Predicting the Timing of the Peak of the Pubertal Growth Spurt in Elite Male Youth Soccer Players: Evaluation of Methods

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Abstract

Background: Three commonly used non-invasive protocols are implemented to estimate the timing at which PHV most likely occurs. Accurate estimation of circumpubertal years can aid in managing training load of adolescent athletes.

Aim: Three protocols were compared against observed age at PHV: an estimate of 13.8 ±1.0 year - generic age at PHV (from longitudinal measures); an estimate based on the maturity offset equation, predicted age at PHV ±1.0 year; a window of PHV based on 85 – 96% of predicted adult height at time of observation.

Subjects and Methods: A final sample of 23 (from 28) adolescent male participants were selected from the academy of an English Premier League club. Anthropometric measures were collected across five playing seasons; age at PHV was estimated with Super-Imposition by Translation and Rotation (SITAR). The three protocols were compared based on measures at 13.0 years.

Results and Conclusions: An age window based on predicted maturity offset did not improve estimation of PHV compared to generic age method; however, the percentage of predicted adult height window showed improvement in performance shown by the following results. Predicted age at PHV correctly assigned 15 participants (65%) as experiencing PHV, while the percentage height correctly assigned 17 participants (74%). Generic age and predicted age at PHV correctly predicted observed age at PHV for 14 participants (61%), percentage of adult height window correctly predicted 22 participants (96%).

Keywords: maturity offset; adolescent spurt; predicting adult height; youth athletes; peak height velocity

Introduction

Characteristics associated with physical growth and biological maturation, and related changes in functional and behavioural characteristics influence the development of athletic ability (Williams and Reilly, 2000). Although the processes of growth and maturation span approximately the first two decades of life, the interval spanning the adolescent growth spurt and pubertal maturation, sometimes labelled the pubertal growth spurt, is highly individual and variable in timing and tempo (Malina et al., 2004b, Malina et al., 2015). The spurt begins with acceleration in the rate of growth in height (labelled take-off), continued acceleration in growth rate until peak velocity is attained (peak height velocity, PHV), and then deceleration and eventual cessation of growth in height (Malina et al., 2004b, Molinari et al., 2013). The interval of the growth spurt is of interest and often presents a challenge to those involved in the identification and development of youth athletes, including decisions regarding retention or exclusion.

Young athletes are traditionally grouped by chronological age (CA) for the purpose of training and competition. Youth of the same CA vary significantly in maturity status at the time of observation, e.g. skeletal age, stage of puberty, and in maturity timing, CA at the onset of puberty and at PHV (Beunen and Malina, 1988, Patel et al., 1998, Marshall and Tanner, 1970, Malina et al., 2004b). Estimation of the CA at which a youngster attains specific maturational landmarks requires longitudinal observations, and inter-individual variation is substantial. For example, youth soccer players of the same CA varied by as much as five to six years in skeletal age (Johnson, 2015), while age at take-off of growth spurt varied between 8.2 – 12.7 years in boys from the Fels longitudinal study (Malina et al., 2016).

Individual differences in maturity status have implications for development and retention / exclusion in many sports, including youth soccer. Players advanced in maturity status have, on average, size and functional advantages (e.g. strength and power) compared to later maturing teammates of the same CA (Malina et al., 2013) and generally possess a competitive advantage (Cumming et al., 2017a). Data are lacking, however, on individual differences in size and function among soccer players relative to timing of the adolescent growth spurt (Malina et al., 2015). Data from longitudinal surveys of the general population clearly indicate higher values for stature from 10 through 15 years of age in boys who attain PHV earlier than peers and a weight advantage through adolescence (Malina et al., 2004b). Of relevance to the development of youth players, those who mature early experience the adolescent growth spurt at a CA when the training load is typically lighter and fewer decisions are made regarding the retention or release of players from the academy system (Cumming et al., 2017a). To accommodate individual differences in rate of growth during the growth spurt, many soccer academies systematically monitor the growth and estimated maturity status of youth players.

Assessment of growth status is rather straightforward and involves measurements of height, weight and perhaps other dimensions. Assessment of maturity status is a different issue as established methods (stage of pubertal development and skeletal age) are often viewed as invasive and require expertise that may not be available at some clubs (Malina, 2017). Assays of hormonal levels are also invasive and expensive, but more importantly, may be influenced by behaviours such as sleep, stress, nutritional status and physical activity (Johnson et al., 1992, Dawes et al., 1999, Shirtcliff et al., 2009, Blakemore et al., 2010). Estimated growth velocities based on longitudinal height and weight records may be useful in identifying the growth spurt; care in estimating velocities is essential and available longitudinal observations may not span the interval of the spurt. Such estimates are, nevertheless, retrospective and have limitations in the context of the needs of individual players.

Current interest in the application of non-invasive and predictive techniques in youth soccer and other sports to accommodate the perceived need for identifying the onset and subsequent progress of the growth spurt is considerable. Sex-specific equations based on CA, height, mass, sitting height and estimated leg length are available to predict maturity offset, defined as the time before or after PHV (Mirwald et al., 2002); CA at observation minus predicted maturity offset provides a predicted age at PHV. Predicted offset is commonly used to classify youth as pre-PHV, circa-PHV or post-PHV, while predicted age at PHV is also used to group youth into maturity categories, i.e. early, on-time or late (Sherar et al., 2007, Malina et al., 2012a). The validity, reliability and accuracy of predicted ages at PHV with the maturity offset protocol have been questioned (Kozieł and Malina, 2018, Malina and Kozieł, 2014, Malina et al., 2016). In addition to dependence upon CA and body size at prediction, and reduced variation in predicted relative to estimated/observed ages at PHV (based on longitudinal data spanning late childhood through adolescence), the prediction equation has major limitations with early and late maturing boys, defined by observed ages at PHV. Further, the median error tends to be magnified considerably in children that are either ‘early’ or ‘late’ maturing, who typically are of most concern in the context of sport (Cumming et al., 2017a). Accordingly, the reliability of this method merits attention.

Another protocol increasingly used to estimate maturity status youth athletes is the percentage of predicted adult height attained at the time of observation; use of percentage of predicted adult height as a maturity indicator was recommended by Roche et al. (1983) and equations for the prediction of adult height without skeletal age were subsequently developed (Khamis and Roche, 1994). Concordance of classifications of maturity status based on percentage of predicted adult height at the time of observation and on skeletal age among youth participants in American football 9 – 14 years (Malina et al., 2007) and in soccer 11 – 14 years (Malina et al., 2012a) were moderate, approximately 60%. Percentage of predicted adult height also had concurrent and predictive validity in samples of North American and British youth (Cumming et al., 2006, Cumming et al., 2014, Malina et al., 2005, Malina et al., 2006). In recent applications, responses of academy soccer players 11 - 14 years of age with current heights ≥ 85.0% and < 90.0% of their predicted adult heights (Cumming et al., 2018, Cumming, 2018) and 13 – 15 years of age with current heights ≥ 90.0% and < 95.0% of their predicted adult heights (Thomas et al., 2017) to participation in maturity matched (i.e. bio-banded) competitions have been monitored. The studies assumed that the ranges of percentage of predicted adult height spanned the interval of the growth spurt.

In the context of the preceding, the purpose of the present study is to evaluate three protocols used to estimate the window in which PHV is most likely to occur for individual male soccer players at 13.0 years of age. This age was selected as it is common for soccer coaches/clubs to consider the retention or exclusion of players, and/or the option of playing a youngster “up” or “down” an age group at about this time.

Methods

The study was approved by the Ethics Committee of the Faculty of Science and Engineering, at Manchester Metropolitan University. Parents/guardians of the participants were informed of the aim of the study, research procedures, requirements, benefits and risks, and provided written informed consent. The youth also provided assent and were advised that involvement in the study was voluntary and that they could withdraw from the study at any point.

A sample of 28 (19 Caucasian, 9 non-Caucasian) male players from a professional soccer academy within the English Premier League was followed across five consecutive competitive playing seasons. Anthropometric measures were taken at two-month intervals during the respective seasons. All participants were born between 2001 and 2004, and represented one of five age groups, defined by age at the beginning of the competitive year (1st of September) and monitored during their time until they were 18 years of age.

Anthropometry

Mass, stature (hereafter, 'height') and sitting height were measured every two months throughout each competitive playing season (six measurements per season). Participants wore a t-shirt and shorts; footwear was removed. Height (cm) and sitting height (cm) were measured using a fixed Harpenden stadiometer (Holtain Ltd., UK) to the nearest 0.10 cm. Height was measured as the distance from the standing surface to the vertex of the head. Participants were instructed to stand in the standard erect posture with weight equally spread between both feet. The head was positioned in the Frankfort horizontal plane. Sitting height was measured as the distance from a flat sitting surface (40 cm high box) to the top of the head with participants sitting in an upright position with the head in the Frankfort horizontal plane, knees together and directed straight ahead. Sitting height was subtracted from height to provide an estimate of leg length. Body mass was measured by means of a weighing scale (Tanita ®, type BC-420 SMA, Japan) to the nearest 0.10 kg.

A sample of 15 participants was selected and measured at the same time of day on a second occasion within 4 days (after their earliest measurement date). The initial and replicate measurements were taken by two experienced observers. Inter-observer technical errors of measurement were as follows: weight (0.38 kg), height (0.24 cm) and sitting height (0.25 cm). The observed technical errors of measurement were well within the range of those reported in several small scale and national surveys of school age children and youth (Malina, 1995), and were similar to corresponding technical errors in the Wrocław Growth Study, 0.29 cm and 0.35 cm for height and sitting height, respectively (Kozieł, 1998).

Age at Peak Height Velocity (PHV)

The longitudinal height records for the 28 individual players were fit with the Super-Imposition by Translation of Rotation (SITAR) model (Cole et al., 2010) to estimate age at PHV. Ages at initial observation ranged from 11.21 to 13.13 years (mean 12.4 ± 0.6 years), while ages at final observation ranged from 14.51 to 16.43 years (mean 15.4 ± 0.6 years). Frequencies of observations ranged from 13 to 20 (mean 18.6 ± 1.6); one participant had 13 height measurements, while the number of measurements in the remainder ranged from 17 to 20.

The SITAR model was successfully fit to the height records for all 28 participants, with a mean age at PHV of 14.0 ± 0.9 years. The estimated age at PHV for one participant preceded his first observation, while four players lacked a measurement of young adult height at 18.0 years (see below). Thus, the sample for analysis was reduced to 23 players (15 Caucasian, 8 non-Caucasian) with a mean age at PHV of 14.2 ± 0.9 years. The height of each player at PHV was accepted as the height measured closest to age at PHV with the SITAR model.

Pubertal Growth Spurt Prediction Protocols

The issues associated with the pubertal growth spurt are thought to occur in a time period around the point of PHV. This is commonly referred in the literature as circumpubertal years, and in soccer academies, as the 'window of PHV' or 'PHV window'. The frequency with which observed age at PHV of each participant (estimated from longitudinal data) occurred within three windows based on different protocols was examined: (1) an age band of ± 1.0 year around the estimated mean age of PHV of males of European ancestry, 12.8 - 14.8 years of age, labelled the generic age band; (2) a band of ± 1.0 year around predicted ages at PHV based on the maturity offset protocol (Mirwald et al., 2002); and (3) a window of 85% to 96% of percentage of predicted young adult height based on observations in two longitudinal studies (Sanders et al., 2017). The logic and details of each protocol are indicated subsequently.

Generic Age at PHV

The estimated mean age at PHV in the three samples upon which the maturity offset prediction equation was developed (Mirwald et al., 2002) was 13.8 years with an estimated standard deviation of 0.9 year (Malina et al., 2012a), which was similar the interval of ± 1.0 year of observed age at PHV commonly used in longitudinal studies to classify youth as late, average or early maturing (Malina, 2017, Malina et al., 2004b). Observed standard deviations for estimated ages at PHV in longitudinal studies have ranged from 0.8 to 1.3 years in boys with most clustering close to 1.0 year (Malina et al., 2004b). As such, a window of ± 1.0 year was used in the present study; a majority of boys should experience PHV within a window of 12.8 to 14.8 years of age. Accordingly, CA at the time of observation within this range was used as an approximate estimate of when the player was likely to experience PHV. This was labelled the generic estimate of age at PHV. Boys with a current CA within this band would be considered to be within the interval of the growth spurt, whereas boys outside the band would be considered, accordingly, as having already attained peak velocity, or not yet in the interval of peak velocity. Further, only participants whose SITAR determined age at PHV was between 12.8 – 14.8 years would have been correctly identified by using this method.

Predicted Age at PHV

Maturity offset at the observation closest to 13.0 years of age (13.03 ± 0.06 years, range 12.93 – 13.13 years) was predicted with the equation proposed by Mirwald et al. (2002):

$$\text{Maturity Offset} = -9.236 + (0.0002708 \times [\text{Leg Length} \times \text{Sitting Height}]) + (0.001663 \times [\text{CA x Leg Length}]) + (0.007216 \times [\text{CA x Sitting Height}]) + (0.02292 \times [\text{Weight by Height Ratio} \times 100]).$$

Note, the need to multiply the weight by height ratio by 100 was overlooked in the original publication (Mirwald et al., 2002). The standard error of estimate for the prediction equation was 0.592. CA at prediction minus maturity offset provided a predicted age at PHV (years).

Window of Percentage of Predicted Adult Height

The adult height of each player at the observation closest to 13.0 years (see above) was predicted with age-specific equations for males of European ancestry in the Fels Longitudinal Study (Khamis and Roche, 1994). The equations require CA, height and weight of the youngster and mid-parent height (average of the heights of the player's biological mother and father). Heights of the biological parents were self-reported and, as in other studies using the protocol, self-reported heights were adjusted for overestimation using sex specific equations (Epstein et al., 1995). The median error bound between actual and predicted young adult height using the Khamis-Roche equations was 2.2 ± 0.6 cm in males between 4.0 to 17.5 years of age; the estimated median error in males at 13.0 years was 2.5 cm (Khamis and Roche, 1994). The height of each player at 13.0 years was expressed (1) as a percentage of his predicted adult height and also (2) as a percentage of his young adult attained height at 18.0 years of age.

Recent analyses of two early longitudinal studies of North American boys and girls noted that PHV occurred within a range of 85% – 96% of adult height and at a mean of approximately 90% of adult height (Sanders et al., 2017). Citing this study, the window of 85% – 96% is currently employed by a number of professional soccer academies to facilitate maturity-specific training strategies (Cumming, 2018, Cumming et al., 2017b). Of potential interest, the upper limit of 96% was noted in one of the longitudinal samples of girls (Sanders et al., 2017). Consistent with the protocol currently employed by some academies, the window of 85% – 96% of young adult height was used in the present analysis. Percentage of predicted adult height at 13.0 years and height at PHV (SITAR) expressed as a percentage of measured young adult height were compared with this window.

The height window was also converted into an age window. In addition to the serial longitudinal observations across five seasons, young adult height at 18 years of age was also measured in 24 players. Heights of each player across the five seasons were expressed as a percentage of his young adult height. By taking the ages when 85% – 96% of observed young adult heights were attained, individual age windows were estimated for each participant.

Statistical Analysis

Chi-square tests were conducted in order to determine whether there was a significant difference for each of the three prediction protocols against an even chance of the prediction being correct. The Predicted Age at PHV and the Window of Percentage of Predicted Adult Height protocols were also compared with the Generic Age at PHV method to test for improvement in estimation. More specifically, if predicted APHV with maturity offset and SITAR derived APHV were between 12.8 - 14.8 years (13.8 ± 1.0 years), the individual was classified as within the window. And, if percentage of predicted adult height based on height measured at 13 years and if percentage of observed young adult height based on height at SITAR derived APHV were between 85% - 96%, the individual was classified as within the window.

Concordance analyses (Cohen's Kappa [κ] coefficients) were used to estimate the degree to which the protocols associated with predicted age at PHV and percentage of predicted adult height correctly identified individuals as being within or outside the respective windows based on maturity classifications at 13.0 years of age. Higher κ coefficients indicate more agreement between methods, while small or negative values indicate poor or no agreement. With the maturity offset protocol, an individual with a predicted age at PHV within ± 1.0 year of observed age at PHV was considered within the PHV window. For percentage of predicted adult height, an individual whose percentage of predicted adult height was between 85% – 96% of their observed young adult height was considered to be within the window of PHV. Subsequent analyses focused on the comparison of the observed age at PHV window and each of the three predictions.

Results

Data for individual participants at 13.0 years of age are summarised in Table 1, while descriptive characteristics of participants in consecutive competitive age groups are summarised in Table 2. Observed ages at PHV based on the SITAR model range from 12.6 - 15.5 years with a mean of 14.2 ± 0.9 years. Applying the range based on youth of European ancestry (12.8 – 14.8 years) to categorise individuals as early, on-time, or late in maturity status (based upon observed age at PHV), 14 participants are classified average or on-time, 3 as early and 6 late maturing.

******INSERT TABLE 1 NEAR HERE******

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Concordance of Predictions

Concordance of predicted maturity status classifications of the participants are summarised in Table 3. Percentage of predicted adult height at 13.0 years of age identifies 21 participants as in the interval of PHV, i.e. within the 85% – 96% window, and 2 participants as outside the window. In contrast, predicted age at PHV based on the maturity offset protocol at 13.0 years of age, shows greater variation in the classification of players within or outside the PHV window.

The percentage of predicted adult height method has a higher degree of concordance with classifications based on observed age at PHV based on the SITAR model; the prediction protocol correctly classified 19 of the 23 participants as being within the 85% – 96% band. Of the four misclassified participants, two are identified as outside the PHV window and two as within the PHV window.

******INSERT TABLE 3 NEAR HERE******

Concordance of the three methods for estimating age at PHV relative to observed age at PHV based on SITAR are summarised in Table 4.

Among the 23 participants, 14 (61%) have an observed age at PHV within the window defined by generic age of PHV (12.8 – 14.8 years), while 14 (61%) have a predicted age at PHV at 13 years of age within the window defined by observed age at PHV ± 1.0 year. However, only 11 participants are similarly classified by the two methods. In contrast, 22 of 23 participants (96%) attain PHV within the window defined by 85% – 96% of predicted adult height at 13 years of age. Results of the Chi-square analyses are not significant for generic age at PHV and predicted age at PHV (χ^2 = 1.09), but that for percentage of predicted adult height is significant (χ^2 = 19.17).

******INSERT TABLE 4 NEAR HERE******

Chi square and Kappa coefficients were also calculated to evaluate the concordance of the predictive methods with the generic age method, i.e. generic age at PHV method at 13.0 years of age compared with predicted age at PHV based on maturity offset at 13.0 years of age and with the percentage of predicted adult height based on height measured at 13.0 years within the 85 – 96% window. Predicted ages at PHV are concordant with the generic age method in 14 of the 23 players (61%, $\chi^2 = 0.0$), but the κ coefficient (0.48) suggests moderate concordance. In contrast, the percentage height window method (converted to an age window) improves upon the generic age method ($\chi^2 = 11.68$) and the κ coefficient (0.65) suggests substantial agreement. At 13.0 years of age, the percentage height window converted to an age window correctly identifies status based upon observed age at PHV in 22 of the 23 participants (96%).

Discussion

The degree to which CA, predicted age at PHV with the maturity offset protocol, and percentage of predicted adult height at the time of observation (13.0 years) effectively predicted the window within which PHV was likely to occur was evaluated in a sample of youth soccer participants. The majority (18 of 23, 78%) experienced PHV when their heights were between 88% and 92% of observed young adult height at 18 years of age, and all 23 participants attained PHV within the 85% – 96% window (Figure 1). The latter was consistent with the observations of Sanders et al. (2017) based on two early longitudinal studies of United States youth. PHV occurred at 90.0 ± 2.1% and 90.2 ± 4.0% of young adult height in boys from the Brush Foundation and Berkeley studies, respectively. Based on measurements taken at 13.0 years, the distribution of percentages of predicted adult heights at PHV are shown in Figure 2. Percentages of predicted adult height in 22 of the 23 participants (96%) were within the 85% – 96% window. The only participant outside the range had a percentage of predicted adult height <85%, while no percentages of predicted adult height were >96%.

******INSERT FIGURE 1 NEAR HERE******

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Although the maturity offset prediction protocol is widely used with soccer players (Kozieł and Malina, 2018), predicted ages at PHV were not consistent with estimates based on the generic age method. Mean predicted age at PHV at 13.0 years of age was 15.1 ± 0.5 years, with a range of 14.0 – 16.0 years; corresponding statistics for observed age at PHV were 14.2 ± 0.8 years with a range of 12.6 – 15.5 years (Table 1). Of relevance, the three early maturing players with observed ages at PHV of 12.59, 12.73 and 12.79 years had predicted ages at PHV at 13 years (based on maturity offset) that exceeded observed ages at PHV by 1.42, 1.58 and 2.50 years, respectively (Table 1). By inference, these participants would not have had training loads adjusted for the interval of rapid growth. A similar trend was apparent in the 14 participants classified as on time based on observed ages at PHV; all predicted ages at PHV exceeded observed ages at PHV by >0.5 year (0.56 to 1.66 years). These participants would also be identified as having PHV after their pubertal growth spurt had already occurred. On the other hand, five of the six late maturing participants had a predicted age at PHV within 0.5 year of their observed age at PHV and thus had a lower chance of such a misclassification. Results were the same for the total sample of 28 players, 4 early, 18 on-time and 6 late.

The results for the small samples of select soccer participants of contrasting maturity status were generally consistent with observations for males in the Wrocław, Poland (Kozieł and Malina, 2018, Malina and Kozieł, 2014, Malina et al., 2016) and the Fels, U.S. (Malina et al., 2016) longitudinal studies classified early, average or late maturing, allowing for the age ranges in the three series and for variation associated with the different methods for estimating age at PHV in the studies, i.e. SITAR in the present study, Preece-Baines model 1 in Polish youth, and the triple logistic Bock-Thissen-du Toit model in U.S. youth. The contrast between predicted and observed ages at PHV was most apparent among early maturing youth, athletes and non-athletes.

Observed ages at PHV estimated with the SITAR model in the 23 participants ranged 12.6 – 15.5 years. Accordingly, the generic age at PHV, i.e. 13.8 ± 1.0 years, was an unreliable indicator of when PHV was likely to occur in this sample of academy soccer players. Observed ages at PHV in 9 of the 23 participants (39%) were outside the generic age window of 12.8 – 14.8 years of age.

As previously noted, evidence based on skeletal age and pubertal status suggests that soccer tends to select for boys who advanced in maturity status based; the selection bias emerges at about 12 – 13 years, although there is variation with method of maturity assessment (Malina, 2011, Malina et al., 2013). In contrast, estimated mean age at PHV, an indicator of maturity timing, in the present sample of soccer players (14.2 ± 0.9 years) was in the range of mean ages at PHV noted in longitudinal studies (Malina et al., 2004b). The corresponding mean age at PHV in the longitudinal records for the original sample of 28 players was slightly earlier, 14.0 ± 0.9 years.

Estimated age at PHV among 33 Belgian youth soccer players, 13.8 ± 0.8 years (Philippaerts et al., 2006), was slightly earlier than the present study, but was also in the range of average ages at PHV. Of relevance, however, 76 Belgian youth players were tracked annually over four or five years beginning at ages ranging from 10.4 to 13.7 years, but the growth curves were successfully modelled with non-smoothed polynomials in only 33 players (43%); at initial observation, chronological and skeletal ages in this sample approximated each other, 12.1 ± 0.7 and 12.4 ± 1.3 years, respectively. In contrast, the majority of players whose height records could not be successfully modelled comprised two groups: (1) 25 players had skeletal ages in advance of chronological ages at initial observation, CA = 12.6 ± 0.5 and skeletal age = 13.5 ± 1.2 years, and were likely early maturing; and (2) 18 players has skeletal ages somewhat delayed relative to chronological ages at initial observation, CA = 11.6 ±0.8 and skeletal age = 11.1 ± 1.1 years, and were likely late maturing (Philippaerts et al., 2006).

Players who experienced an earlier age at PHV were under-represented in the present study and also in the sample of Belgian youth players compared to the general population. An indicator of skeletal maturity status at 11.0 – 12.0 years was not available for the current sample. However, height at 13.0 years of age expressed as a percentage of predicted adult height was 87.7 ± 2.1 % and as a percentage of observed young adult height at 18.0 years was 88.6 ± 2.2% (Table 1). Both percentages were similar to the percentage of estimated adult height without skeletal age attained by boys in the Fels Longitudinal Study at 13.0 years, 88.7 ± 1.8% (Roche et al., 1983) and to the percentage of adult height attained by boys in the Berkeley Longitudinal Study at 13.0 years, 87.3 ± 3.0% (Bayer and Bayley, 1959). The preceding thus suggests that the sample of players in the present study approximated average maturity status based on percentage of predicted adult height attained as the time of observation.

Relative to the proposed band of 85% – 96% of adult height as reflecting the window of PHV (Sanders et al., 2017), 21 of 23 players had percentages of predicted adult height at 13.0 years of age that correctly identified them as being in the window of PHV; the range of percentages, however, was somewhat narrow, 84.2% to 92.0% (Table 1). This would suggest that the percentage of predicted adult height attained at 13.0 years of age was a comparatively more accurate predictor of age at PHV.

Age, height and weight at SITAR derived age PHV were estimated from the longitudinal records for each participant and were used along with mid-parent height to predict adult height at this time (Khamis and Roche, 1994). Height at PHV was then expressed as a percentage of predicted adult height attained at PHV. Accordingly, the 23 players attained PHV at 88.9 ± 3.1% of predicted adult height (range 81.1% – 93.9%). When height at PHV was expressed relative to young adult height at 18.0 years, the 23 participants attained PHV at 91.2 ± 2.3% (range 84.9% – 95.7%). Both estimates were similar to those for boys observed by Sanders et al. (2017), 90.0 ± 2.1% in the Brush Foundation (range 85.6% - 93.8%) and 90.2 ± 4.0% in the Berkeley (75.3% – 94.8%) longitudinal studies. Note, however, estimated age at PHV in the present study (14.2 ± 0.9 years) was later than estimated for boys in the Brush Foundation and Berkeley studies, 13.0 ± 0.7 years and 13.4 ± 1.4 years, respectively.

Predicted age at PHV is used by many English professional soccer clubs to classify players as early, on time or late maturing (Cumming et al., 2017b). Results of the present study highlight the need for caution when using maturity offset *per se* as a predictor of age at PHV and maturity timing for players. All predictions have associated errors and application to individuals, specifically select samples of adolescent athletes, requires caution. Inter-individual differences in the timing and tempo of the growth spurt need to be considered.

The contrast of maturity status and maturity timing (age at PHV) should be emphasised; the concepts are not equivalent. The former indicates the state of skeletal or sexual maturity, or the percentage of predicted adult height attained at the time of observation. The latter indicates the age (time) when a specific maturity event occurs, in the present study, age at PHV. It is thus possible that some youth may be selected due to their advanced maturity status, whereas equally talented youth average or delayed in biological maturity status relative to their age peers may not be selected. This may be more apparent in sports such as soccer where height, mass, velocity, power and strength are viewed as advantageous (Meylan et al., 2010). Indeed, youth soccer players tend to be, on average, advanced in sexual maturity status compared to non-athletes of the same age (Malina et al., 2010), while skeletal maturity status based on three commonly used methods of assessment, the Greulich-Pyle, Tanner-Whitehouse 2 radius-ulna-short bone (TW2 RUS) and Fels methods of skeletal age assessment (Malina et al., 2004b) were consistent in showing advanced maturity status among soccer players from several countries (Malina et al., 2018, Malina, 2011). Note, however, observations of soccer players using the modified TW3 RUS method did not indicate advanced skeletal ages among youth soccer players 11.0 – 15.0 years; rather, skeletal ages with the TW3 RUS methods were, on average, one year lower than corresponding skeletal ages with the TW2 RUS method at these ages (Malina et al., 2018).

A limitation of the present study was the small number of early maturing players based on SITAR derived ages at PHV, which likely skewed the results; as such, the sample may not be representative of male youth soccer players in general. Unfortunately, longitudinal data spanning 9 years of age through adolescence are lacking for soccer players. Of potential relevance, the estimated age at PHV of youth soccer players based on the Preece-Baines model 1 applied to age group-specific grand means of heights spanning 9 through 18 years in studies reported between 2000 and 2015 was 12.9 years (Malina, 2017), and was consistent with the sexual and skeletal maturity data for youth soccer players (Malina et al., 2010).

Further development of these protocols should consider the international and ethnically diverse makeup of soccer in general and now of elite soccer academies. The maturity offset prediction equation was established on samples of European ancestry in Canada and Belgium (Mirwald et al., 2002). Similarly, the Khamis-Roche method for the prediction of adult height was based on youth of European ancestry in the Fels Longitudinal Study (Roche et al., 1983). Ethnic variation in body proportions, specifically evident in the sitting height / standing height ratio and by inference in leg length merits attention (Malina et al., 1987, Martorell et al., 1988) and implies a need for care when applying the prediction protocol to other ethnic groups (Malina, 2009). In the present study, the non-European participants were taller and displayed a lower sitting height / height ratio than the European participants. Therefore, the evaluation of players of non-Caucasian ethnicity may need to be investigated. Considerations should also be given to the findings of Malina et al. (2012b) which indicate that in the half-century between the Berkeley and Fels longitudinal studies, there appears to have been an acceleration in the maturational process. Optimization against these two factors could improve predictions of timing of PHV. Both the Mirwald and Khamis-Roche equations utilise coefficients that differ between sexes, and the expected age and height at PHV are also different for males and females (Sanders et al., 2017, Malina et al., 2004a). The current study was conducted only with male participants, thus further development could look at females or studies involving both males and females to validate the results across sexes.

Predicted maturity offset and in turn age at PHV, and the window of PHV based on percentage of predicted adult height in the present study were based on measurements taken at 13 years of age. Predicted age at PHV (15.1 ± 0.5 years) was later than observed age at PHV (14.2 ± 0.9 years) in the 23 soccer players; the standard deviation for the former was considerably less than that of observed age at PHV. Generic age at PHV and predicted age at PHV correctly predicted observed age at PHV for 14 participants (61%), while the percentage of adult height window correctly predicted 22 participants (96%). Generation of a specific age window based on predicted maturity offset did not improve estimation of PHV compared to the generic age method, while the percentage of predicted adult height window of PHV showed improvement in accuracy.

The results suggest the potential utility of the percentage of height window for PHV. While the percentage of predicted adult height performed statistically better, the Khamis-Roche equation requires the most information such that the improvement in prediction accuracy may be offset against input data reliability and potential calculation complexity. Future studies could consider improvement of existing methods in order to further constrict the age at PHV window or to consider height at PHV as an alternative for scenarios where less information is available (e.g. extrapolation from Office of National Statistics data), as the trade-off between calculation complexity and accuracy of the results must be considered.

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Declaration of Interest

The authors have no conflicts of interest.

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Table 1: Characteristics of individual players: observed and predicted estimates (at 13.0 years).

Participant	Observed (SITAR) age at PHV (years)	Maturity classification*	Predicted age at PHV (years) at 13 years	Predicted minus observed age at PHV (years)	Attained height at 13.0 years as a % of observed young adult height	Attained height at 13.0 years as a % of predicted adult height	% of predicted minus % of observed young adult height (cm)	Window % of Predicted Adult Height expressed as an age window
1	14.18	On-time	14.84	0.66	84.6	87.4	2.8	13.0 – 15.2
2	14.29	On-time	14.96	0.67	85.9	87.0	1.1	12.9 – 16.0
3	15.16	Late	15.07	-0.09	84.0	87.5	3.5	12.6 – 15.5
4	13.90	On-time	14.59	0.69	87.6	88.4	0.8	12.6 – 15.4
5	14.25	On-time	15.14	0.89	85.5	89.1	3.6	12.4 – 15.5
6	12.73	Early	14.31	1.58	92.2	92.0	-0.2	12.0 – 17.3
7	12.79	Early	15.29	2.50	89.3	88.4	-0.9	13.2 – 18.1
8	14.60	On-time	15.94	1.34	88.4	84.4	-4.0	14.0 – 17.3
9	12.95	On-time	14.92	1.97	89.6	84.2	-5.4	12.8 – 18.3
10	15.47	Late	16.02	0.55	88.6	85.6	-3.0	13.4 – 16.1
11	14.46	On-time	15.03	0.57	89.7	88.1	-1.6	13.2 – 15.7
12	15.09	Late	15.10	0.01	91.1	87.3	-3.8	13.2 – 15.9
13	15.49	Late	15.62	0.13	90.1	85.1	-5.0	14.9 – 18.3
14	14.84	Late	15.26	0.42	89.8	88.1	-1.7	13.0 – 16.8
15	15.03	Late	15.23	0.20	89.7	89.4	-0.3	13.0 – 15.7
16	13.73	On-time	15.05	1.32	87.0	88.2	1.2	13.1 – 16.0

17	13.87	On-time	15.53	1.66	89.2	86.7	-2.5	13.1 – 17.1
18	14.07	On-time	15.09	1.02	89.9	88.1	-1.8	12.4 – 16.6
19	14.23	On-time	14.80	0.57	89.0	87.7	-1.3	13.0 – 16.2
20	14.54	On-time	15.10	0.56	88.2	85.9	-2.3	13.4 – 17.0
21	13.68	On-time	14.80	1.12	90.1	90.6	0.5	12.5 – 15.0
22	12.59	Early	14.01	1.42	92.5	91.9	-0.6	12.1 – 16.6
23	14.73	On-time	15.37	0.64	86.2	86.9	0.7	13.7 – 16.3
Mean	14.20		15.09	0.89	88.6	87.7	-0.9	
± SD	0.87		0.45	0.65	2.2	2.1	2.5	

*Participants were classified as early maturing if their age at PHV was observed more than one standard deviation (1.0 years) before the mean age of PHV in European boys (13.8 years) and classified as late if they were more than one standard deviation after the mean. Otherwise, they were classified as on-time.

Table 2. Descriptive statistics for player characteristics by competitive age groups through the 2013 – 2017 seasons.

Variable	U13 (*n*=20) Mean ± SD	U14 (*n* = 24) Mean ± SD	U15 (*n* = 23) Mean ± SD	U16 (*n* = 23) Mean ± SD	U17 (*n* = 16) Mean ± SD
Chronological Age (years)	12.6 ± 0.3	13.5 ± 0.3	14.5 ± 0.3	15.5 ± 0.3	16.5 ± 0.3
Maturity offset (years)	-2.3 ± 0.4	-1.6 ± 0.6	-0.6 ± 0.7	0.4 ± 0.7	1.8 ± 0.4
Predicted age at PHV	14.8 ± 0.4	15.1 ± 0.5	15.1 ± 0.6	15.0 ± 0.6	14.4 ± 0.4
Predicted age minus observed age at PHV	0.9 ± 0.6	0.9 ± 0.6	0.8 ± 0.6	0.6 ± 0.7	-0.3 ± 0.6
Current height (cm)	162.2 ± 7.6	167.8 ± 8.1	175.5 ± 7.0	178.8 ± 4.6	179.2 ± 4.2
Predicted adult height (cm)	190.2 ± 4.2	188.4 ± 4.5	187.1 ± 4.7	186.2 ± 4.7	188.5 ± 2.4
Height as a percentage of predicted adult height (%)*	83.4 ± 2.6	86.1 ± 2.5	89.9 ± 2.4	93.5 ± 2.2	96.9 ± 1.2
Height as a percentage of observed young adult height at 18.0 years (%)	82.6 ± 1.9	85.8 ± 2.5	89.9 ± 2.5	93.3 ± 2.1	96.6 ± 1.1

*Predicted adult height was calculated at 13.0 years with the equations of Khamis and Roche (1994).

Table 3: Concordance of predicted and observed classifications of participants based on predicted age at PHV at 13.0 years and percentage of predicted adult height at 13.0 years relative to classifications based, respectively, on observed ages at PHV (SITAR) and on height at PHV (SITAR) expressed as a percentage of young adult height. Values in brackets indicate the number of correct predictions.

Method	Yes	No	κ
Age at PHV between 12.8 – 14.8 years:			
Predicted ages at PHV	0	23	
Observed ages at PHV	8	15	
Concordance between prediction and observation for age at PHV	0	15	0.65
Percentage of adult height 85 – 96%			
As % predicted adult height at 13.0 years	21	2	
Height at PHV as % young adult height	21	2	
Concordance between prediction and observation for height at PHV	19	0	0.83

Table 4: Performance of each method for estimating window of age at PHV based on observed age at PHV (SITAR) and results of the chi-squared analyses.

Method	Observed ages at PHV within the prediction window defined by each method	χ^2
Generic Age at PHV	14	1.09
Predicted Age at PHV	14	1.09
Window % of Predicted Adult Height expressed as an age window	22	*19.17

**p<0.01*

Figure 1: Frequency of observed heights at PHV expressed as a percentage of observed young adult heights at 18.0 years.

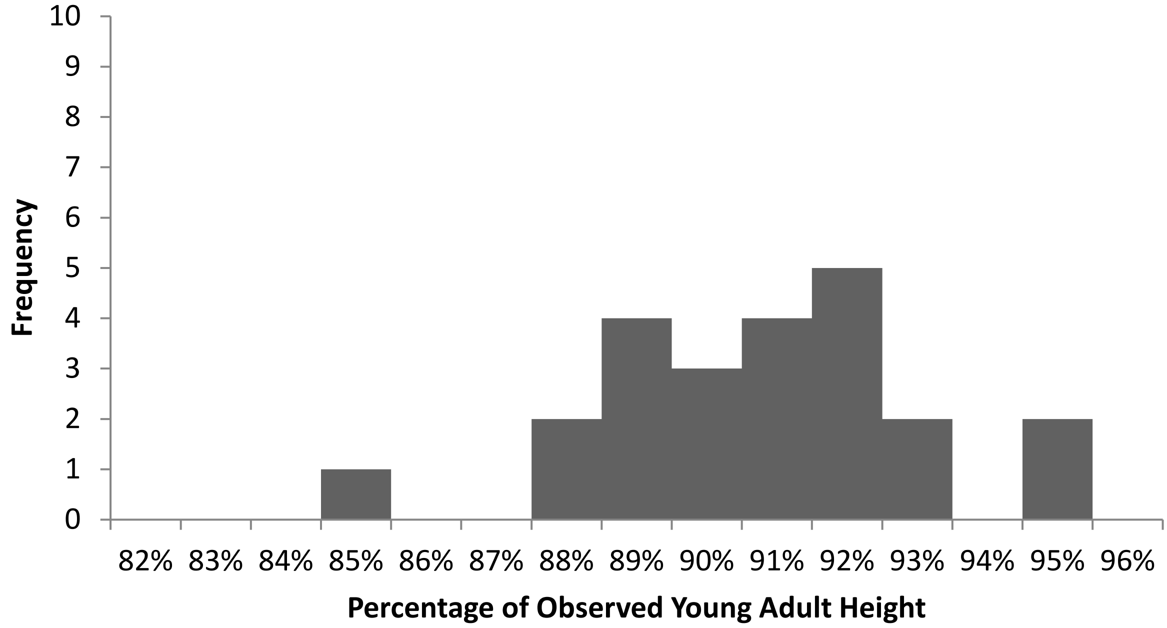

Figure 2: Frequency of observed heights at PHV expressed as a percentage of predicted adult heights at 13.0 years.