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Associations between biological maturity level, match locomotion, and physical capacities in youth male soccer players

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Introduction: Biological maturity level has shown to affect sport performance in youths. However, most previous studies have used noninvasive methods to estimate maturity level. Thus, the main aim of the present study was to investigate the association between skeletal age (SA) as a measure of biological maturation level, match locomotion, and physical capacity in male youth soccer players.
Method: Thirty-eight Norwegian players were followed during two consecutive seasons (U14 and U15). Match locomotion was assessed with GPS-tracking in matches. SA, assessed by x-ray, physical capacities (speed, strength and endurance) and anthropometrics were measured in the middle of each season. Analysis of associations between SA, match locomotion, and physical capacities were adjusted for the potential confounding effect of body height and weight.
Results: In matches, positive associations were found between SA and maximal speed and running distance in the highest speed zones. Further, SA was associated with 40 m sprint time and countermovement jump (CMJ) height, and with intermittent-endurance capacity after adjusting for body height (U14). Associations between SA and leg strength and power, and between SA and absolute VO_{2max} were not significant after adjusting for body weight. There was no association between SA and total distance covered in matches.
Conclusion: Biological maturity level influence match locomotion and performance on physical capacity tests. It is important that players, parents and coaches are aware of the advantages more mature players have during puberty, and that less mature players also are given attention, appropriate training and match competition to ensure proper development.

KEYWORDS

biological maturation, GPS-tracking, match locomotion, physical capasity, skeletal age, youth soccer

1 | INTRODUCTION

In most organized sports, youths compete in age classes based on their chronological age, with the aim of providing fair competitions. However, chronological age and biological maturity level may not correlate, as puberty onset and developmental rate varies between individuals.[1,2] Hence, youths may compete with both biologically younger and older peers within their chronological age class. During adolescence, biological maturation may generate both anthropometric and physical variations between individuals within the same chronological age group. Knowledge of the association between biological maturation and performance in soccer is especially important as the onset of puberty often corresponds with selection of players to youth academies and elite- and national teams.

Growth and maturation influence strength, power and aerobic fitness,[3,4] and athletic performance during adolescence might thus be affected during puberty. Previous studies have found that biological maturity influence performance in different team sports,[5–7] indicating that more mature youth players may have advantages in matches compared to their less mature counterparts. Thus, a challenge when comparing performance of youth soccer players is that important physical capacities as speed, strength and endurance are related to maturity level, thus giving early-maturing players a potential competition advantage in matches.[4,8] Additionally, both height and weight alone,[9] and the increase in body weight and height from maturation might potentially affect physical performance outcomes in young soccer players.[4]

SA (skeletal age) and growth rate (somatic maturity) are maturity indicators that reflect the stage of maturity. SA assessed by x-ray and subsequent image analyses has been proposed as the gold standard for determining bone maturity in infants, children, and adolescents.[10] Due to radiation exposure, albeit minimal, and need of x-ray equipment, several alternative/noninvasive methods to assess biological maturity level has been proposed. However, these methods (e.g., age at peak height velocity, percent of predicted adult height, self-reported puberty level) have limitations in their accuracy to determine maturity level.[11,12,13] Thus, although there is growing evidence of the effect of biological maturation on physical performance in youth soccer, there is a need for studies using reliable and validated methods to assess maturity level. To the best of our knowledge, there are no previous studies following the same players during two consecutive seasons in male youth soccer, and only a few studies investigating match locomotion and physical capacity in Scandinavian youth soccer. Thus, to increase the knowledge of the influence of biological maturity and performance in male youth soccer, we aimed to study the associations between biological maturity level, assessed by x-ray, physical capacities and match locomotion in two consecutive seasons (U14 and U15). As a secondary aim, we compared match locomotion and physical capacities between the seasons.

2 | METHODS

The present study is part of a longitudinal research project examining factors related to talent development in youth soccer from the age of 14 years (U14). In the present study, match locomotive data from matches in the U14 (April to November 2018) and U15 (April to October 2019) seasons were included. In addition, biological maturity status assessed through SA, anthropometric and physical capacity data were examined in the middle of each seasons (June in 2018 and August in 2019), with the slight discrepancy between seasons being due to logistical constraints.

2.1 | Participants

A total of 38 male outfield players from Western Norway were included (Table 1). To be included, the players had to participate in the two subsequent seasons (U14 and U15).

The Regional Committee for Medical and Health Research Ethics approved the study (2017/1731), which was conducted in accordance with the Helsinki declaration. Since players were under the legal age of consent, both the players and their parents gave a written informed consent for participation. All results were treated unidentified.

2.2 | Skeletal maturation

X-ray of the left hand was performed to estimate SA as a measure of skeletal maturity level, using Siemens Ysio Max with the integrated imaging system FLUORPSPO Compacts (software version VE10; Siemens Healthineers). The x-ray file of view covered the whole hand

TABLE 1 An overview of chronological age, skeletal age and anthropometrics of the players ($n = 38$)

	U14	U15
Chronological age (years)	14.1 ± 0.2	15.3 ± 0.2
Skeletal age (years)	14.1 ± 1.1	15.4 ± 1.3
Height (cm)	167.2 ± 7.5	174.5 ± 6.0
Body mass (kg)	52.6 ± 8.0	60.9 ± 8.0
Body fat (%)	8.2 ± 2.7	7.9 ± 3.2

Note: Data are presented as mean ± standard deviation.

(posterior–anterior view), including 3 cm of the distal arm to include the epiphyseal plates in radius and ulna. The tube-detector distance was 1 m, the x-ray energy 50-kilo volt (kV) and 1–1.5 milliampere-seconds (mAs). There was no processing or filtering of the images. The x-ray image analyses were done using BoneXpert Stand-alone version 3.1.4 (Visiana). The skeletal age determinations were based on Greulich Pyle (GP) rating of bone maturation in BoneXpert. X-rays were taken on the same day as height, weight and physical tests were performed.

2.3 | Anthropometric data

Height was measured with a stadiometer (Seca 206 and Seca 217), recorded to the nearest 0.1 cm. Measures were performed using the ISAK procedure and by the same personnel. Body mass and body fat (%) were estimated using an eight-polar bioimpedance method using multifrequency current (InBody™ 720, Biospace CO).[14] All measurements were performed barefoot.

2.4 | Physical tests

Physical tests were performed during two different days for each player in both seasons. There was approximately one week between test day one and two. All tests were performed between 16 and 20 PM. Test day 1 included the 40 m sprint test and the Yo–Yo intermittent recovery level 1 test (IR1-test). On the second day, leg strength and peak power, countermovement jump (CMJ) height and maximal oxygen uptake (VO_{2max}) were tested. All procedures and tests are previously described in detail.[15]

2.5 | 40 m sprint

The 40 m sprint tests were performed on an indoor track with a wall-mounted electronic photogate system (IC Control TrackTimer). Before the sprint tests, all players performed a standardized 30-minute warm-up protocol with increasing intensity and running speed. After the warm-up, all players performed three maximal sprints of 40 m separated by 2–3 min of rest. The fastest of the three attempts was included in the analysis.

2.6 | Intermittent endurance

The Yo–Yo IR1 test was used to evaluate the players intermittent-endurance capacity. Players performed a 10 min warm-up, which included low intensity jogging and the first 5 levels of the test to be familiar with the procedures and the starting speed. The test was performed indoor on a wooden sports floor, with a standardized starting speed for all players, and in line with the procedures suggested previously.[16] Total distance (m) covered was used for statistical analysis.

2.7 | Countermovement jump

A 10-min warm-up on a bike was done before the CMJ test, which was performed using a Kistler 9286B force plate (Kistler Instruments AG). From a standing position (with hands on hips and extended knee and hip), a CMJ was performed to a self-selected depth. Maximum jump height (cm) was calculated using Kistler Measurement, Analysis and Reporting Software (MARS, 2015, S2P). The best of three attempts was used in the statistical analyses.

2.8 | Leg strength and power

Leg strength and power was measured with the Keiser leg press (LP) machine (Keiser A300, Keiser Co. Inc.) and analyzed with the Keiser Air 420 software (version 9.3.42). Initially, knee angle in seated position was measured with a goniometer and placed as close to 85 degrees as possible (U14: 84.0 ± 2.2, U15: 83.9 ± 2.1). For familiarization, all players performed two repetitions guided by experienced test personnel. The protocol used consisted of 10 repetitions with gradual increasing load and time between repetitions.[17] The protocol is set by the Keiser software and determined by the players 1RM (Keiser A420 operations and maintenance manual). Players were instructed to conduct all repetitions with maximal effort (e.g., extend the knees as fast as possible). Maximal load obtained in the test and peak power (Watt) were used in the statistical analyses.

2.9 | Maximal oxygen consumption

Each player performed a low intensity 10-min warm-up (increasing gradually from 8 to 10 $km \cdot h^{-1}$) on a treadmill prior to testing. The maximal oxygen consumption (VO_{2max}) test was performed on a motorized treadmill (Woodway PPS55) at a constant inclination of 5.3%. The test personnel were highly experienced and have conducted tests in all age groups and athletic levels. The test started with a speed between 8 and 10 $km \cdot h^{-1}$ (U14) and 9–12 $km \cdot h^{-1}$ (U15), where the test personnel made a subjective assessment of an appropriate starting speed for each participant. After the start of the test, speed was increased by 1 $km \cdot h^{-1}$ every minute to voluntary exhaustion. VO_2 was measured using a computerized metabolic system with mixing chamber (Oxycon Pro, Erich Jaeger GmbH). Prior to each test, the flow-meter was calibrated with a 3-L volume syringe (Hans Rudolph Inc.), and the volume of oxygen (VO_2) and carbon dioxide (VCO_2) was calibrated using high-precision gases (16.00 ± 0.04% O_2 and 5.00 ± 0.1% CO_2, Riessner-Gase GmbH & Co). VO_{2max} was defined as the highest average of two consecutive 30-s measurements.[18]

2.10 | Matches

All matches were official league or cup matches at the highest local level or at national level with 11 players per team played on artificial grass. Data were analyzed from 326 (U14) and 294 (U15) match halves: 177 (U14) and 165 (U15) match observations from first half, and 149 (U14) and 129 (U15) form second half. Official match playing time was 2 × 35 min for U14 and 2 × 40 min for U15. To allowed direct comparison between seasons, all matches were normalized to 2 × 40 min.

2.11 | GPS-tracking and match-running categories

During the matches, the players wore a portable and previously validated GPS device[19] (Apex, STATSsport) monitoring their motions and position with a sampling frequency of 18 Hz. The units were placed in vests located between the players' scapula. The players wore, in most cases, the same unit in every game to limit inter-unit reliability issues, although the present GPS system has been shown to have excellent inter-unit reliability. All GPS devices were placed outside in record mode prior to testing, to ensure adequate satellite connection. Given the latitudes of the location, the data were collected, minimum four were accessed during matches. The raw GPS data were synchronized to the start and end of each half match period and exported for further analysis. Since competitions in Norwegian youth soccer permits rolling substitutions during matches, only GPS measurements from full match halves by the same player were included in the dataset.

Locomotion was divided into different speed categories: walking (<0–4.5 kmh^{-1}), low intensity running (<4.5–8 $km \cdot h^{-1}$), medium intensity running (8.5–13.5 $km \cdot h^{-1}$), high intensity running (HIR, <13.5–18.5 $km \cdot h^{-1}$), and very high intensity running (VHIR, >18.5 $km \cdot h^{-1}$). In addition, sprint distance (speed above 25.2 $km \cdot h^{-1}$ for at least 1 s) was included.[20] We used speed thresholds adapted from previous studies on U14 soccer players.[21] To be able to compare match locomotion in U14 and U15 seasons, same speed categories were used for U14 and U15 matches. Total distance includes all motions during match. To be able to compare match locomotion in U14 and U15 seasons, same locomotion categories are used for both. In addition, maximal speed in each half was registered. Number of accelerations and decelerations were also examined and defined as an action when speed was increased or decreased by more than 3 ms^{-2} lasting for more than 0.5 s. Only accelerations and decelerations at speed above 13.5 $km \cdot h^{-1}$ was included to investigate the demanding accelerations.

2.12 | Statistics

Data are presented as mean with standard deviation (SD) or 95% confidence interval (95% CI). Visual inspection confirmed that all data were normally distributed. Pearson's correlation analyses were used to investigate the associations between SA and the anthropometric data. Dependent sample t-tests were performed to compare SA, anthropometric and physical test results from the U14 and the U15 season. Linear regression models were used to investigate the associations between SA and physical capacities. The fixed effects (E) of SA on match locomotion was assessed using linear mixed-effect models with the player as a random effect to adjust for multiple match observations by the same player. Match locomotion (total match distance, HIR distance VHIR distance, sprint distance, maximal speed and number of accelerations and decelerations) were dependent variables in separate models.

The potential confounding effect of body height and weight on the association between skeletal age and physical capacities and match locomotion was investigated by Hosmer's manually backward elimination technique. An r-value/standardized beta between 0.01 and 0.29 was defined as a small correlation, between 0.30 and 0.49 as a medium correlation, and from 0.50 to 1.0 as a large correlation. Analyses were performed both for the U14 and the U15 season. When comparing match locomotion differences between the U14 and the U15 season, independent of the players SA, U14 and U15 matches were included as an independent factor. IBM SPSS Statistics for Windows, Version 27.0. (IBM Corp) was used for all statistical analyses. Significance for all analyses was accepted at $p \leq 0.05$.

3 | RESULTS

SA measured in the U14- and U15 season ranged between 11.9–17.7 and 12.6–19.0 years, respectively, with corresponding CA between 13.6–14.4 and 14.8–15.6 years. See Figure 1 for an example of x-rays of two players in two consecutive seasons (U14 and U15). The radiographs demonstrate the variability in skeletal age between the players despite the same chronological age. There were positive correlations between SA and body height (U14: $r = 0.588$, $p < 0.001$, U15: $r = 0.391$, $p < 0.019$) and body mass (U14: $r = 0.754$, $p < 0.001$, U15: $r = 0.657$, $p < 0.001$) at both time points. No correlation was found between SA and body fat (%). All descriptive statistics of SA, chronological age and anthropometrics of the players are presented in Table 1.

3.1 | Associations between SA and physical capacities and match locomotion

Analyses showed a large negative correlation between SA and 40 m sprint time and a medium positive correlation between SA and CMJ height. There was a large positive correlation between SA and leg strength (U14: $r = 0.685$, <0.001, U15: $r = 0.551$, $p < 0.001$) and power (U14: $r = 0.710$, $p < 0.001$, U15: $r = 0.605$, $p < 0.001$) and between SA and absolute VO_{2max} (U14: $r = 0.753$, $p < 0.001$, U15: $r = 0.647$, $p < 0.001$), but the correlations were small and not statistically significant after adjusting for body weight (Table 2). SA was associated with intermittent-endurance capacity at U14 only after adjusting for body height.

Moreover, there was a positive association between SA and VHIR distance (U15), sprint distance (U14 and U15), and maximal speed (U14 and U15) obtained in one match half (Table 2). There was no association between SA and total running distance, HIR distance, VHIR distance (U14), nor in number of accelerations or decelerations.

3.2 | Physical capacity and match locomotion

There was an improvement in performance on all tests from U14 to U15 except for VO_{2max} (ml·kg^{-1} min^{-1}). Besides total match distance, there was an increase in HIR

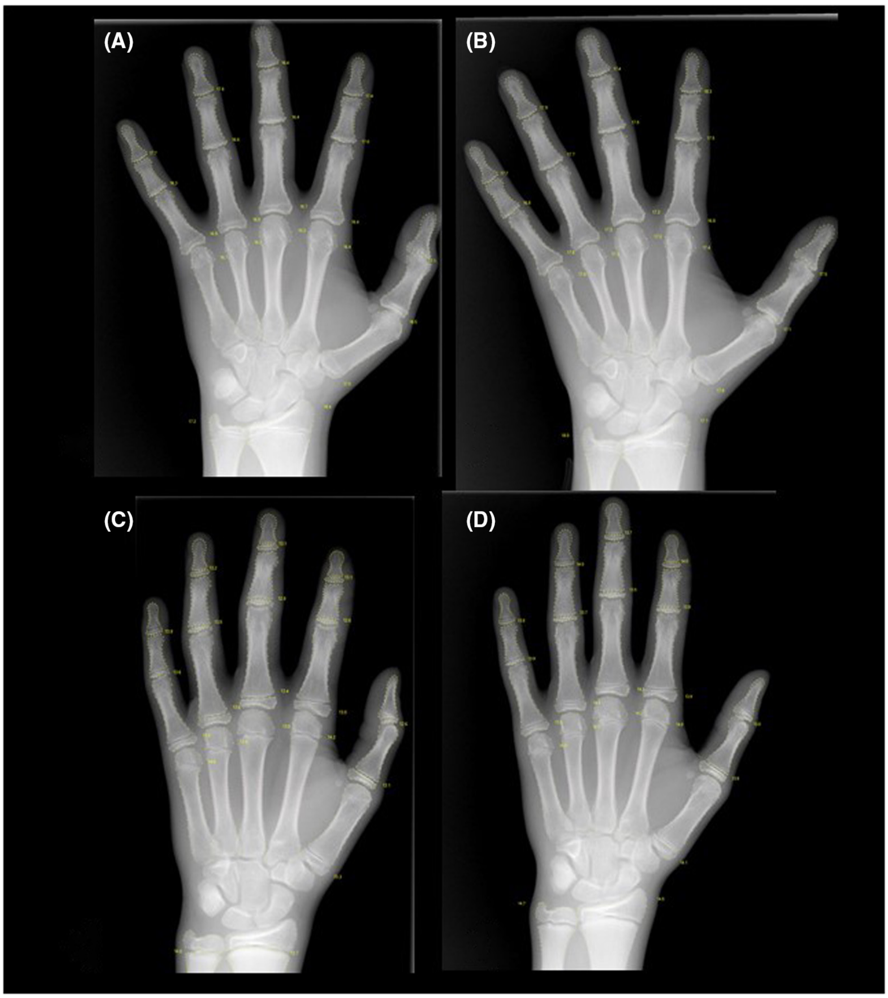

FIGURE 1 It demonstrates radiographs of the left hand and distal arm of two different players in two consecutive seasons (A, C: U14 and B, D: U15). The yellow dotted lines delineate the bones that were used for measuring the skeletal age in each radiograph using BoneXpert. The skeletal age for player one was measured to (A) 16.6 years and (B) 17.4 years and for player two (C) 13.4 years and (D) 14 years in the U14 and U15 season, respectively.

TABLE 2 An overview of associations between players ($n = 38$) skeletal age and physical capacities and match locomotion

	Skeletal age (U14)		Skeletal age (U15)	
Physical capacities[a]	β	***p*-value**	β	***p*-value**
40 m (s)	−0.691	<0.001	−0.590	<0.001
Countermovement jump height (cm)	0.471	0.003	0.396	0.022
Leg strength				
Maximal load (kg)	0.214[e]	0.203	0.161[e]	0.330
Power (watt)	0.177[e]	0.243	0.155[e]	0.271
Maximal oxygen consumption ($ml\,min^{-1}$)	0.251[e]	0.074	0.181[e]	0.151
Yo–Yo intermittent recovery test level 1 (m)	0.486[f]	0.016	0.069	0.721
Match locomotion[b]	**E [CI]**		**E [CI]**	
Total distance (m)	−55.6 [−183.4–72,2]	0.383	7.6 [−101.3–116.4]	0.888
HIR distance (<13.5–18.5 $km{\cdot}h^{-1}$) (m)	−34.6 [−92.6–23.5]	0.325	−4.2 [−57.0–48.6]	0.872
VHIR distance (>18.5 $km{\cdot}h^{-1}$) (m)	17.4 [−11.3–46.1]	0.226	30.4 [3.7–56.9]	0.026
Sprint distance (m)[c]	8.9 [3.0–14.8]	0.004	7.4 [0.8–14.0]	0.030
Maximal speed ($km{\cdot}h^{-1}$)	0.5 [0.1–0.9]	0.028	0.7 [0.3–1.1]	<0.001
Accelerations (n)[d]	0.03 [−1.93–1.99]	0.979	0.84 [−0.96–2.63]	0.953
Decelerations (n)[d]	−1.01 [−3.51–1.49]	0.418	1.31 [−0.89–3.51]	0.233

Abbreviations: HIR, High intensity running; VHIR: Very high intensity running.

[a]Linear regression (β = standardized beta coefficient).

[b]Linear mixed-effect model analyses correcting for multiple match observations by the same player (E = estimate, [95% confidence interval]). $p \le 0.05$ was considered statistically significant.

[c]Speed above 25.2 $km{\cdot}h^{-1}$ for more than 1 s.

[d]Increase/decrease in speed with 3 ms^{-2} lasting for at least 0.5 s in speed zones above 13.5 $km{\cdot}h^{-1}$.

[e]Confounded by body weight.

[f]Confounded by height.

distance, VHIR distance, sprint distance, maximal speed, and number of accelerations and decelerations from U14 to U15. Players physical capacities and match locomotion are presented in Table 3.

4 | DISCUSSION

In the present study, the main aim was to investigate the influence of biological maturity level on match locomotion and physical capacity in male youth soccer players. Our results showed that biological maturity level was associated with 40 m sprint time and CMJ height, and with intermittent-endurance capacity (U14) after adjusting for body height. In addition, positive associations were found between biological maturity level and leg strength and power, and between biological maturity level and absolute VO_{2max}; however, the associations were not significant after adjusting for body weight. Further, the biological maturity level measured as SA was positively associated with VHIR distance (U15), sprint distance (U14 and U15) and maximal speed (U14 and U15) in matches. No associations were found between biological maturity level and acceleration/deceleration or total running distance in matches, or intermittent-endurance capacity (U15). Finally, players covered greater distance in higher speed zones in U15 compared to U14, although the total match-running distance was similar. Players also improved physical capacities from U14 to U15, except for VO_{2max} ($ml{\cdot}kg^{-1}\,min^{-1}$).

Our results also showed associations between maturity level and 40 m sprint time and countermovement jump height. Our findings are in line with those by Itoh and Hirose (2020)[22] who found that average and more mature players (U13) from a national professional league in Japan ran faster on a 50 m sprint test and performed better on a 5-step bounding test compared to the late mature players. Also, Rommers and colleagues[23] showed that early-maturing Belgian U14 and U15 soccer players ran faster compared with on-time or late-maturing players of the same chronological age. The advantage more mature players may have, could be explained by physiological adaptations that naturally develops through adolescence because of puberty, such as increased muscle mass[24] and neuromuscular changes.[25] The abovementioned adaptations will likely be an advantage on efforts requiring a

TABLE 3 An overview of players ($n = 38$) physical capacities measured in the middle of the U14 and U15 seasons and match locomotion during both seasons

Physical tests[a]	*n*	U14	U15	*p*-value
40 m (s)	32	5.78 ± 0.3	5.51 ± 0.3	<0.001
Countermovement jump height (cm)	32	31.4 ± 5.1	34.3 ± 5.5	<0.001
Maximal leg strength				
Maximal load (kg)	33	173 ± 40	216 ± 45	<0.001
Power (Watt)	32	842 ± 227	1061 ± 256	<0.001
Maximal oxygen consumption (ml·kg^{-1} min^{-1})	33	62.2 ± 5.9	61.8 ± 4.9	0.650
Yo–Yo Intermittent Recovery Test Level 1 (m)	29	1385 ± 451	1757 ± 514	<0.001
Match locomotion[b]	***n***	**U14 (*n* = 326 halves)**	**U15 (*n* = 294 halves)**	***p*-value**
Total distance (m)	38	4384 ± 62	4416 ± 62	0.203
HIR distance (<13.5–18.5 km·h^{-1}) (m)	38	706 ± 27	739 ± 27	0.006
VHIR distance (>18.5 km·h^{-1}) (m)	38	271 ± 15	313 ± 15	<0.001
Sprint distance (m)[c]	38	22 ± 4	37 ± 4	<0.001
Maximal speed (km·h^{-1})	38	26.8 ± 0.3	27.8 ± 0.3	<0.001
Accelerations (*n*)[d]	38	22 ± 1	25 ± 1	<0.001
Decelerations (*n*)[d]	38	26 ± 1	30 ± 1	<0.001

Note: Data are presented as mean ± standard deviation.

Abbreviations: HIR, High intensity running; VHIR, Very high intensity running.

[a]Paired sample t-tests for comparisons of U14 and U15 measurements.

[b]Data are corrected for multiple match observations by the same player.

[c]Speed above 25.2 km·h^{-1} for more than 1 s.

[d]Increase/decrease in speed with 3 ms^{-2} lasting for at least 0.5 s in speed zones above 13.5 km·h^{-1}. $p \leq 0.05$ was considered statistically significant.

high level of strength or power, such as high-speed running and sprinting in matches and in laboratory tests demanding explosive actions.

Our finding showed an association between SA and intermittent-endurance capacity in U14. Height was negatively associated with intermittent-endurance capacity in the model, indicating that more mature players with low body height performed superior to others. This may be explained by more effective turning technique and lower center of gravity in lower but more mature players. On the other hand, maturity level was not associated with intermittent-endurance capacity in U15, or with VO_{2max} (ml min^{-1}) after adjusting for body weight nor in U14 or U15. Regardless, a different study showed no difference between maturity level (early, average and late) and performance on the Yo–Yo IR2 test, and the Cooper run test in U13 players.[22] Also, a previous study from Brazil using x-ray to measure SA showed that intermittent-endurance running capacity in youth soccer players was independent of SA.[26] Our results indicate that aerobic capacity is not associated with maturity level in youth soccer players in these age groups after adjusting for body weight.

Our results showed that more mature players reached higher maximal speed and covered more distance at the higher speed zones (>18.5 kmh^{-1}) in matches. High-speed running, sprinting and maximal speed seems to be physical capacities that are important for match performance. Indeed, speed and power has been shown to differentiate playing standards and age groups in youth soccer,[15,27,28] and also to be a key performance indicator during significant moments of the match.[29] A few previous studies have investigated the association between estimated maturity level, using age at peak height velocity, and match locomotion. Francini and colleagues[6] found a small to moderate relationship between maturity level among Italian U14–U17 players and match-running distance at the higher speed zones (>18 and >23 kmh^{-1}), and Buchheit and Mendez-Villanueva[30] showed that more mature U15 players covered greater high-speed running distance (>16 kmh^{-1}) and reached higher peak speed compared to their less mature peers. On the other hand, Goto and colleagues who investigated U9–U16 English Premier League academy players found that maturity level was associated with distances covered at the higher speed zones only among the U13/U14 players, but not among the younger (U9/U10, U11/U12) or older (U15/U16) players. Since the abovementioned studies have used noninvasive estimates of maturity level, caution needs to be addressed when interpreting the associations between maturity level and match-related running performance. However, our results show that maturity level must be considered when evaluating players high-intensive and sprinting performance during matches.

Further, our results showed no association between total distance covered in matches and maturity level. This is in agreement with previous studies,[7,30] with the exception of the study by Francini and colleagues[6] who found greater total distance covered in matches in more matured players when rate of perceived exhaustion (RPE) was above 5. Moreover, previous studies have shown that total distance are not different between playing standards in senior soccer,[31] and thus not the most essential factor for match performance. Additionally, we found no association between maturity level and number of accelerations and decelerations during matches. This is somewhat a surprise as maturity level was linked with both higher VHIR distance and higher maximal speed during matches. Hence, it would be expected that more mature players would also express their superior acceleration capabilities on the pitch. Still, our findings are in line with Francini and colleagues[6] who found no association between maturity level and acceleration distance in youth soccer. Based on these results, it could be speculated that a higher number of acceleration and decelerations per se are not a key performance indicator during youth matches at U14 and U15 level. We cannot rule out that better executive function in more mature players[32] means that they perceive situations better and, therefore, do not need to accelerate more often than less mature players. Regardless, more research is warranted to further understand the discrepancy between acceleration, high-speed and sprint capabilities during youth matches.

As expected, our results showed improved physical performance from U14 to U15 both in matches and in laboratory tests. The increase in physical capacity between the age groups align well with the natural adaptations from growth and maturation and corresponding increase in physical performance.[4,33–38] Exception was seen for relative VO_{2max} ($mlkg^{-1}$ min^{-1}), which may be explained by the increase in body mass from U14 to U15, as discussed above. Increased high-speed running in U15 matches may be explained by the increase in sprinting abilities from U14 to U15.

A strength of the present study is the use of x-ray to assess biological maturity. Maturation of the skeletal system involves a well described transition from cartilaginous structures to a fully developed skeleton of bones in an invariable manner. Radiographs provide detailed information about ossification status and hence, skeletal age,[10] which indicates the level of biological and structural maturity. Moreover, image analysis software using machine learning such as BoneXpert, eliminates the dependency of user experience and source of inter-reader variance[39] and is also in clinical use for assessment of skeletal maturation for the same reasons. As x-ray availability were of no concern, radiographs of the hand were considered as the superior method to estimate biological maturity level. Also, during a hand and wrist x-ray procedure, the radiation exposure to the hand is <0.00012 mSv of radiation, which is lower than other daily physiological risks.[40] To the best of our knowledge, this is the first study using the gold standard of left-hand x-ray to investigate the associations between skeletal maturity level and match-running performance in youth soccer players. Although we have players with a large range of skeletal age in our study population, we cannot exclude that including only players that played full halves have led to an under-representation of less mature players. Further, GPS data were related to a maturity assessment in the middle of each of the seasons and may not reflect the actual maturity status of the player during each of the seasons. All GPS devices were placed outside in record mode prior to testing, to ensure adequate satellite connection. In addition, all matches were played in soccer fields with minimal stands surrounding the pitch. However, it's worth noting that we do not have the exact numbers of satellites each of the GPS devices were accessing.

5 | PERSPECTIVES

Our findings showed that maturity level influence match locomotion and performance on physical capacity testing, for example, more mature players covered greater distance in the highest speed zones during matches and ran faster and jumped higher in laboratory tests. Hence, the academies, regional teams and national teams that evaluate players capabilities must be aware that physical performance during matches can be affected by maturation. This is an important finding to communicate as their judgment of players might be clouded by players maturational development and not their potential to become elite players. If SA measurements are not possible, body height and/or body weight might be used as indicators of maturation status on a group basis in an academy setting with highly trained male youth athletes. However, precautions must be taken as adult height varies between individuals and might be reached at early age in some individuals despite lower body height than average. Also, body weight might be used as an estimate of muscle mass in a homogenous group of highly trained male youths, but not as a stand-alone parameter for biological maturity. Further, the relative physiological demands in games between players are likely very different, highlighting the need for appropriate load monitoring to ensure safe progression throughout the developmental years. Within this context, comparing match demands of different age cohorts with individual physical performance can give coaches and practitioners better insight to know when players are physically capable to be challenged in an older chronological age group. Hence, our findings suggest that players, parents and coaches should seek and develop suitable strategies to give appropriate attention, training and match competition to all players regardless of maturity level.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study require permission from the Regional Committee for Medical and Health Research Ethics. If interested send an email to the corresponding author.

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