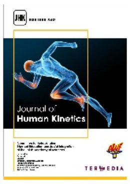

Variation Associated to Chronological Age and Bio-Banded Competitive Groups in Youth Soccer

by
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The aim of the study was to compare the body size, skeletal maturity status and functional characteristics of soccer players aged 9–16 years in competitive chronological age (CA) and bio-banded (BB) groups; the latter were defined by the percentage of predicted adult height (%PAH). Body height, mass and functional capacities (sprints, jumping, agility, strength) were measured for 110 players in four competitive CA groups (U10, U12, U14, U16). Assessments of skeletal age (SA) and predicted adult height (PAH) were based on methods developed in the Fels longitudinal study. Current body height was expressed as %PAH which was used to classify players into BB groups approximating take-off (TO) of the adolescent spurt [BB1, %PAH <85%], the interval between TO and peak height velocity (PHV) [BB2, ≥85<90%], PHV [BB3, ≥90<95%] and post-PHV [BB4, ≥95%]. Characteristics of players in adjacent CA and BB groups were compared. Differences in body size, SA and functional capacities between adjacent CA and BB groups were variable but were most marked between U12 and BB2 players. The latter were older in CA, advanced in SA, taller, heavier and stronger than U12 players, but other functional test results did not differ significantly. Though not as marked, a similar trend was apparent between U10 and BB1, as well as U14 and BB3 players, while differences between U16 and BB4 players were negligible. Allowing for variation within CA and BB groups, the results highlight the potential utility of bio-banding especially among early adolescent and adolescent players (U10, U12, U14). Considering that BB groups are not fixed, they can be modified as needed.

Keywords*: fitness; predicted adult height; youth sport; skeletal age; maturity status*

Introduction

Variation in maturity associated with skeletal age (SA) and pubertal status among youth soccer players is well documented (Malina, 2003; Malina et al., 2013, 2017; Perroni et al., 2024). Players who are advanced in maturity status, but of the same chronological age (CA), tend to be taller, heavier, and perform better in functional tests, though not necessarily in soccer-specific skills (de Dios-Álvarez et al., 2015; Malina, 2003). These players are also more represented in samples of soccer players with increasing CA between 11 and 16 years (Coelho-e-Silva et al., 2010a; Gouvêa et al., 2017; Mendes et al., 2025). Similar maturity trends have been observed among male athletes in other sports, including ice hockey, baseball, American football, basketball, swimming, and several track and field disciplines (Malina, 1994, 2011).

Efforts to accommodate maturity-related variation among adolescent male athletes by

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"matching" participants based on biological maturity status have a relatively long history (Beunen and Malina, 2008; Malina and Beunen, 1996). However, SA and pubertal status, two established maturity indicators, are increasingly viewed as "invasive". Radiographs for the assessment of SA involve a low dose of radiation, while direct assessments of stages of pubic hair or genital development are considered personally invasive for the youngster. The expense of radiographs and the lack of technicians with formal training in the assessment and application of these maturity indicators are related factors. As a result, predicted estimates of maturity status, the percentage of predicted adult height attained at the time of observation (Roche et al., 1983) and of maturity timing, along with maturity offset or time before peak height velocity (Mirwald et al., 2002; Moore et al., 2015), are increasingly used in studies of youth athletes. However, several limitations of the predicted indicators of maturity status and timing have been noted (Malina et al., 2015, 2019), and will be considered in more detail in the discussion.

Bio-banding is a recent effort to accommodate individual differences in maturity status among youth athletes, and the percentage of predicted adult height attained at the time of observation (%PAH) is increasingly used as the maturity indicator (Malina et al., 2019). Bio-banded groups defined by %PAH among youth athletes within a given CA range, such as 11–14 or 11–15 years, or within competitive CA ranges, such as Under 10 (U10) through Under 14 (U14), are increasingly common in studies of youth soccer players, although bands vary, e.g., 85.0% to <90.0% or 90% to <95.0%. The approach has been used in training, injury prevention, and experimental competitions (Cumming et al., 2018; Hill et al. 2020). It is important to note, however, that bio-banding is not an effort to modify established competitive CA groups in specific sports.

Though widely applied, it should be noted that bio-banding does not eliminate variation in maturity status within bands (Malina et al., 2012, 2019). There is a need to address variation in maturity status assessed with established indicators, i.e., skeletal and/or pubertal maturity status, and in body size and functional characteristics associated with maturity status within commonly used bio-bands. The objective of this study was thus to compare the CA, SA, skeletal maturity status (late, on time, advanced), body size and functional characteristics of youth soccer players aged 9–16 years in four competitive CA groups and in four bio-bands defined by %PAH. Given normal variation in growth and maturity status and the selectivity of soccer during adolescence, it was hypothesized that bio-banding might reduce but not eliminate variability in the growth and maturity status as well as functional characteristics of youth players.

Methods

Design and Procedures

The project was approved by the Human Ethics Research Committee of the Karol Marcinkowski Medical University in Poznań, Poznań, Poland (protocol code: 186/19; approval date: 07 February 2019) prior to data collection. Subsequently, parents or legal guardians provided written informed consent. Participants were also informed about the objectives of the project and that participation was voluntary. Participants were instructed to dress appropriately (shorts, a t-shirt, training shoes) for their visit to the Poznań University of Physical Education facilities. Measurements and tests were conducted in the morning. Body dimensions were initially measured in the laboratory for anthropometry; subsequently, players completed a warm-up that included dynamic stretches and light jogging, supervised by qualified examiners. Several functional tests were then conducted to assess, in the following sequence, speed (including acceleration), agility, explosive strength, and static strength. Standard radiographs of the left hand and wrist were obtained for each player during a visit to a certified clinic

Participants

The sample included 110 male soccer players of European ancestry from two soccer clubs in West-Central Poland. The date of birth of each player was obtained by interview; CA was calculated as the difference between the date of observation and the date of birth. CA ranged from 9.6 to 16.4 years. Players participated in 90-min training sessions five days per week and usually competed in one game during the weekend during the 9-month season (about 24–30 games). Training sessions were held on mixed artificial or natural turf and included a combination of physical, technical, and tactical activities.

According to the Polish Soccer Federation, competitive CA groups span two years and players are classified by CA based on the calendar year (January 1st to December 31st). Game duration varies among competitive CA groups: 2 x 25 min halves (U10: CA>10.9 years); 2 x 30 min halves (U12: CA 11.0–12.9 years); 2 x 40 min halves (U14: CA 13.0–14.9 years); and 2 x 45 min (U16: 15.0–16.9 years). Unfortunately, information on the number of matches and specific playing time for individual players taking part in this study was not available.

Anthropometry

With shoes removed, body height was measured to the nearest 0.1 cm using a portable stadiometer (Harpenden, Crosswell, Crymych, Pembrokeshire, UK), while body mass was measured with a scale to 0.1 kg (Tanita MC-780 scale, Tanita Corporation, Japan).

Maturity Status

Two indicators of maturity status were estimated, %PAH attained at the time of observation and SA. Prediction of adult height was based on equations developed for American boys of European ancestry (White) who were participants in the Fels Longitudinal Study (Khamis and Roche, 1995). The prediction protocol required the CA, height and body mass of the player, and the heights of his biological parents. Parental heights were obtained from personal identification cards and were adjusted to account for overestimation of reported heights using the sex-specific equations (Epstein et al., 1995). The current height of each player was then expressed as a percentage of his predicted adult height at the time of observation (%PAH) which served as the indicator of maturity status. Players were subsequently grouped into four maturity groups labeled bio-bands (BB) on the basis of %PAH as follows: BB1: <85%; BB2: 85% <90%; BB3: 90 <95%; and BB4: 95%. Median error bounds between observed and predicted heights at 18 years in the Fels sample ranged from 2.4 cm to 2.8 cm at ages 11 through 14, and decreased to 1.0 cm at 16 years. The 90th percentile error bounds increased from about 5.5 cm at 11 years to 7.3 cm at 13 years, then decreased to about 3.5 cm at 16 years (Khamis and Roche, 1994). The errors translated to about 1.5% to 3.0% of predicted adult height for the average adolescent boy in the Fels study.

Skeletal maturity status was estimated as SA and its standard error using The Fels method of assessment (Roche et al., 1988). A single experienced observer assessed all radiographs. Skeletal maturity status of each players was based on the difference of SA minus CA. An SA within ±1.0 year of CA defined a player as "on time" or average in maturity status. The band of ±1.0 year allowed for errors in the assessments as previously documented (Malina, 2011; Malina et al., 2018). An SA in advance of CA by more than +1.0 year defined a player as early maturing (advanced), while an SA less than CA by more than −1.0 year defined a player as late maturing (delayed).

Functional Tests

The considered functional capacities included speed, agility and strength (Konarski et al., 2021). Speed assessments were based on performance of two sprints. The 5-m sprint test began with players in a standing position behind the starting line. Running time was measured using a digital photocell system (Witty, Microgate, Italy) with precision of 0.001 s. After a 30-min rest interval, the protocol was repeated for a 20-m sprint; the time at crossing 10 m during the 20-m sprint was also recorded and provided an estimate of acceleration (Mendez-Villanueva et al., 2011). Each player completed two trials for each distance. The better result for each test (the 5-m sprint, acceleration, and the 20-m sprint) was retained for further analysis.

Agility was assessed as a run which required changes of direction (Hoffman, 2012). The player stood at the starting line midway between two 1.2-m bars placed 5 m apart, and was instructed to run three laps around the bars as fast as possible. Elapsed time was measured to 0.01 s using the digital photocell system (Witty, Microgate, Italy). The best result of two trials was retained for subsequent analysis.

Explosive strength was assessed based on vertical jumping performance as described in previous studies (Deprez et al., 2015; Konarski et al., 2021; Martínez et al., 2025). The result of the highest of three jumps was registered for further analysis.

Grip strength was measured with a Lafayette dynamometer (model 78010, Lafayette

Instrument Company, Indiana, USA) adjustable to the size of the hand (Coelho-e-Silva et al., 2010b). Players performed a maximal voluntary contraction for each hand. The test was repeated with each hand three times with a 1-min rest interval in between to avoid the effects of fatigue. The best trial result (in kg) for each hand was retained and the average from right and left hands was used for analysis.

Statistical Analysis

As indicated above, the CA of players spanned 9.6–16.4 years. Following official regulations, the sample was divided into four competitive CA groups: U10 (n = 27), U12 (n = 33), U14 (n = 33), and U16 (n = 17). Players were also classified into four bio-bands based on %PAH. The bands were assumed to represent different phases of the adolescent growth spurt (Cumming et al., 2017; Malina et al., 2019): BB1 (<85% PAH, interval of take-off [TO] of the growth spurt, n = 52); BB2 (≥85<90% PAH, interval between TO and PHV, n = 19); BB3 (≥90<95% PAH, interval of PHV, n = 19); and BB4 (≥95% PAH, post-PHV, n = 20). Descriptive statistics (means [M], standard deviations [SD], ranges) were calculated for all variables in the four CA and the four bio-banded groups. Analyses of variance were used to compare characteristics of players in the four CA and the four BB groups. Effect sizes were estimated as partial eta squared (η_p^2) and interpreted as follows: ≥0.01 and <0.06: small, ≥0.06 and <0.14: medium, and ≥0.14: large (Cohen, 1988). Variables were converted to Z-scores within each specific pair of competitive CA and BB groups to facilitate graphic comparisons. Mean values for the percentage of predicted adult height, CA, SA, body size and functional characteristics were also estimated for the players grouped by skeletal maturity status (late, on time, early) within the four BB groups separately by CA groups. Analyses were performed with SPSS Statistics 19, Statistica Software version 13. The level of significance was set at 0.5.

Results

The distribution of soccer players by competitive CA and bio-banded groups based on PAH% and the distribution of players by skeletal maturity status based on the difference of SA minus CA within the respective groups are summarized in Table 1. U10 through U14 players were represented in BB1, U12 and U14 players were represented in BB2, while U14 and U16 players were represented among U16 and U16 players; alternatively, U14 players spanned the four bio-banded groups. Moreover, neither U14 nor U16 players were classified as skeletally late maturing.

Characteristics of players in competitive CA and BB groups as well as results of the respective analyses of variance are summarized in Table 2. Although the mean differences between SA and CA (SA-CA) increased across CA and BB groups, the differences between SA and CA were not significant (F = 0.275, p = 0.843; F = 1.202, p = 0.311). This suggests that the tempo of biological maturation varied considerably among the players in CA and BB groups. Subsequent pairwise comparisons were significant except for the 5-m sprint, agility and vertical jump performance between U12 and U14 players. In contrast, BB1 and BB2 differed significantly only in grip strength. BB2 players did not differ in agility relative to BB3 and BB4 players, while the latter players did not significantly differ in performance of any of the functional tests.

The contrasts of CA, SA, body size and functional characteristics of players in each pair of CA and adjacent BB groups, expressed as z-scores, are illustrated in Figure 1. The trends in z-scores highlight the significant differences between U12 and BB2 players, and suggest somewhat similar trends among U10 and BB1 as well as U14 and BB3 players, although the differences in the latter two comparisons were smaller and largely non-significant.

Characteristics of players classified as late, on time or early in skeletal maturity status within competitive CA groups represented in each BB group are summarized in Table 3. Players classified as late, on time and early maturing based on SA relative to CA were represented among U10 and U12 players, while no U14 and U16 players were late maturing.

The percentage of predicted adult height showed, on average, a slight skeletal maturity gradient, whereas body height and mass along with grip strength showed a clear skeletal maturity-related gradient among U10 and U12 players in BB1, i.e., early > on time > late. In contrast, a skeletal maturity-related gradient in

%PAH was not apparent among players in the CA groups represented among BB2, BB3 and BB4 players, although there was some exception (U14 players in BB4, n = 3 on time and 3 early). Moreover, a skeletal maturity-related gradient in height, body mass and grip strength, i.e., early > on time, was apparent among players in BB2, BB3 and BB4. In contrast, variation in performances of the vertical jump, agility and sprint tests by skeletal maturity status within each BB group was inconsistent.

Table 1. Cross tabulation of soccer players by competitive chronological age (CA) groups and bio-banded groups based on PAH% and distributions of players by skeletal maturity status within the respective groups.

CA groups	Skeletal maturity Status*	Bio-banded groups (PAH%)				Total
		BB1 (<85%)	BB2 (85–89%)	BB3 (90–94%)	BB4 (>95%)	
U10		27				27
U12		23	10			33
U14		2	9	16	6	33
U16				3	14	17
Total sample	Late	9				9
	One Time	26	9	7	9	51
	Early	17	10	12	11	50
U10	Late	3				3
	One Time	15				15
	Early	9				9
U12	Late	6				6
	One Time	9	2			11
	Early	8	8			16
U14	Late					0
	One Time	2	7	6	3	18
	Early		2	10	3	15
U16	Late					0
	One Time			1	6	7
	Early			2	8	10
TOTAL		52	19	19	20	110

** Skeletal maturity status: On Time or Average = SA within ± 1.0 year of CA; Late = SA less than CA by >1.0 year; Early = SA in advance of CA by > 1.0 year; U10 (under-10); U12 (under-12); U14 (under-14); U16 (under-16); PAH% (percentage of predicted adult height at the time of observation): BB1 (<85%); BB2 (85–89%); BB3 (90–94%); BB4 (≥95%)*

Table 2. Variation in chronological age (CA), skeletal age (SA), SA minus CA, body size and functional tests of the soccer players in competitive CA and bio-banded (BB) groups and results of the analyses of variance (Table 2a).

	Chronological age groups				F	*p*	Effect size
	U10	U12	U14	U16			
CA (yrs)	10.43 ± 0.38	12.17 ± 0.63	13.76 ± 0.58	15.48 ± 0.43	56.771	<0.001	0.79
SA (yrs)	11.00 ± 1.49	13.01 ± 1.60	14.78 ± 1.05	16.58 ± 0.90	5.597	0.001	0.38
SA − CA (yrs)	0.56 ± 1.40	0.84 ± 1.37	1.02 ± 0.80	1.11 ± 0.90	0.275	0.843	0.09
PAH (%)	78.6 ± 1.7	84.4 ± 2.6	89.9 ± 3.7	95.6 ± 1.8	24.140	<0.001	0.65
Stature (cm)	141.7 ± 6.6	153.7 ± 8.3	162.1 ± 8.6	170.2 ± 7.4	3.714	0.014	0.33
Body Mass (kg)	33.9 ± 5.2	42.4 ± 7.2	50.3 ± 6.6	59.9 ± 6.8	3.178	0.028	0.31
5-m Sprint (s)	1.22 ± 0.09	1.13 ± 0.07	1.10 ± 0.07	1.02 ± 0.04	5.102	0.003	0.38
Accel. (s)	2.10 ± 0.12	2.00 ± 0.09	1.86 ± 0.11	1.73 ± 0.06	5.434	0.002	0.39
20-m Sprint (s)	3.69 ± 0.21	3.49 ± 0.15	3.22 ± 0.19	3.01 ± 0.09	6.688	<0.001	0.43
Agility (s)	13.57 ± 0.75	12.89 ± 0.52	12.75 ± 0.48	12.28 ± 0.39	4.239	0.007	0.35
HG (kg)	34.2 ± 5.5	43.5 ± 7.6	60.3 ± 13.4	76.4 ± 8.0	3.781	0.013	0.33
VJ (cm)_	32.1 ± 4.3	38.4 ± 6.6	43.3 ± 9.6	56.8 ± 3.1	4.482	0.006	0.36
	Bio-banded groups				**F**	***p***	**Effect size**
	BB1	BB2	BB3	BB4			
CA (yrs)	11.77 ± 0.88	12.99 ± 0.60	14.60 ± 0.56	15.15 ± 0.73	10.990	<0.001	0.50
SA (yrs)	12.15 ± 1.60	14.14 ± 0.68	15.83 ± 0.86	16.47 ± 0.89	4.814	0.004	0.35
SA − CA (yrs)	0.39 ± 1.39	1.15 ± 0.79	1.23 ± 0.71	1.31 ± 0.95	1.202	0.311	0.19
PAH (%)	81.7 ± 2.6	86.9 ± 1.3	93.3 ± 1.6	96.3 ± 1.3	50.346	<0.001	0.77
Stature (cm)	146.4 ± 7.1	158.7 ± 6.9	166.8 ± 3.9	173.9 ± 6.2	12.962	0.000	0.55
Body Mass (kg)	37.5 ± 5.5	47.8 ± 5.2	54.8 ± 5.3	61.1 ± 5.9	10.082	0.000	0.50
5-m Sprint (s)	1.17 ± 0.09	1.14 ± 0.07	1.04 ± 0.06	1.03 ± 0.04	3.954	0.011	0.34
Accel. (s)	2.00 ± 0.13	1.98 ± 0.09	1.78 ± 0.09	1.73 ± 0.07	5.155	0.002	0.38
20-m Sprint (s)	3.50 ± 0.22	3.44 ± 0.16	3.10 ± 0.15	3.00 ± 0.10	5.301	0.002	0.39
Agility (s)	13.15 ± 0.72	12.85 ± 0.40	12.51 ± 0.48	12.38 ± 0.50	0.436	0.728	0.12
HG (kg)	40.2 ± 6.5	50.8 ± 9.4	70.2 ± 12.4	76.2 ± 7.3	9.269	0.000	0.48
VJ (cm)	34.7 ± 6.2	38.3 ± 8.1	53.6 ± 7.7	54.0 ± 4.0	9.388	0.000	0.49

*PAH: predicted adult height; U10: under-10; U12: under-12; U14: under-14; U16: under-16; BB1: <85% PAH; BB2: 85–89% PAH; BB3: 90–94% PAH; BB4: ≥95% PAH; ** $p \leq 0.01$; * $p < 0.05$; n.s.: not significant; Accel.: acceleration; HG: hand grip; VJ: vertical jump*

Table 2a. Results of the analysis of variance of the data presented in Table 2.

	U10 U12	U10 U14	U10 U16	U12 U14	U12 U16	U14 U16
CA (yrs)	**	**	**	**	**	**
SA (yrs)	**	**	**	**	**	**
SA – CA (yrs)						
PAH (%)	**	**	**	**	**	**
Stature (cm)	**	**	**	**	**	*
Body Mass (kg)	**	**	**	**	**	**
5-m Sprint (s)	**	**	**	n.s.	**	*
Accel. (s)	**	**	**	**	**	*
20-m Sprint (s)	**	**	**	**	**	**
Agility (s)	**	**	**	n.s.	*	n.s.
HG (kg)	**	**	**	**	**	**
VJ (cm)	**	**	**	n.s.	*	n.s.
	BB1 BB2	B1 BB3	BB1 BB4	BB2 BB3	BB2 BB4	BB3 BB4
CA (yrs)	**	**	**	**	**	**
SA (yrs)	**	**	**	**	**	*
SA – CA (yrs)						
PAH (%)	**	**	**	**	**	**
Stature (cm)	**	**	**	*	**	*
Body Mass (kg)	**	**	**	*	**	*
5-m Sprint (s)	n.s.	**	**	**	**	n.s.
Accel. (s)	n.s.	**	**	**	**	n.s.
20-m Sprint (s)	n.s.	**	**	**	**	n.s.
Agility (s)	n.s.	*	**	n.s.	n.s.	n.s.
HG (kg)	**	**	**	**	**	n.s.
VJ (cm)	n.s.	**	**	**	**	n.s.

*** $p \leq 0.01$; * $p < 0.05$; n.s.: not significant;*
Accel.: acceleration; HG: hand grip; VJ: vertical jump

Table 3. Means and standard deviations for the percentage of predicted adult height (PAH), chronological age (CA), skeletal age (SA), body size and functional performances of players by skeletal maturity status (late, on time, early) within competitive CA and BB groups.

	BB1			BB2			BB3			BB4		
	L	OT	E	L	OT	E	L	OT	E	L	OT	E
PAH (%)												
U10	78.0 ± 1.4	78.2 ± 1.5	79.6 ± 1.8									
U12	81.2 ± 1.5	82.3 ± 2.2	83.0 ± 1.5	86.7	86.5 ± 0.5							
U14		84.3			87.3 ± 1.6	87.4		92.1 ± 1.5	92.8 ± 1.5		95.6 ± 0.3	95.4 ± 0.1
U16								94.1	94.1		96.9 ± 1.2	97.4 ± 1.3
CA (years)												
U10	10.5 ± 0.4	10.3 ± 0.4	10.6 ± 0.3									
U12	11.8 ± 0.5	11.9 ± 0.6	11.7 ± 0.4	12.7	12.5 ± 0.4							
U14		13.1			13.4 ± 0.4	13.2		14.1 ± 0.5	14.0 ± 0.6		14.6 ± 0.3	14.4 ± 0.6
U16								15.1	15.2		15.8 ± 0.5	15.8 ± 0.4
SA (years)												
U10	8.7 ± 1.2	10.5 ± 0.6	12.6 ± 0.8									
U12	10.1 ± 0.6	11.9 ± 0.9	13.4 ± 0.7	13.4	14.2 ± 0.4							
U14		13.5			14.0 ± 0.8	14.9		14.8 ± 0.6	15.8 ± 0.6		15.5 ± 0.2	16.6 ± 0.3
U16								15.4	16.7		15.9 ± 0.5	17.6 ± 0.2
Stature (cm)												
U10	136.1 ± 2.7	140.8 ± 6.7	145.1 ± 6.1									
U12	145.9 ± 6.0	146.2 ± 5.4	152.3 ± 5.9	155.9	160.4 ± 5.9							
U14		149.5			157.1 ± 6.0	164.7		167.1 ± 3.5	170.1 ± 5.9		173.4 ± 1.5	173.5 ± 5.7
U16								163.0	167.5		172.3 ± 8.4	176.4 ± 5.8
BM (kg)												
U10	28.5 ± 4.1	33.4 ± 3.1	36.5 ± 6.9									
U12	35.7 ± 4.1	37.3 ± 6.3	39.9 ± 4.9	45.0	48.1 ± 6.3							
U14		41.2			46.5 ± 3.3	50.9		50.3 ± 4.8	58.5 ± 6.6		58.8 ± 2.7	59.2 ± 4.3
U16								49.9	59.9		61.1 ± 8.1	66.8 ± 4.1
5-m sprint (s)												
U10	1.20 ± 0.08	1.23 ± 0.09	1.21 ± 0.10									
U12	1.14 ± 0.07	1.11 ± 0.07	1.13 ± 0.17	1.08	1.16 ± 0.08							
U14		1.17			1.14 ± 0.05	1.16		1.07 ± 0.07	1.08 ± 0.05		1.00 ± 0.06	1.05 ± 0.05
U16								0.95	1.02		1.06 ± 0.03	1.01 ± 0.03
Accel. (s)												
U10	2.10 ± 0.09	2.09 ± 0.11	2.14 ± 0.14									
U12	1.96 ± 0.11	2.01 ± 0.09	1.98 ± 0.11	1.98	2.01 ± 0.09							
U14		1.92			1.95 ± 0.11	1.95		1.83 ± 0.09	1.81 ± 0.10		1.67 ± 0.05	1.81 ± 0.04
U16								1.77	1.73		1.76 ± 0.04	1.67 ± 0.04
20-m sprint (s)												
U10	3.68 ± 0.20	3.67 ± 0.19	3.73 ± 0.27									
U12	3.43 ± 0.20	3.54 ± 0.15	3.45 ± 0.15	3.41	3.53 ± 0.15							
U14		3.32			3.39 ± 0.18	3.36		3.21 ± 0.14	3.13 ± 0.16		2.94 ± 0.08	3.09 ± 0.04
U16								3.07	3.02		3.03 ± 0.08	2.91 ± 0.08
Agility (s)												
U10	13.3 ± 0.3	13.5 ± 0.7	13.8 ± 0.8									
U12	12.5 ± 0.5	13.0 ± 0.5	13.2 ± 0.5	12.4	12.9 ± 0.5							
U14		12.9			12.9 ± 0.2	12.7		12.9 ± 0.6	12.6 ± 0.4		12.2 ± 0.4	12.7 ± 0.8
U16								12.5	12.2		12.3 ± 0.3	12.4 ± 0.6
HG (kg)												
U10	30.7 ± 5.0	32.7 ± 4.5	37.9 ± 5.6									
U12	35.2 ± 6.6	37.4 ± 4.4	43.0 ± 4.5	46.0	48.4 ± 7.7							
U14		47.5			50.9 ± 6.8	62.0		63.3 ± 10.6	72.7 ± 16.7		71.7 ± 2.5	75.0 ± 2.6
U16								66.0	77.5		76.2 ± 7.3	81.9 ± 6.9
VJ (cm)												
U10	30.0 ± 4.6	31.9 ± 4.3	33.0 ± 4.6									
U12	41.1 ± 8.2	36.6 ± 4.9	38.4 ± 7.4	38.0	38.4 ± 7.8							
U14		33.5			38.0 ± 13.4	39.0		47.7 ± 5.5	52.7 ± 9.5		51.3 ± 4.5	51.3 ± 2.5
U16								61.0	55.0		56.2 ± 2.5	57.2 ± 3.8

Sample sizes are indicated in Table 1; OT: on time or average = SA within ± 1.0 year of CA; L: Late = SA less than CA by >1.0 year; E: Early = SA in advance of CA by > 1.0 year; U10: under-10; U12: under-12; U14: under-14; U16: under-16; CA: chronological age; SA: skeletal age; PAH: Predicted Adult Height; BM: body mass; HG: hand grip; VJ: vertical jump; BB1: <85% of PAH; BB2: 85–89% of PAH; BB3: 90–94% of PAH; BB4: ≥95% PAH; U10: under-10; U12: under-12; U14: under-14; U16: under-16; Accel.: Acceleration

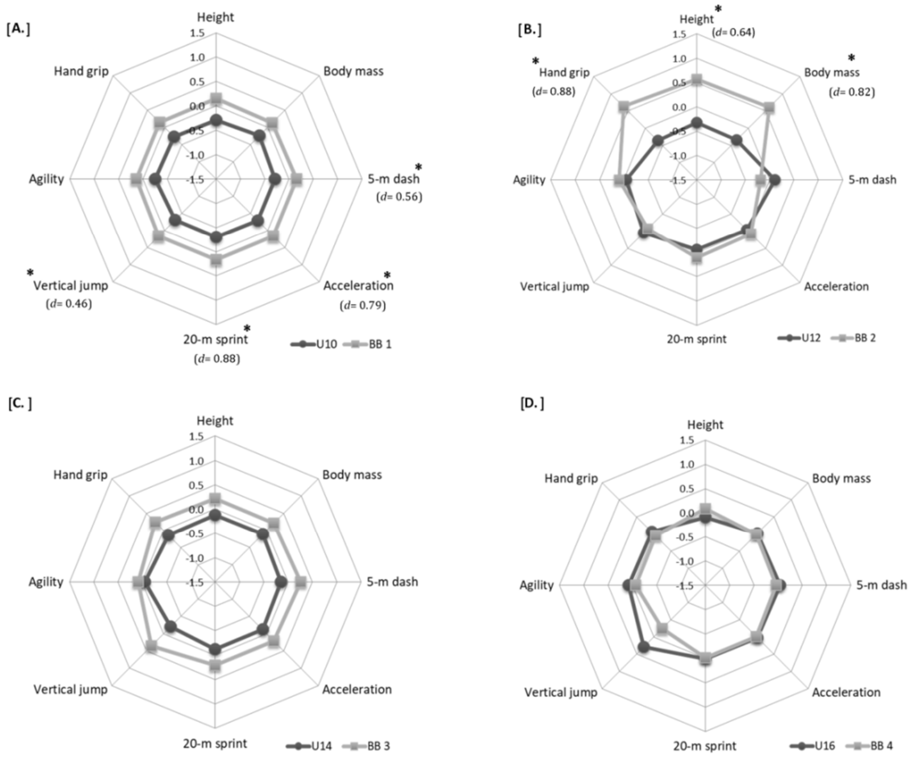

Figure 1. Profiles for chronological age and bio-banded groups based on z-scores.
panel A: Under-10 versus BB1; panel B: Under-12 versus BB2; panel C: Under-14 versus BB3; panel D: Under-16 versus BB4

Discussion

Comparisons of players in competitive CA and BB groups have important implications for coaches and others working with youth athletes as well as for applications of the bio-banding protocol. Our results highlight the need to recognize individual differences in growth (size attained), biological maturity status (SA) and several functional characteristics among players within competitive CA and BB groups. Of relevance, bio-banding accommodates individual differences in estimated maturity status among players to some extent, but does not eliminate variation associated with skeletal maturity status.

Players spanning the spectrum of late through early skeletal maturity status were represented among U10 and U12 players in the present study, while late maturing players were absent among U14 and U16 players (Tables 1 and 3). The distribution of players based on skeletal maturity status assessed with the Fels method was generally consistent with other studies of soccer players using the Fels, Greulich-Pyle and Tanner-Whitehouse 2 RUS methods of SA assessment (Malina, 2011).

Of relevance to applications of bio-banding with youth players, variation in skeletal maturity status, defined by SA minus CA, within the BB groups was considerable. Players classified as late, on time and early maturing based on SA were represented among BB1 players, while only players classified as on time and early maturing were represented among BB2, BB3 and BB4 players. Moreover, only players in BB1 showed a slight gradient in %PAH consistent with that noted for skeletal maturity status. Allowing for limited numbers, there was no consistent gradient in %PAH among players classified as on time and early in skeletal maturity status in the respective BB2, BB3 and BB4 groups.

Although %PAH and SA are related, they are not equivalent indicators of biological maturity status. In the total sample of players in the present study, the overwhelming majority (85%) was classified as average in maturity status based on %PAH compared to 47% classified as average based on SA, and there was variation among competitive CA groups. Among the 33 U12 players, for example, 85% were classified as average with %PAH, while 33% and 48% players were classified, respectively, as average and early maturing with SA. Moreover, 85% of the 33 U14 players were also classified as average based on %PAH, while 58% and 42% were classified, respectively, as average and early maturing based on SA. Generally similar trends were noted in other studies of U12 and U14 Portuguese soccer players using similar criteria to define maturity status with %PAH and Fels SA; among 85 U12 players, 74% were classified as average with %PAH compared to 52% with SA (52%), while among 93 U14 players, 72% were classified as average with %PAH compared to 59% with SA (Malina et al., 2012).

Corresponding trends were somewhat variable among participants in a local level American football program (Malina et al., 2007). Among 65 players aged 11–12 years, 54% were classified as average with %PAH compared to 22% classified as average with SA; on the other hand, 40% were classified as early with %PAH and 62% were classified as early with SA. Among 33 American football players aged 13–14 years, in contrast, no players were classified as late maturing with either %PAH or SA, while 61% were classified as average based on %PAH compared to 33% based on SA; the remaining players were advanced in maturity status, 39% with %PAH and 67% with SA (Malina et al., 2007). The results likely reflect the size and perhaps performance demands of American football and soccer.

Predicted maturity offset (MO) (Mirwald et al., 2002; Moore et al., 2015) is increasingly used as an indicator of maturity status in studies of youth soccer players and to a lesser extent among participants in other sports. Players are commonly classified as pre-PHV, at or close to PHV, or post-PHV, and to a lesser extent as late, average or early maturing based on predicted ages at PHV. Nevertheless, evidence from three longitudinal samples followed from 8 years through adolescence indicated that predicted MO and in turn predicted ages at PHV were influenced by maturity status based on observed ages at PHV in the respective samples. Predicted ages at PHV were later than observed ages at PHV in early maturing boys and were earlier than observed ages at PHV among late maturing boys (Kozieł and Malina, 2018; Malina et al., 2016). Predicted MO was also consistently later than observed MO (CA at prediction minus observed age at PHV) in early maturing boys, and was consistently earlier than MO observed in late maturing boys from 9 years of age through adolescence (Malina et al., 2021a). Similar results were also noted in a longitudinal series of male soccer players (Malina et al., 2021b).

It is important to note that predicted MO or age at PHV and %PAH are not equivalent maturity indicators. The former is an indicator of maturity timing, while the latter is an indicator of maturity status. Moreover, using similar criteria to define maturity status among 87 U12 and 93 U14 soccer players, 84 (97%) and 77 (89%), were, respectively, classified as average in maturity status based on predicted age at PHV compared to 64 (74%) and 67 (72%), respectively, classified as average with %PAH. Furthermore, among the 87 U12 and 93 U14 players, 45 (52%) and 55 (59%), respectively, were classified as average based on SA (Malina et al., 2012, 2015).

In contrast to the present study which compared the growth and skeletal maturity status along with functional characteristics of soccer players in competitive CA and BB groups, applications of bio-banding have largely focused on comparisons of players competing in CA- and BB-based competitions. For example, soccer players aged 11–14 years with %PAH ≥85.0% <90.0% participated in three games on a regular size field (11 vs. 11, 25-min halves); 16 players were randomly selected to participate in focus groups for the purpose of evaluating experiences of early (younger, playing up) and late (older, playing down) maturing players competing in the two formats (Cumming et al., 2017, 2018). Another related study considered experiences of 115 U10 through U15 players participating in a bio-banded tournament (Bradley et al., 2019). Similarly, the physical and technical demands of 11 vs. 11 regular and bio-banded (%PAH ≥90.0<95.0%) games among 13 players (14.0 ± 0.4 years) were compared (Thomas et al., 2017). The results indicated no differences in time spent in different heart rate intensity zones and the overall percentage of the maximal heart rate in the two formats. The bio-banded games, however, involved more technical and tactical demands (shots on the goal, touches, passes, etc.). Physical performances of soccer players aged 11–15 years also did not differ in CA and BB (%PAH 85.0–90.0%) games, although technical demands associated with the BB format varied with maturity status and a higher level of perceived exhaustion was noted among players advanced in maturity status (Hill et al., 2020).

Several recent studies examining game demands have used predicted MO as the maturity indicator. Among soccer players aged 11.7–13.7 years, MO-banded games required reduced physical demands but were more technically and tactically challenging than CA-based games (Lüdin et al., 2022; Romann et al., 2020). A comparison of performances in small-sided games (4 on 3) on a smaller playing area among 11–14 year-old soccer players classified as pre-, at- or post-PHV based on predicted MO and also %PAH suggested that bio-banded games reduced physical and psychological demands compared to regular games. Of interest, the BB format had a limited impact on technical, tactical and spatial indicators of performance (Towlson et al., 2021, 2022). Although not considered in the study, it is possible that the smaller playing area promoted a style of play that placed a priority on technical and tactical over physical skills, and may have also functioned to limit the size, strength and power advantages associated with advanced maturity status.

The previous studies have used predicted estimates of maturity status. More recently, a sample of soccer players aged 13–18 years was grouped by pubertal status and also by performance considering a functional indicator—change of direction (agility)—measured by a zig-zag run, as fast, intermediate or slow (Moran et al., 2022). Players' performances on soccer-specific skill tests (ball control, passing, shooting) did not differ among pubertal groups, but differed significantly among the agility groups, leading the authors to propose grouping youth players by skill (labeled "discreet performance banding") along with CA and maturity status to equalize competitions. Of interest in the present study of soccer players aged 9–16 years, indicators of speed and acceleration (sprints), agility (figure-of-8 run) and power (vertical jump) did not consistently differ between the respective CA and BB groups.

The present study is not without limitations. Sample sizes in the competitive CA and BB groups varied and were relatively small (except for BB1, n = 52). Moreover, selected bands of %PAH are to some extent arbitrary. Reported parental heights in contrast to measured heights were used in the equations for predicting adult height which were developed on American youth of European ancestry in the Fels Longitudinal Study. The results were also limited to players from two soccer clubs. In future studies it would be appropriate to expand sample sizes by including players from other clubs, which would permit club-specific comparisons. Nevertheless, an issue that cannot be addressed is the selectivity of the sport per se, i.e., voluntary drop-out and differential selection/exclusion of youth players.

Conclusions

The current study compared CA, SA, skeletal maturity status (late, on time or early maturing), body size and functional characteristics of youth soccer players in several competitive CA and BB groups defined by %PAH at the time of observation. Overall, the observations were consistent with the hypothesis of the study, i.e., bio-banding may reduce but does not eliminate variability in growth and maturity status of soccer players. Differences between U12 players and players in BB2 (≥85<90%PAH, estimated interval between take-off and PHV) highlighted the size and strength advantages associated with advanced skeletal maturity status at these ages. Contrasts between U10 and BB1 (<85% PAH, take-off of the growth spurt) players, between U12 and BB2 (85% <90% PAH, interval between TO and PHV), and between U14 and BB3 (≥90<95%%PAH, interval of PHV) players were generally similar, but the contrasts in skeletal maturity status, size and functional indicators were not as marked. On the other hand, the corresponding differences between

U16 and BB4 (≥95%PAH, post-PHV) players were negligible. Although %PAH and SA are not equivalent maturity indicators, all four bio-bands were represented among U14 players. The results highlight both the utility and limitations of %PAH as an indicator of maturity status, especially during the transition between the onset of the growth spurt and PHV. Nevertheless, bio-banded groups are not fixed and can be modified to meet the needs of specific training/competition programs and research questions.

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