Biological maturation and match running performance: A national football (soccer) federation perspective

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Abstract

Objectives: To examine the influence of maturation and its interaction with playing position upon physical match performances in U15 footballers from a national federation.

Design: Observational Study

Methods: 278 male outfield players competing in a national tournament were assessed for somatic maturity and match physical performances according to playing position. Stature, sitting height, and body mass were measured and entered into an algorithm to estimate the age at peak height velocity (APHV). Players match movements were recorded by Global Positioning System devices (10Hz), to determine peak speed, and total- (TD), low-speed running (LSR; ≤ 13.0 km·h^{-1}), high-speed running (HSR; 13.1 - 16.0 km·h^{-1}), very high-speed running (VHSR; 16.1 - 20.0 km·h^{-1}) and sprint distances (SPR; > 20.0 km·h^{-1}) expressed relative to match exposure (m·min^{-1}).

Results: Linear-mixed models using log transformed response variables revealed a significant contribution of estimated APHV upon TD (1.01; 95% CI: 0.99-1.02 m·min^{-1}; $p < 0.001$), HSR (1.05; 95% CI: 0.98-1.13 m·min^{-1}; $p < 0.001$) and VHSR (1.07; 95% CI: 1.00-1.14 m·min^{-1}; $p = 0.047$). An increase by one year in APHV was associated with an increase of 0.6, 5.4 and 6.9% in TD, HSR and VHSR respectively. No effects of APHV were observed for LSR, SPR, and peak speed. Further, no APHV effects were observed relative to players' field position.

Conclusion

Later maturing players covered substantially more higher-intensity (HSR and VHSR) running in matches, irrespective of playing position. The greater match intensity of later maturing players may inform talent identification and athletic development processes within a national federation.

Key Words: somatic maturity; match running performance; football

Introduction

National Football (soccer) Federations provide resources and infrastructure to talent development programs to accelerate or optimize young player advancement (Bennett); often in collaboration with regional level member federations and club academies. Selection into national talent development pathways is typically based upon identification by experienced coaches by benchmarking players' potential talent against age-matched peers. These observations are sometimes supplemented by objective measures of anthropometry, fitness, motor skill competence, decision-making or football-specific skill {Deprez:2015br}{Figueiredo:2009jh}. Accordingly, age-categorization in youth sport is used to provide safe and appropriate competition structures to facilitate between-player comparisons for talent identification{Helsen:2005fk}. However, within talent development programs, transient physical advantages are afforded to relatively older (known as the relative age effect[1,2]) or earlier maturing players[3,4] with more favorable body size and physical fitness characteristics[5-8]. These enhanced physical attributes have implications for talent selection[9], and ought to be considered to limit the confounding effect of biological maturation on progression through talent pathways[10,11].

With advancing maturity, youth players show robust improvements in locomotor capacities, including peak and maximal aerobic speed[5,12,13]. Superior physical capacities in turn manifest in greater distances covered or higher absolute intensities during competition[6,14]. For example, in Australian Rules Football, somatic maturation is positively associated with greater total distance, high-speed running, and peak speed in matches[8], with earlier maturing U15 players covering more total- and high-speed (>14 $km{\cdot}h^{-1}$) running distances[7]. However, smaller playing areas, specific tactical formations, and the different athletic characteristics of this sport[15] impinge the generalizability of these findings to association football. In youth football, factors such as playing position influence match running performance to a greater extent than players' physical capacities or age[12,16], and thus soccer-specific data is required.

Only one study has examined the impact of maturation on running performance in football. Buchheit and colleagues[6] categorised 36 U15 Academy players into less (maturity offset: -0.3 ± 0.3 years) and more (maturity offset: +0.9 ± 0.4) mature groups, comparing their 1st half match running performances from 115 match observations. Players with advanced maturity (years from peak height velocity; YPHV) showed greater peak speeds and distances covered at high-speed in matches (>16 $km{\cdot}h^{-1}$), with no difference in total distance covered. Within-position correlations between YPHV and match running performances also varied, with only midfielders and wingers showing a positive association between increased maturation and greater first-half running performance. Whilst pioneering work, further research is warranted on the following grounds: 1) although earlier maturing players have enhanced capacities to perform more running in matches, this does not always translate into greater match running performances in youth players[12,17]; 2) the high-degree of variability in match running performances [18] influenced by opposition standard or situational factors (score-line, environment etc.;[19]) may require larger sample sizes; 3) as match running performances are also governed by tactical factors[20], the impact of maturity may have also been moderated by the different opposition teams in previous work[6]; and 4) football federations adopt playing formations across their national team development pathway that differ [6], and likely influence interpretation of match running performances[20], and their association with maturity.

Accordingly, this study assessed the impact of maturity upon match running performance in a national football federation context, with particular emphasis on how playing position may moderate the effect of maturity. Consequently, the study represented a unique opportunity within a tournament environment to limit the impact of tactical factors upon match running performances, as each team adopted the federation tactical formation based on the national coaching curriculum.

Materials and Methods

With parental assent and ethical approval (H11985), data were collected across two consecutive Australian national talent camps in 2016 and 2017. Data were collected from 278 U15 players (Age: 15.3 ± 0.4years; Stature: 173.5 ± 7.1cm; Body Mass: 61.8 ± 7.4kg) invited to participate in a tournament in which 9-member federation teams competed in two matches per day over three consecutive days. Matches were 50-min in duration (2 x 25-min), with a 10-min half-time break. Substitutions were only permitted during half-time, unless an injury was sustained. The purpose of the tournament was to identify players with potential to represent their country, and to assign those players to talent development programs. Each squad was comprised of 18 players, including two goalkeepers, and coaches were instructed to provide a minimum of 150 minutes of playing time for each player across the six matches. A minimum of three hours recovery was allocated between subsequent matches scheduled on the same day, with all squads accessing cryotherapy facilities following each match. Anthropometric data to estimate somatic maturity was collected prior to the first tournament match, and match-running performance was monitored in outfield players only.

Players' stature and sitting height was measured in duplicate to the nearest 0.1 cm (WS-HRP, Wedderburn, Australia). Sitting height was measured on an anthropometric box of 40cm height, with the buttocks and thoracic spine against the stadiometer. Body mass was assessed with electronic scales reporting to the nearest 0.1 kg (BC-545N, Tanita Corporation, Japan). All measurements were performed in training attire, without socks and shoes. Mean values were used for ensuing analysis, unless duplicate measures differed by > 0.4 cm or kg, in which case a third measure was collected and the median value assigned.

Anthropometric measures and chronological age were used to estimate somatic maturity using the maturity ratio algorithm[21]. The maturity ratio was adopted in this study considering the original non-invasive prediction equation developed by Mirwald and colleagues[22] over-estimates the age at peak height velocity (APHV) in the year preceding PHV[23], and in boys over 16 years[22,24]. Furthermore, the Fransen maturity ratio was used because it was validated in a sample of high-level youth soccer players and found to provide a more robust non-invasive prediction of APHV, especially in boys who are relatively far removed from their APHV[21]. Predicted APHV rather than YPHV was used as an indicator of maturity given the fact that this sample consisted of players who had passed their APHV (YPHV between -0.3 – 2.8 years), with the exception of eight players who were younger than their predicted APHV. Given the homogeneity in CA and YPHV observed in this sample, as well as the strong correlation observed between predicted YPHV and APHV ($r = -0.72$, $p<0.001$), predicted APHV was used an indicator of maturity.

Players' movements on the pitch were monitored using 10 Hz global positioning systems (GPS; S4 and X4, Catapult Sports, Australia). The units were housed in neoprene undergarments, with the appropriate garment size selected for each player before the tournament commenced. GPS files were trimmed to exclude any data other than that collected when participating in tournament matches (i.e. warm-up, half-time, substituted). GPS devices were switched on prior to the warm-up, approximately 15-30min before kick-off to facilitate maximum signal connection with orbiting satellite network (Satellites: 10.22±1.57; Horizontal dilution of precision:

0.97±0.11). Of note, given the tournament setting it was not possible for players to use the same unit for each match.

The distance covered was also categorized into speed zones, using a dwell-time of 0.2 sec. The transition velocity between low- (LSR) and high-speed running (HSR; 13.0km·h^{-1}) was selected in accordance with previous elite-youth football studies[12]. Very-high speed running (VHSR) was categorized as distance covered above 16.0km·h^{-1}, which corresponds to maximal aerobic speed in similar aged elite-youth players[12]. The speed threshold to classify sprinting (SPR) was anchored (approximately) to 30% of the anaerobic speed reserve (20km·h^{-1};[16]) based upon maximal aerobic speed and maximal speed assessments taken from elite U15 football players[12]. Total distance covered, together with the distance covered in each speed category were calculated on a relative basis (m·min^{-1}) to account for the different playing times. Peak speed attained in matches was also determined according to previous research {Massard:2017hm}. GPS data were exported from the manufacturers software (Sprint, version: 5.1.7, Catapult Sports, Australia) having been pre-filtered to eliminate spurious data ("intelligent motion filter").

The FFA curriculum mandates a common tactical approach across the talent development pathway. The playing formation may be considered as a 4-3-3 configuration (see supplemental figure 1). The approach adopts a holding midfield player (#6) tasked to assist the defenders and permit lateral defenders (#2 & #5) to support offensive play. Lateral midfield players are instructed to adopt a higher starting position on the pitch, with a predominant focus on offensive strategy. Central defenders, midfielders and the striker operate in a more traditional manner as described in other football match running literature[12,25]. *A priori* analysis of the current data set demonstrated distinct running profiles of the positions, and therefore we adopted the following positional categories: central defenders (CD; #3 & #4), lateral defenders (LD; #2 & #5), holding midfielder (HM; #6), central midfielders (CM; #8 & #10), lateral midfielders (#7 & #11) and striker (S; #9). The playing position was determined at the start of each playing half by visual observation and confirmation on post-match video footage Observations where players played less than 10min within a game were removed from analysis as they significantly skewed the data. This resulted in a total of 1162 observations from 278 players, whom often changed positions to meet tournament regulations for playing time (observations [players]; CD: 217 [83]; LD: 240 [92]; HM: 121 [48]; CM: 232 [59]; LM: 237 [97]; S: 115 [46]).

To investigate the effect of the estimated timing of the adolescent growth spurt on match running demands, a series of linear mixed models were developed. A stepwise approach was used in which additional predictors were added to the model with each step, and model fit was evaluated using the Aikaike Information Criterion (AIC), observation of increases in degrees of freedom, a -2 log likelihood ratio test and the normal distribution of model residuals. Log-transformed match running demands (distance covered per minute of match play (m$\cdot$min^{-1}), peak speed (km$\cdot$h^{-1}), and distance covered in speed zones (m$\cdot$min^{-1}), were entered as response variables. APHV (fixed), Player (random), Team (random) and Position (fixed) were entered as predictors to account for the random variance associated with the clustering of players' repeated measures and representative team membership. Prior to analysis, pre-modeling assumption checks (multicolinearity and linearity of relationships) were executed. Following analysis, model appropriateness was analysed through the normal distribution of model residuals and homogeneity of variance (Levene's) tests. The significance level for the -2 log-likelihood ratio tests and Levene's was set at $p<.05$ and estimate precision was provided via Wald-based 95% confidence intervals. Further detailed outline of the statistical process is presented in Supplementary Table 1.

Results

APHV of the cohort was 13.8 ± 0.6 years (range: 12.3-16.5) and athletes' average YPHV was 1.59 ± 0.54 (range -0.3 – 2.8 years). Three linear mixed models (Total distance·min^{-1}, HSR·min^{-1} and VHSR·min^{-1}) were retained where there was a significant contribution of estimated APHV on running demands. No significant effect ($p>0.05$) of estimated APHV on playing time, peak speed or LSR were observed; therefore, these models were not retained for further analysis. The best model fit was achieved using a random-intercepts (Player ID and Team) and slopes (APHV) model to explain the variance in total distance and HSR. However, a random intercept only model (Player ID and Team) provided the best model fit when explaining the variance in VHSR (model parameters available in Table 1).

Table 1 around here

The models indicate that a positive relationship exists between estimated APHV and match running demands, accounting for the random variance associated with repeated measurements clustered in players and team membership. TD (1.01; 95% CI: 0.99-1.02 m·min^{-1}; $p < 0.001$), HSR (1.05; 95% CI: 0.98-1.13 m·min^{-1}; $p < 0.001$) and VHSR (1.07; 95% CI: 1.00-1.14 m·min^{-1}; $p = 0.047$) each increased by ~1 m/min for each advancing year of APHV, representing 0.6 (95% CI: -0.7 to 1.9%), 5.4 (95% CI: -1.6 to 12.6%) and 6.9% (95% CI: 0.2 to 14.1%) increases in match running performances with every year increase in APHV, respectively.

Whilst playing position was observed to be a significant contributor to the models explaining the variance in TD and HSR, there were no significant contributions of an APHV*Position interaction (see Table 1). The main effect of position is presented in

Table 2 and a visual depiction of the main effects of APHV on relative TD and HSR are represented visually in Figure 1A and B, respectively.

Table 2 around here

Figure 1 around here

Discussion

The principal aim of this study was to examine the impact of the timing of the adolescent growth spurt, as an indicator of maturity, upon match running performances in a national federation tournament used for the identification of talented youth football players. Given the standardized playing formation used, we also examined the influence of playing position on the interaction between match running and maturity. The key finding of the study was that TD, HSR and VHSR were increased by 0.6, 5.4 and 6.9%, respectively, per year of estimated APHV. Importantly, the effects of APHV on TD, HSR, and VHSR were independent of playing position. Of note, there was no effect of APHV on peak speed, LSR, and sprinting. Collectively, these data suggest that later maturing players cover substantially more distance at higher absolute running speeds, while only marginally covering more overall distance, irrespective of their field position.

The match running volumes reported here (~116 $m{\cdot}min^{-1}$) are comparable with previous studies of U15 cohorts in matches with a similar match exposure (~50 min duration; [26,27]). Relative total distance covered was greater than a similarly structured elite U15 club tournament (~106 $m{\cdot}min^{-1}$; [26]), but slightly lower than English academy matches (119 $m{\cdot}min^{-1}$; [27]). The running volumes reported herein are substantially higher when compared to matches observed in the Qatar national academy (~100-102 $m{\cdot}min^{-1}$; [12,16]), likely due to their longer match durations (80 mins) played in higher ambient temperatures. Whilst the total distance covered increased in later-maturing players, the magnitude (0.6% per year of APHV) of the effect may be considered marginal. Our model suggested that a player with an APHV of 16 versus 12 years, the later maturing player would cover ~2.4% more total distance, which is within the typical between-match variation reported during matches[18]. Contextualization of the relative HSR (17 $\text{m}\cdot\text{min}^{-1}$) and VHSR (11.6 $\text{m}\cdot\text{min}^{-1}$) are limited by the different velocity thresholds adopted in the literature, with the only available comparisons from the aforementioned Qatar studies (HSR: 12-13 $\text{m}\cdot\text{min}^{-1}$; VHSR: 7.3 $\text{m}\cdot\text{min}^{-1}$;[12,16]). The greater HSR and VHSR performances of later maturing players identified in this study directly contrasts with findings from both soccer [6] and Australian Rules Football[7,8]. The contrasting findings in the current study are difficult to reconcile, with a number of methodological confounders between the studies, including the different equations used to predict APHV, the use of different indicators of maturity, size and ethnicity of the populations, and match characteristics (i.e. duration, scheduling, environmental conditions). Reasons for the increased match running performances of later maturing players reported here are speculative, but may include more ‘off the ball’ movement to receive possession in space to avoid physical contests with more mature opponents. An alternate view is perhaps due to inefficient running to offset weaker tactical positioning or decision making, supported by the higher HSR/VHSR but minimal change in TD. Further work is warranted to examine these suggestions, though practitioners should consider biological maturity when interpreting external load data.

With regards to talent selection, it was previously hypothesized that greater match running performances of early maturing team sports players result in more match involvements[6,7,14], potentially confounding coaches evaluations of player potential and presenting a selection bias according to maturity status[3,28]. Alternatively, the current data infers that late maturing players incur a higher external load during matches; the intuitive consequence of which would be higher accumulation of fatigue. By extension, previous research suggests fatigue compromises technical proficiency in critical match involvements[29], and if this were the case, may be unfavorable for later maturing players. Furthermore, players with a greater intermittent endurance capacity have a reduced fatigue-related decline in technical proficiency[29], and whilst physical capacity was not measured in this study, robust improvements in endurance performance with advancing maturity are commonly observed[5,12], until ~2.1 YPHV[13]. A maturity-conferred advantage in endurance capacity would enable early maturing players to perform the same absolute match running performance at a lower relative intensity. However, in this study later maturing players covered substantially more distance at higher intensity, coupled with the assumption that these players may have lower physical capacities, supports the notion that later maturing players have a considerable disadvantage. Whether this results from or translates into weaker technical proficiency in matches[29] remains speculative. Yet, its consideration within the selection bias for early maturers in football is warranted.[3].

Playing position has a well-established influence on youth football match-running performances[12,30] an effect that transcends other factors such as chronological age [12] and fitness [16,17]. In this study, we observed typical positional differences in match running performances, with central (#8 and #10) and holding (#6) midfield players covering the most total distances and HSR, and faster peak speeds observed in lateral and attacking positions. However, the effect of maturation on match running performances was not mediated by playing position. Again, this observation contrasts with Buchheit & Mendez-Villanueva[6], who showed that associations between APHV and running performances were only observed in central and lateral midfield players. It is possible that previous studies have been underpowered to examine the impact of APHV on distinct positional roles in football, particularly considering the between match variability in match running performances [18] owing to situational factors such as match status, playing formation or environment [19,20]. A unique aspect of the current study was that all tournament teams adopted a common tactical formation and playing principles both with and without ball possession, and that all players were developed under a common national football framework. One of the key principles of the Football Federation Australia development system is the adoption of a ‘high-press’ when out of ball possession, a strategy that likely mandates greater match running performances, and may partially explain why the influence of APHV was consistent across all playing positions.

We acknowledge a number of limiting factors that ought to be considered when interpreting the current data. Given the logistical challenges of tournament-wide monitoring, we used two different GPS models from the same manufacturer, and players were unable to wear the same unit for each match. Accordingly, we used the same processing software, and examined only metrics that were unlikely to be influenced by the subtle differences in GPS hardware. Tournament matches were played under varying environmental conditions (dry-bulb temperature: 22.7 ± 4.3ºC; relative humidity: 45.7 ± 18%) at differing times of the day (8:30 AM – 6:30 PM). Biological maturation was estimated with a modified non-invasive prediction equation using anthropometric measures, and whilst validated[21], this technique is not considered the criterion measure for biological maturity and considerable errors are associated with any estimation of APHV from anthropometric data[24]. Moreover, the population sampled in our study was largely post-adolescent, and further work may be warranted to examine the role of maturation in match running performances of circa-adolescent players, where more heterogeneous within-group differences around APHV may exaggerate its impact. The findings may also be unique to the playing standard, tactical formation and playing principles of the U15 national level cohort examined.

Conclusions

In summary, this study observed increased high-speed running in later maturing U15's in all outfield playing positions within a national federation. These findings suggest that the external and internal loads of later maturing players can be underestimated when biological maturity status is not considered. As late maturers players commonly possess inferior fitness compared to average or late maturing players, match-induced fatiguing symptoms may be more prevalent in these players, which may have implications for talent selection and development opportunities.

Practical Implications

- Estimates of biological maturity should be available to coaches, talent selectors, and load monitoring practitioners to robustly evaluate talented football players.
- Biological maturity status should be considered when prescribing and interpreting external load data in elite youth football.
- Talent identification programs might adopt strategies such as bio-banding, maturity-ranked jersey numbers, and maturity-related selection quotas to overcome the advanced maturity bias in player development pathways.

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Tables

Table 1: Retained models that explain the effect of APHV and position on players' match running demands. * indicates best fitting model based on AIC value and - 2log-likelihood ratio test. TD = relative distance covered, HSR = high-speed running, VHSR = very high-speed running, APHV = Age at Peak Height Velocity, Position = field position, Team = representative state team, Player = individual player identification number.

	AIC	df	Chi^2	p	R^2 fixed only (%)	R^2 random + fixed (%)
Final model: log10(TD) ~ APHV + Position + (1+APHV|PlayerID) + (1|Team)						
Null Model: TD ~ 1 + (1|Player) + (1|Team)	-4474.100	4			0	51
Random intercepts model APHV	-4481.200	5	9.075	0.003	2	51
Random slopes (player) model APHV	-4484.200	7	6.990	0.030	2	51
Random slopes (player) model APHV with Position*	-4594.000	12	118.828	<0.001	15	52
APHV*Position interaction model	-4592.000	17	8.003	0.156	16	52
Final model: log10(HSR) ~ APHV + Position + (1+APHV|PlayerID) + (1|Team)						
Null Model: HSR ~ 1 + (1|Player) + (1|Team)	-58.162	4			0	15
Random intercepts model APHV	-59.110	5	2.948	0.086	0	12
Random slopes (player) model APHV	-57.293	7^2	2.183	0.336	0	16
Random slopes (player) model APHV with Position*	-97.561	12	50.268	<0.001	6	15
APHV*Position interaction model	-91.985	17	4.424	0.490	6	16
Final model: log10(VHSR)~ APHV + Position + (1+APHV|PlayerID) + (1|Team)						
Null Model: VHSR ~ 1 + (1|Player) + (1|Team)	11.238	4			0	10
Random intercepts model APHV*	9.277	5	3.961	0.047	0	10
Random slopes (player) model APHV	11.520	7	1.757	0.415	0	10
Random intercepts model APHV with Position	11.914	10	5.606	0.132	1	10
APHV*Position interaction model	18.240	15	3.673	0.597	1	11

Table 2: Least-square means, confidence intervals, standard errors, t-values and random effect parameters from three linear mixed models investigating the effect of APHV on match running performance in different positional groups. Coefficients shown have been back-transformed.

TD (m.min^{-1})

Fixed effects

	Estimate	Lower CI	Upper CI	Std. Error	t value
(Intercept)	102.06	84.92	122.74	1.10	49.15
Fransen.APHV	1.01	0.99	1.02	1.01	0.81
PositionCM	1.11	0.92	1.13	1.01	10.21
PositionFWD	1.02	0.99	1.04	1.01	1.33
PositionHM	1.09	1.06	1.11	1.01	7.31
PositionLD	1.04	1.02	1.06	1.01	4.55
PositionLM	1.66	1.03	1.07	1.01	5.14

Random effects

		Variance	SD
Player ID	*Intercept*	1.006	1.120
	APHV slopes	1.000	1.012
Team	*Intercept*	1.000	1.018
Residual		1.002	1.066

HSR (m.min^{-1})

Fixed effects	Estimate	Lower CI	Upper CI	Std. Error	t value
(Intercept)	7.57	3.15	18.48	1.58	4.48
Fransen.APHV	1.05	0.98	1.13	1.03	1.51
PositionCM	1.08	0.97	1.21	1.06	1.41
PositionFWD	0.74	0.65	0.85	1.07	-1.39
PositionHM	1.08	0.95	1.23	1.07	1.15
PositionLD	0.96	0.86	1.07	1.06	-0.74
PositionLM	0.82	0.73	0.91	1.06	-3.56

Random effects		Variance	SD
Player ID	*Intercept*	1.097	1.587
	APHV slopes	1.001	1.045
Team	*Intercept*	1.003	1.089
Residual		1.119	1.664

VHSR (m.min^{-1})

Fixed effects	Estimate	Lower CI	Upper CI	Std. Error	t value
(Intercept)	3.95	1.62	9.65	1.58	3.02
Fransen.APHV	1.07	1.00	1.14	1.03	2.03

Random effects		Variance	SD
Player ID	*Intercept*	1.010	1.160
Team	*Intercept*	1.004	1.099
Residual		1.133	1.711

Figures Legends

Figure 1: The effects of age at peak height velocity (APHV) and playing position on relative A) total distance and B) high-speed running in U15 footballers from a national federation. Data presented are log-transformed least squares means obtained from the best fitting model.