CA) competition, in BB competition late maturing players are provided with more opportunities to show technical-tactical skills, such as conquering the ball or playing an attack ball. Early maturing players face a higher physiological challenge manifested by more high accelerations in BB compared to CA competition.

To conclude, present findings show the potential of bio-banding to improve the process of talent development and help apply bio-banding more focused and adjusted to the player's developmental needs.

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No potential conflict of interest was reported by the author(s).

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