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Developmental fitness curves: Assessing sprint acceleration relative to age and maturity status in elite junior tennis players

Gillian K. Myburgh[1,2] Sean P. Cumming[2] Manuel Coelho-e-Silva[3] & Robert M. Malina[4]

[1]National Tennis Centre, Lawn Tennis Association, Roehampton, London, United Kingdom; [2]Sport, Health and Exercises Science Research Group, Department of Health, University of Bath, Bath, UK, [3]Faculty of Sports Science and Physical Education, University of Coimbra, Portugal; [4]Professor Emeritus, Department of Kinesiology and Health Education, University of Texas at Austin

Corresponding Author:

Gillian K. Myburgh

Lawn Tennis Association

100 Priory Lane

London

SW15 5JQ

+447930118689

gill.myburgh@LTA.org.uk

ORCID: 0000-0002-2762-7335

Abstract

Background

The influence of maturity-status on athletic performance is reasonably well documented. Methodological and practical issues of assessment and lack of longitudinal data have impacted the success of various models.

Aim

To develop age- and sex-specific developmental curves for sprint acceleration in elite youth tennis players and to address variation in performance relative to chronological and biological ages

Methods

Measures of acceleration were available for 3120 elite youth tennis players 8-15 years attending National and Regional Talent Identification days. Variation in acceleration by chronological and estimated biological ages was evaluated in corresponding data for an independent sample of elite youth players 8.9 to 15.1 years.

Results

Acceleration varied as a function of chronological and biological age relative to developmental curves. Early maturing males and females had significantly poorer performances when acceleration was considered relative to biological age. Significant discrepancy in percentiles relative to biological versus chronological ages was also evident between early and late maturing players of each sex.

Conclusion.

Evaluating performance relative to developmental curves and maturity status may be a practical means of monitoring long-term athlete development in tennis.

Word count: 181

Keywords: youth athletes, speed, puberty, predicted adult height

Introduction

Tests of physical performance are routinely implemented in elite youth tennis and are generally used to monitor athlete development (Fernandez-Fernandez, Mendez-Villanueva, & Pluim, 2006; Fernandez-Fernandez, Ulbricht, & Ferrauti, 2014). The physical performance tests typically focus on attributes considered requisite for success in tennis at the adult level: strength, speed, power, agility and endurance (Pearson, Naughton, & Torode, 2006; Ulbricht, Fernandez-Fernandez, & Ferrauti, 2013).

Measures of speed are predictors of tennis performance and generally differentiate youth players of different abilities (Girard & Millet, 2009; Groppel & Roetert, 1992; Kramer, Huijgen, Elferink-Gemser, Lyons, & Visscher, 2010; Kramer, Valente-dos-Santos, et al., 2016; Roetert, Garrett, Brown, & Camaione, 1992). National and regional players U12 German Federation players differed significantly in a tennis specific sprint test (Ulbricht et al., 2016), while elite Dutch male youth tennis players were faster than sub-elite peers over 5 m and 10 m up to 13 years of age (Kramer, Valente-dos-Santos, et al., 2016).

Given that 80% of movements in tennis occur within a 2.5 m radius of a player's ready position (Fernandez-Fernandez et al., 2006; Gescheit et al., 2017; Kramer et al., 2016; Parsons & Jones, 1998), players do not attain maximum speed in sprinting (Cronin & Hansen, 2005; Salonikidis & Zafeiridis, 2008). Rather, the complexity and multiple variations in ball velocity, spin and placement emphasize the importance of reaction time and first step quickness (Kovacs, 2006). Measures of first step quickness and acceleration would seemingly be better indicators of performance in tennis rather than measures of maximal velocity (Cronin & Hansen, 2005; Salonikidis & Zafeiridis, 2008).

Development of speed among youth does not follow a linear pattern of improvement with age. Improvements in speed during childhood (5 to 9 years) are generally attributed to neuromuscular maturation and associated changes in coordination and efficiency in both sexes, but performances of girls and boys diverge during the adolescent spurt (Oliver & Rumpf, 2014; Viru et al., 1999). Sprint times show accelerated improvement in boys ~12 to 14 years; corresponding improvements occur earlier among girls, but sprint performances plateau about 2 to 3 years earlier than boys (Papaiakovou et al., 2009; Viru et al., 1999).

Changes in limb length and muscle mass associated with pubertal growth and maturation impact strength, power, stride length and stride frequency stabilization in boys, and a potential maturity-related component of speed is suggested (Meyers et al., 2017; Meyers, Oliver, Hughes, Cronin, & Lloyd, 2015). However, limitations of predicted maturity offset as an indicator of maturity status should be noted (Malina, 2017). Corresponding data for girls are lacking, while limited data suggest better performances among late maturing in contrast to early maturing tennis players over 5 m and 10 m distances (Van Den Berg, Coetzee, & Pienaar, 2006).

Among elite youth soccer players 13 years of age, early maturing players (skeletal age) performed better than later maturing peers in 10 m, 20 m and 40 m sprints (Carling, Le Gall, & Malina, 2012). In contrast, soccer players 11-12 and 13-14 years of contrasting maturity status (skeletal age) did not differ significantly in the mean of seven sprints or the fastest sprint, but a maturity-related gradient, early>average>late, was suggested among older players (Figueiredo et al., 2009). In a sample of largely average maturing male youth soccer players followed for longitudinally 4-5 years, peak velocities in a 30 m sprint were attained, on average, around the time of peak height velocity (PHV), and subsequently levelled-off (Philippaerts et al., 2006).

Individual differences in the timing and tempo of puberty and the growth spurt present significant challenges to those involved in the implementation and interpretation of performance tests in young athletes (Baxter-Jones, Eisenmann, & Sherar, 2005), as inter-individual variability in timing and tempo may influence performance during adolescence (Cumming, 2018). Although awareness of maturity-associated variation in size and function among youth athletes is essential, the variation, largely transient, is attenuated in later adolescence (Malina et al., 2004), and may be reversed in adulthood (Lefevre et al. 1990).

Although the physical fitness of youth athletes generally rely on comparisons of with chronological age (CA)- and sex-specific reference values, the development of maturity-sensitive strategies for assessing performance in youth has been advocated (Cumming, Lloyd, Oliver, Eisenmann, & Malina, 2017; Till, Morrison, Emmonds, Jones, & Cobley, 2018). The approach is limited in that it generally involves assessments at a single point in time and often classifies athletes into specific maturity bands or groups. Indeed, percentiles for several fitness tests based on chronological age and predicted maturity offset have been developed for elite youth tennis players (Ulbricht et al., 2013). Though interesting, the prediction of maturity status has major limitations especially among early and late maturing youth of both sexes (Malina, 2017).

The aim of this study is to develop age- and sex-specific performance curves for the 5 m sprint test in elite British youth tennis players. A secondary objective is to evaluate the impact of biological maturity status on acceleration scores relative to the developmental curves. It is hypothesised that players advanced in maturity status will present higher (poorer) percentiles when acceleration scores are expressed relative to biological maturity status than to CA, while the opposite will be the case among later maturing players.

Materials and Methods

Participants

Data collected by the Lawn Tennis Association as part of the National (NTID) and Regional Talent Identification (RTID) programs were the basis for the construction of developmental curves for 5 m sprint performance. The performances of 3120 youth tennis players (1850 males, 1270 females) were measured (see below) biannually between 2009 and 2014. Players were grouped into two-year CA categories: U8 (499 males, 287 females), U10 (904 males, 573 females), U12 (309 males, 299 females) and U14 (138 males, 111 females). Although multiple measurements were available for each player, data were treated cross-sectionally.

Participation in TID sessions was by invitation. For both females and males, the Tennis Performance Manager nominated players in single year U8 and U9 groups, while the Age Group Captain nominated the U10 group. U11 and U12 NTID sample represented the top 16 players on the National seasonal rankings, while U13 players were limited to the top 10 in the National seasonal rankings and/or to those ranked among the top 125 on the Tennis Europe rankings list. Criteria varied for U14 players. Males invited to NTID days represented the top 10 on the National season rankings or were ranked within the top 50 on Tennis Europe rankings or within the top 150 Tennis Europe Combined rankings. On the other hand, U14 females were among the top 8 players on the National seasonal rankings list and/or were ranked within the top 50 among U14 players in the Tennis Europe rankings or within the top 500 in the International Tennis Federation rankings.

National Age Group Training Camp Participants

National Age Group Training Camps (NAGTC) were used. For the analyses of acceleration scores relative to age and estimated maturity status, data were collected during 2011-2012 and 2016-2017. The cross-sectional sample included 258 players, 145 males and 113 females, 8.9 to 15.1 years of age. The players represented the top eight in their respective age groups according to the Great Britain National rankings at the time of selection. Only ranked participants with an estimate of maturity status and 5 m sprint times (see below) were included in the analysis.

Ethics

Ethics approval for the analysis of the NAGTC data and the retrospective use of the anonymised data were obtained from the Research Ethics Approval Committee for Health at the University of Bath, with the approval of the Lawn Tennis Association. In accordance with the Declaration of Helsinki, participants were informed of their right to withdraw from the study at any point without incurring any negative repercussions (World Medical Association, 2013). Written assent and consent was obtained from both participants and parents/guardians.

Anthropometry

All data were collected on the indoor tennis courts at the National Training Centre in Roehampton, London on the TID and NAGTC days. The same trained technician was assigned to a specific testing area at each venue.

Height (0.1 cm) was measured with a calibrated Harpenden stadiometer fixed to the wall following standard procedures (Malina, 1995). Standing barefoot, feet together, with arms hanging loosely by the sides, participants took a deep breath prior to the headboard of the stadiometer being placed on their head; the measurement was the recorded.

A 41 cm bench was placed against the wall to which the stadiometer was attached was used to measure seated height. Players sat with their trunk upright and their back placed firmly against the wall. Depending on lower limb length, players either dangled their legs free of the floor or extended their lower leg at the knee. Height while seated was measured (0.1 cm); seated height was derived as the difference between standing height and height of the bench.

Weight was measured to the nearest 0.1 kg using a calibrated Marsden Weighing Company DP2400 BMI Indicator scale. Wearing only a T-shirt and shorts, participants stood barefoot with their weight balanced evenly on the scale before the measurement was recorded.

Acceleration

After a standardised warm up, acceleration was measured over 5 m linear intervals with electronic timing gates (Smartspeed, Fusion Sport pte, Australia), which have established accuracy and reliability (Fernandez-Fernandez et al., 2014). Participants lined up in a tennis ready position (feet square on), 30 cm behind the start line, and in their own time, sprinted as fast as possible through the electronic timing gates. The three trials were performed; the best trial retained for analysis.

Developmental Curves

Data from the National (NTID) and Regional Talent Identification (RTID) programs were used to derive sex-specific developmental curves for the 5 m-sprint test. Selected quantiles (10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th}) were calculated by age using the R Package Quantreg (Koenker, 2016; R Core Team, 2017). Smoothness of fit was controlled via B-splines with different penalties by sex (male: 5 λ, female: 3 λ) in order to identify potentially important covariates and exclude unimportant ones. In addition to providing medians and percentiles, this non-parametric technique makes no assumption on the underlying distribution of the data and is robust to outliers.

Maturity Status

Data for the NAGTC sample included reported heights of each player's biological parents, which were adjusted for overestimation. Age, height and weight of the player and midparent height were used to predict his/her adult height using equations developed for children and youth in the Fels Longitudinal Study (Khamis & Roche, 1994). Current height was then expressed as a percentage of predicted adult height attained at the time of observation, which is an indicator of maturity status (Roche, Tyleshevski & Rogers, (1983). Percentage of predicted adult height attained at time of observation for each player was then compared to age- and sex-specific growth reference data for the UK (Freeman et al., 1995; Gillison, Cumming, Standage, Barnaby, & Katszmarzyk, 2017) to derive an index of maturity status, labelled biological age (BA), for each participant. Sex-specific reference values for percentage of adult stature were calculated at approximately 0.1 yearly intervals relative to the UK reference data. Percentages at each age interval were based upon mean attained height attained at each age relative to mean stature at/above 18 years (Gillison et al., 2017). Accordingly, a boy with a CA of 12.5 years attained 88% of his predicted adult height at the time of observation; his percentage of predicted adult height was equivalent to the mean percentage of adult height attained by a UK boy of 13.2 years, which was accepted as his BA. Maturity status was estimated as BA minus CA (BA - CA). Participants were subsequently classified as on-time or average if the difference between BA and CA fell within ± 1.0 year, advanced if the difference was > +1.0 year, and delayed if the difference was > -1.0 year. The band of ±1.0 year approximates standard deviations of skeletal ages (SA) within specific CA groups between 11 and 16 years with the Fels and other methods of assessment (Malina, 2011). Allowing for measurement variability associated prediction of adult height, the band of ±1.0 year provides for a broad range of youth classified as on time or average in maturity status.

Analysis

Descriptive statistics for the TID and NAGTC data sets were calculated with SPSS version 22 (IBM Corp., 2013). Visual inspection of the histograms, normal Q-Q plots and box plots was done to evaluate the normality of the percentile differences attained with BA and CA. Distributions of continuous variables were examined for skewness and kurtosis using the Shapiro Wilk's test ($p < .05$) and associated z-values (Shapiro & Wilk, 1965). A Wilcoxon Signed Rank Test was employed to determine whether there was any performance benefit associated with BA versus CA when evaluating 5 m sprint times of early, on-time and late maturers in the male and female samples, respectively (Laerd Statistics, 2015). Additional analyses, evaluating the number of players that moved in and out of the top 10% was performed with a Wilcoxon signed rank test. Percentile discrepancy scores were calculated for BA and CA percentile values by subtracting the percentile attained with CA from the percentile attained with BA (BA percentile – CA percentile). For example, if a player's 5 m sprint score placed them on the 45th percentile for CA and at the 75th percentile for BA, the percentile discrepancy score was 30% (75% - 45% = 30%). The Mann-Whitney U test was used to evaluate the difference in acceleration percentile scores by maturity groups (Laerd Statistics, 2015).

Since comparisons of small samples are prone to Type II errors, a significance level of $p < 0.1$ was utilised. Effect sizes for nonparametric data (z-score divided by the square root of total sample number) were calculated to indicate the magnitude of differences in each variable (Rosenthal, 1991). A value of ≤ 0.20 was considered a small effect, 0.50 a moderate effect and ≥ 0.80 a large effect (Cohen, 1998).

Results

Descriptive statistics for CA, body size and 5 m sprint times for the National (NTID) and Regional Talent Identification (RTID) samples are summarized by sex and age in Table 6.1, while corresponding statistics for the National Age Group Training Camp (NAGTC) sample are summarized in Table 6.2. As expected, mean height, weight and the BMI increase and acceleration times improve, on average, with age in both sexes. Sex differences are negligible in the NTID and RTID series, while males in the NAGTC series are, on average, taller, heavier and faster than females, which reflects, in part, the older CA of the males. Estimated BA approximates CA in both males and females, and the majority of players are classified as on-time, males 88% and females 82%.

Table 6.1 inserted here

Table 6.2 inserted here

Descriptive statistics for NAGTC players classified by estimated maturity status are summarized in Table 6.3. Early maturing players are, on average, taller and heavier and quicker in acceleration scores than average and late maturing players, allowing for the relatively small samples of late and early maturers. In contrast, on time and late maturing players of each sex differ negligibly in acceleration scores.

Table 6.3 inserted

The 5 m sprint times of NAGTC players are plotted by CA relative to the respective developmental curves for males (Figure 6.1) and females (Figure 6.2). Lower percentiles for sprint times reflect better performances. Almost three-fourths of the males (72%) have 5 m sprint times below CA-specific means, with 35% having sprint scores $\leq 10^{th}$ percentile (fastest). In contrast, only 12% of males have sprint scores >75th percentile (slowest).

The majority of female players (61%) have 5 m sprint times below CA-specific means (faster) but only 14% of these players have sprint times ≤10th percentile (fastest). As in males, a minority (15%) of females have sprint scores > 75th percentile. Of note, the 5 m sprint times of female players are rather proportionally distributed between the 10th and 75th percentiles.

Figure 6.1 and Figure 6.2 inserted here

When 5 m sprint times are evaluated relative to BA, a minority (17%) of male players (17%) attain lower percentiles (improved performance) while 58% attain higher percentiles (poorer performance). On the other hand, 25% of the players achieve the same percentile value relative to both BA and CA. Players with lower (improved) percentiles for the sprint relative to BA are either on-time or late in estimated maturity status, while those with higher (poorer) percentiles for the sprint relative to BA include a mixture of players classified as on-time and advanced in estimated maturity status.

The contrast in 5 m sprint scores between early and late maturing male players is illustrated in Figures 6.3 and 6.4, respectively. An arrow connects the scores for CA and BA in individual players; the tail of the arrow indicates the 5 m sprint score by CA and the head indicates the score with BA. Males with no difference between percentile scores for CA relative to BA are either on-time or late in estimated maturity status. Overall, the mean percentile discrepancy scores approximates 26% in early, 22% in late and only 3.1% in average maturing males.

When 5 m sprint times are expressed relative to BA in female players, 43% have higher percentiles (poorer performance) and 40% have lower percentiles (improved performance), while 17% show no change in percentile scores relative to BA and CA. Players with lower (improved) percentiles are either on-time or delayed in estimated maturity status, while those with higher (poorer) percentiles include players classified as on-time and advanced in estimated maturity status. Players showing no change in 5 m sprint percentiles are on-time and early maturing. Overall, the percentile discrepancy score of players advanced in maturity status declined by 16%, improved by 17% in the small sample of late maturing players, but was unchanged (0%) among players average in maturity status. The contrast among early and late maturing female players is illustrated in Figures 6.5 and 6.6, respectively.

Figure 6.3, 6.4, 6.5 and 6.6 inserted here

The preceding results focus on trends in the distributions of 5 m sprint times among male and female players. The distribution of the scores, however, was not normal (Shapiro Wilk's test, $p<.05$). Skewness and kurtosis values were 1.363 (SE = .226) and 3.543 (SE = .449), respectively, in males, and -0.473 (SE = .201) and 2.740 (SE = .400), respectively, in females. Z-values for skewness (males -2.35, females 6.03) and kurtosis (males 6.85, females 7.89) were generally above the value recommended for medium sized samples (Kim, 2013). As such, the non-parametric Wilcoxon Signed Rank and Mann Whitney U tests were implemented in further analyses.

Results of the Wilcoxon Signed Rank Test are illustrated in Figures 6.9 and 6.10. Percentile scores for 5 m sprint times are significantly higher (poorer performances) when expressed relative to BA than to CA in males maturing early and on-time ($p < .05$), while corresponding differences are not significant among late maturing males (Figure 6.9). A significant number of early maturing males (89%) moved out of the top 10% when 5 m sprint percentiles were evaluated with BA rather than CA, with 50% (1 of 2 players) of late maturers moving into the top 10%.

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Among females, significantly higher (poorer) percentile scores are apparent when 5 m sprint times are evaluated relative to BA than to CA in early maturing players, while significantly lower (improved) percentile scores are apparent when times are evaluated relative to BA than to CA in late maturing players. In contrast, percentile scores for players classified as on time in maturity status do not differ when expressed relative to BA and CA (Figure 6.10). Similar to the male population, but in smaller proportion, 27% of advanced female maturers, moved out of the top 10% when 5 m sprint percentiles were evaluated with BA rather than CA. In relation, 25% (1 of 4 players) of late maturers moved into the top 10%.

Figure 6.9 and 6.10 inserted here

Results of the Mann Whitney U Test are illustrated in Figure 6.11. Among males, early maturing players achieve moderate (r =-.63) but significantly (ρ<.05) higher (slower) percentile discrepancy scores than late maturing players. Significant (p<.05) differences in percentile discrepancy scores are also apparent between early and on-time, and between on-time and late maturing players, although the differences are negligible (r =-.00 and r =-.01, respectively). Among females, early maturing players also achieve moderate (r =-.68) and significantly (ρ<.05) higher (slower) percentile discrepancy scores than late maturing players. And also similar to male players, significant differences (p<.05) in percentile discrepancy scores are evident between early and on-time, and between on-time and late maturing female players, although the differences are negligible (r =-.04 and r =-.00, respectively).

Figure 6.11 inserted here

Discussion

The potential utility of developmental curves for 5 m sprint times (acceleration) relative to CA among tennis players for the purpose of comparing sprint times relative to CA and estimated BA in a separate sample of elite youth players is considered. Among players of both sexes, acceleration scores were poorer for early maturing players when expressed relative to BA compared to CA, but were superior for late maturing players when expressed relative to BA compared to CA. The differences in mean percentile scores when expressed relative to BA versus CA in both early and late maturing players are generally consistent with previous literature (Ulbricht et al., 2013). Note, however, the maturity indicators used in the two studies are not equivalent. The present study used an estimate of maturity status derived from percentage of predicted adult height at the time of observations, while the latter (Ulbricht et al., 2013) used maturity categories based on predicted maturity offset in tennis players <11 to ≥16 years. The 12 maturity groups were based on predicted maturity offset intervals of 0.5 year, < -2.5 to +2.5 to +3.0. Of note, the standard errors of estimate of the prediction equations were 0.569 and 0.592 years in girls and boys, respectively (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). Moreover, evidence from two longitudinal series shows that predicted maturity offset varies with age at prediction, has a reduced range of variation relative of observed maturity offset (date of measurement minus observed age at PHV), and has major limitations with early and late maturing youth of both sexes defined by observed age at PHV (Malina, Choh, Czerwinski & Chumlea, 2016; Kozieł & Malina, 2018).

Nevertheless, the difference in percentiles achieved with BA versus CA in the present study was most pronounced among individuals of both sexes at the opposite ends of the maturity status spectrum (early versus late), but percentage changes between BA and CA were greater in males than females. The non-significant results in late maturing males was likely due to the very limited number of players so classified (n = 3). The latter, however, is generally consistent with observations of a limited number of late maturing elite tennis players defined by the difference between SA and CA (Myburgh, Cumming, Coelho-e-Silva, Cooke, & Malina, 2016).

Age and/or maturity-associated variation in sprint performance are related in part with stride length, which increases with growth (Kramer et al., 2016; Meylan, Cronin, Oliver, Hopkins, & Contreras, 2013; Schepens, Willems, & Cavagna, 1998). Taller individuals tend to have longer legs compared to shorter CA peers, and by inference, a greater stride length, which may impact sprint performances and times (Kramer et al., 2016; Malina, Bouchard, & Bar-Or, 2004). In addition, hormonal (testosterone, growth hormone) and neuromuscular factors and gains in muscle mass and power associated with the growth spurt (Kramer et al., 2016; Rowland, 2005) may also contribute to faster sprint times in this cohort of elite youth tennis players. Variation in the differential timing of growth spurts in segments of the lower extremities is an additional factor.

A practical utility of sport-specific developmental curves for fitness tests, such as the 5 m sprint, is that it may permit practitioners to consider performances of youth players in the context of both CA and biological maturity status (BA). With 89% of early maturing males and 27% of early maturing females moving out of the top 10% when 5 m sprint performances were compared with BA rather than CA, the benefits associated with early maturation can be clearly highlighted.

The athletic advantage associated with acceleration in the early maturing sample of tennis players is generally consistent with observations of elite youth athletes in several sports. Many current studies, however, use predicted maturity offset, time before PHV, as the maturity indicator (Buchheit & Mendez-Villanueva, 2014; Coelho-e-Silva et al., 2010; Matthys, Vaeyens, Coelho-e-Silva, Lenoir, & Philippaerts, 2012; Meylan, Cronin, Oliver, & Hughes, 2010). Limitations of this predicted indicator have been noted earlier in the discussion. Other current studies have used established maturity indicators, such as stage of pubic hair and skeletal age; the former is often considered as "invasive" while the latter is considered expensive and requires expertise in the assessment protocols (Malina, 2011; Malina, Rogol, Cumming, Coelho-e-Silva, & Figueiredo, 2015). Studies comparing performances of youth athletes using percentage of predicted adult height at the time of observation as the maturity indicator are apparently not available.

The greater relative differences in 5 m sprint performances of male tennis players when expressed relative to BA and CA likely reflect performance advantages associated with earlier maturation, specifically for indicators of strength, power and speed (Malina et al., 2004). Male athletes in a variety of sports tend to be advanced in maturity status beginning at about 12-13 years of age (Malina, 2011; Malina et al., 2015).

Corresponding trends for female tennis players were inconsistent, likely reflecting small numbers of early and late maturing youth. Nevertheless, based on self-assessments of pubertal status among tennis players 12-14 years, late maturing girls showed an advantage in the 5 and 10 m sprints compared to early and average maturing girls (Van Den Berg et al., 2006). The late maturing players were also chronologically older (13.6±0.7 years) than the early (13.0±1.3 years) and average (13.0±0.5 years) maturing players, and CA was apparently not controlled in the comparisons. In female athletes, performance advantages associated with advanced maturity status during adolescence are less clear compared to the trends among male athletes (Malina et al., 2004), while the maturity status of female athletes varies considerably by sport (Malina, Ackerman, & Rogol, 2016). Nevertheless, observations in the current study are generally consistent with those for female athletes in sports that emphasize strength and power (Baxter-Jones, Thompson, & Malina, 2002; Erlandson, Sherar, Mirwald, Maffulli, & Baxter-Jones, 2008).

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The findings of the present study have several implications for those working with youth tennis players. First, the current study used a non-invasive estimate of biological maturity status, percentage of predicted adult height at the time of observation. Second, plotting individual sprint scores on developmental curves, a novel approach used in the study, provides a means of deriving measurable differences in acceleration scores of individual players relative to both CA and estimated BA. Both approaches may be a practical solution for organisations, administrators and practitioners in efforts to account for individual differences in maturity status of youth tennis players when identifying and assessing talent and potential. The information may also assist in aligning strength and conditioning strategies for individuals according to estimated maturity status rather than CA. This strategy has been effectively implemented at the premier league football club Arsenal, where players are grouped according to estimated stage of maturation for the purpose of adjusting training for individual differences in maturity status during the adolescent growth spurt (Ryan, Lewin, Forsythe, & Mccall, 2018).

The present study was not without limitations. It was cross-sectional which may limit its applicability. There is a need for serial data spanning late childhood through adolescence which would facilitate the understanding of the direction and magnitude of trends in acceleration among elite youth British tennis players (Duthie, Pyne, Ross, Livingstone, & Hooper, 2006). Such data for tennis are limited to a single study that longitudinally monitored development of the 5 m sprint in male tennis players, although maturity status was not considered (Kramer et al., 2016).

The study was also limited to a small sample of elite British youth tennis players, and as such, the results may not apply to players from other countries or at different levels of ability. The small sample also limited the statistical power of the analysis. In addition, a non-invasive estimate of maturity status was used, percentage of predicted adult height expressed relative to reference data for UK youth. The protocol has not been validated within UK samples (Gillison et al., 2017), although percentage of predicted adult height at the time of observations had moderate concordance with estimates of maturity status based on SA in elite tennis players (Myburgh, Cumming, & Malina, 2019), youth soccer players (Malina et al., 2012) and youth American football players (Malina et al., 2007). Finally, the developmental curves for 5 m sprint performance was based on CA and potential confounding effects of height, weight and maturity status were not considered.

In summary, results of the present study provide a practical means of quantifying the effects of variation in estimated biological maturity status on a measure of acceleration in sprinting in elite youth tennis players of both sexes. Future research should perhaps extend this strategy to other performance measures in a larger sample and perhaps in other sports.

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Declaration of interest

The Lawn Tennis Association funds the part time studentship (i.e., academic fees) of Gillian Myburgh. Gillian Myburgh, Sean Cumming and Robert Malina declare that they have no competing interests.

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Appendices

Tables

Table 6.1 Descriptive statistics (M, SD) for chronological age, body size and the 5 m sprint of elite tennis players attending NTID and RTID days by sex and age group

	U8		**U10**		**U12**		**U14**	
	Male n=499	Female n=287	Male n=904	Female n=573	Male n=309	Female n=299	Male n=138	Female n=111
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
CA (years)	8.5 (.3)	8.5 (.4)	9.8 (.5)	9.9 (.6)	12.0 (.6)	12.0 (.6)	13.8 (.5)	13.8 (.6)
Height (cm)	133.0 (6.0)	133.0 (6.0)	141.0 (6.0)	141.0 (7.0)	155.0 (8.0)	154.0 (7.0)	167.0 (9.0)	166.0 (8.0)
Weight (kg)	29.0 (3.9)	29.2 (4.1)	33.8 (5.0)	33.9 (5.2)	45.3 (8.0)	44.3 (7.2)	56.5 (8.1)	55.1 (8.6)
BMI (kg/m^2)	16.4 (1.5)	16.5 (1.5)	17.1 (1.7)	17.0 (1.6)	18.9 (2.2)	18.6 (2.0)	20.2 (1.8)	20.1 (2.1)
5 m Sprint (s)	1.306 (.082)	1.315 (.083)	1.265 (.074)	1.268 (.073)	1.220 (.072)	1.220 (.076)	1.114 (.071)	1.131 (.069)

Table 6.2. Descriptive statistics (M, SD) for chronological age, estimated biological age, body size and the 5 m sprint of elite tennis players by sex and age group attending a National Age Group Training Camp

	Male n=145	Female n=113
	M (SD)	M ± SD
Chronological Age (years)	12.5 (1.2)	11.6 (1.3)
Biological Age (years)	12.8 (1.4)	11.8 (1.6)
Height (cm)	159.0 (1.0)	153.0 (9.0)
Weight (kg)	45.8 (9.0)	41.8 (9.2)
Percentage of adult height (%)	86.8 (5.0)	90.6 (5.1)
Percentage of adult height (z-score)	0.31 (.74)	-0.10 (.80)
5 m Sprint (s)	1.144 (.743)	1.194 (.080)

Table 6.3 Descriptive statistics (M, SD) for chronological age, estimated biological age, body size and the 5 m sprint of elite youth tennis players attending a National Age Group Training Camp by sex and maturity status

	Male			Female		
	Late n=3	On-Time n=127	Early n=15	Late n=4	On-Time n=93	Early n=16
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Chronological Age (years)	12.7 (1.3)	12.5 (1.3)	12.8 (.9)	10.8 (1.0)	11.6 (1.3)	11.8 (.7)
Biological Age (years)	11.6 (1.3)	12.6 (1.4)	14.0 (.9)	9.7 (1.0)	11.6 (1.5)	13.1 (.8)
BA-CA (years)	-1.1 (.6)	.2 (.4)	1.2 (.23)	-1.1 (.2)	.0 (.5)	1.3 (.3)
Height (cm)	152.0 (7.0)	160.0 (10.0)	170.0 (11.0)	138.0 (10.0)	152.0 (10.0)	163.0 (10.0)
Weight (kg)	36.3 (2.1)	45.0 (8.3)	54.5 (10.8)	28.5 (4.0)	40.6(8.4)	52.0 (4.9)
Percentage of adult height (%)	82.7 (3.8)	86.4 (4.9)	91.5 (3.9)	83.6 (3.4)	90.1 (5.0)	95.1 (2.2)
Percentage of adult height (z-score)	-1.37 (.21)	.21 (.60)	1.47 (.49)	-1.50 (.27)	-0.26 (.59)	1.20 (.34)
5 m Sprint (s)	1.150 (.043)	1.149 (.074)	1.097 (.066)	1.218 (.070)	1.202 (.080)	1.144 (.065)

BA-CA: Biological age minus chronological age

Figures

Figure 6.1. Developmental curves showing specific percentiles for 5 m sprint times derived from 1850 elite male tennis players 8 to 15 years in the TID program and the individual times of 145 males in the National Age Group Training Camps

Figure 6.2. Developmental curves showing specific percentiles for 5 m sprint times derived from 1270 elite female tennis players 8 to 15 years in the TID program and the individual times of 113 females in the National Age Group Training Camps

Figure 6.3. Difference of early maturing elite male tennis players 5 m sprint times based on estimated biological and chronological ages relative to developmental percentile curves.

Figure 6.4. Difference of late maturing elite male tennis players 5 m sprint times based on estimated biological and chronological ages relative to the developmental percentile curves

Figure 6.5. Difference early maturing elite female tennis players 5 m sprint times based on estimated biological and chronological ages relative to the developmental percentile curves

Figure 6.6. Difference of late maturing elite female tennis players 5 m sprint times based on estimated biological and chronological ages relative to the developmental percentile curves

~~Figure 6.7. Mean percentile values and standard errors for 5 m sprint times of elite male youth tennis players classified as early, average or late maturing by biological and chronological ages~~

~~Figure 6.8. Mean percentile values and standard errors for 5 m sprint times of elite female youth tennis players classified as early, average or late maturing by biological and chronological ages~~