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Longitudinal development of 5m sprint performance in young female tennis players

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ABSTRACT

Sprint performance over short distances is a central component in young tennis players' development. This study aimed to examine the longitudinal development of sprint performance in young female tennis players, and to investigate differences between performance levels. Also potentially explanatory variables were investigated. Female tennis players aged 10–15 ($N = 167$) participated in a, mixed-longitudinal study ($n = 48$ elite; $n = 119$ sub-elite). Players were measured annually on the 5 m sprint as well as for possible explaining variables for 5 m sprint performance development (age, height, body mass, maturity status, lower limb explosive strength). Multilevel analysis was used to obtain a developmental model. Moreover, it was possible to predict sprint performance (5 m) based on chronological age, body size given by height, and lower limb strength performance ($p < .05$). Significant different developmental patterns were found for elite and sub-elite players, with elite players aged 10–14 being faster. After age 14, no significant differences were found in sprint performance between elite and sub-elite players ($p > .05$). Sprint performance is an important characteristic of young female tennis players and seemed to depend on growth and maturation in parallel to physical fitness.

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Growth; physical fitness; strength; talent development; racquet sports

Introduction

Professional tennis has become an increasingly intensive physical sport (Gale-Watts & Nevill, 2016; Kovalchik & Reid, 2017). One key indicator for success in tennis is the performance of fast sprints over short distances (< 10 m) (Gale-Watts & Nevill, 2016; Kovacs, 2006; Parsons & Jones, 1998) with most sprints on a tennis court being 5 m or less (Salonikidis & Zafeiridis, 2008). The better a player's sprint performance, the faster a player can get to the ball, and the more time the player has to prepare for a shot. Small differences in sprint performance could therefore result in a great advantage for a player and thus for their playing level (Bloomfield, Polman, O'Donoghue, & McNaughton, 2007; Keiner et al., 2014; Kovacs, 2006; T. Kramer et al., 2010; Munivrana et al., 2015; Roetert et al., 1995). In other sports, for example, soccer, field hockey, rugby and handball, sprint performance has also shown to be a discriminating factor between performance levels (e.g., Huijgen et al., 2009; Elferink-Gemser et al., 2007; Matthys et al., 2013).

Young players aiming to make it to the top need to be fast sprinters (Kovacs, 2007; Kovalchik & Reid, 2017; Kramer et al., 2017; Munivrana et al., 2015). In junior tennis, Kramer et al. (2016) found that up to age 14, young elite male tennis players are faster over 5 m than young sub-elite male tennis players. Munivrana et al. (2015) showed that 5 m sprint performance explained a large part of tennis performance during late adolescence for female players ($R^2 = .39$; $\beta = .56$). Development of sprint performance therefore seems important for reaching elite level. To gain insight into the development of sprint performance in young tennis players, longitudinal research is advocated and considered essential (see for a review on talent identification in sport Johnston et al., 2018). Unfortunately, there is a lack of this type of research on young tennis players, especially on females (Johnston et al., 2018; Kovalchik & Reid, 2017). Johnston et al. (2018) noted that only 10% ($n = 2$) of in total 20 longitudinal studies examined a female-only sample, and five studies used a combination of both male and female participants. This means that coaches have less information about how young females develop in their sport than about young males.

One of the scarce longitudinal studies in tennis showed that the development of sprint performance in elite and sub-elite tennis boys is non-linear and levels off at age 14 regardless of performance level (Kramer et al., 2016). Earlier studies in male soccer players confirm that sprint performance develops over age (Huijgen et al., 2010; Valente-dos-Santos et al., 2012). A 3-year longitudinal study in soccer players aged 11 to 14 showed that sprint performance development was non-linear over time for elite and non-elite players (Leyhr et al., 2018). Highlighting the need of sprinting fast for soccer success, Deprez et al. (2015) made clear that players who ultimately signed a professional contract scored better on sprint performance during adolescence than the players who ultimately did not reach the professional playing level (Deprez et al., 2015). Although by far most studies so far focused on male players, a recent study by Leyhr et al. (2020) confirmed the prognostic

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relevance of adolescent motor performance development including sprinting for elite female soccer players. The importance of sprinting for future success may also apply to female tennis.

Young male and female tennis players become faster in their pubertal years (Bloomfield et al., 2007; Kramer et al., 2016; Roetert et al., 1995; Rowland, 2005; Ulbricht et al., 2010). Not surprisingly, young male players reach their maximum sprint speed at senior age (18+), while young female tennis players tend to reach their maximum sprint speed aged 16 (Munivrana et al., 2015). This difference between boys and girls in their development could be due to male players being taller and heavier than females of the same age after late adolescence. Males produce more anabolic hormones than females during puberty and therefore develop greater muscle strength. As a consequence, young male and female tennis players are expected to have different development patterns in sprint performance.

Sprint performance and its developmental changes in young players are partly explained by their maturity (Malina et al., 2004). Somatic maturity can be indicated by predicting the years from peak height velocity (PHV; the adolescent growth spurt in stature). Leg length and sitting stature are commonly used measures to predict PHV (Mirwald et al., 2002; Moore et al., 2015). This method appears applicable during the growth spurt, from approximately 12–15 years (Malina & Kozieł, 2014). An earlier maximum PHV can be a temporary advantage for a player (Malina et al., 2004), as earlier PHV results in longer legs, which can be beneficial for sprinting fast. Meyers et al. (2015), (2017) showed that leg length in boys with advancing maturation is highly correlated with stride length, which is important for sprint performance. In females, adolescent growth spurt given by age at peak height velocity, tends to occur at an earlier age in girls than in boys, around 12 years and 14 years respectively (Malina et al., 2004).

The biological maturation of a player plays a role in the increase of muscle mass and muscle strength (Malina et al., 2004). Muscle strength and explosive strength is of importance for sprint performance and tennis performance, for example, the tennis serve (Hayes et al., 2018). Hayes et al. (2018) showed that the countermovement height was positively correlated to serve speed and thus to tennis performance. A study of young male tennis players found that better lower limb explosive strength explained part of the development of sprint performance (Kramer et al., 2016). Lower limb explosive strength is needed to produce initial acceleration (Chelly & Denis, 2001). Between the ages of 10 and 15, muscle mass and muscle strength increase (for a review, see T. Kramer et al., 2010). Other studies report that an increase in muscle strength results in faster sprint times (Salonikidis & Zafeiridis, 2008; Torres-Luque et al., 2011).

Knowledge of sprint performance development and whether sprint performance discriminates between performance levels in young female tennis players is needed to optimize talent development programmes. The Netherlands has approximately 1500 competitive young tennis players of which around 250 participate in a talent development programme. In this study, we focus on improving our knowledge of young female tennis players' physical development. Therefore, this study aimed to examine the longitudinal development of sprint performance in young female tennis players, and to investigate differences between performance levels. Also potentially explanatory variables were investigated.

Materials and methods

Participants

This study used a mixed-longitudinal design, measuring players from 2005–2013. All players were part of a talent development programme of the Royal Dutch Lawn Tennis Association (KNLTB). The study included young female players (N = 167) with 502 measurement points and a total of 2008 data points. Player chronological age was recorded in months at the time of measurement; chronological age is used as a variable in the multilevel analyses and in creating figures. However, to clarify the analyses shown in the Tables and Figures, we created six standardized age groups (10, 11, 12, 13, 14 and 15 years old), for example, players whose age at measurement fell between 10.50 and 11.49 years were categorized as 11-year-old players. The distinction between elite (n= 48) and sub-elite players (n = 119) was made based on year-end rankings in the Dutch tennis national youth ranking list. Elite players were consistently nationally ranked as the top eight players for their year of birth. The sub-elite players were also talented players selected for the KNLTB training programme, and consistently ranked between 9 and 65 for their year of birth. Table 1 presents the distribution of players and number of measurements for each age group, both for the elite and sub-elite players. Fewer players were measured in the older age groups because with increasing age, fewer players are selected for the programme, and several stopped playing tennis.

Measures

5 m sprint test

The 5 m sprint test was used to measure a player's sprint performance, using the same protocol as in Kramer et al. (2016). The player started the sprint in a standing position with feet shoulder wide, behind the starting line. The

Table 1. Distribution of the number of young female tennis players and measurements per age group and performance level.

	Elite		Sub-elite		Total	
Age groups	Players	Measurements	Players	Measurements	Players	Measurements
10 years	12	15	33	41	45	56
11 years	29	40	90	132	119	172
12 years	23	43	44	71	67	114
13 years	26	50	19	30	45	80
14 years	25	37	8	15	33	52
15 years	10	16	7	12	17	28

researchers used an infrared light mat and light gates to electronically record time. Time recording began automatically when the player's feet left the mat (Muscle Lab, Ergotest Technology AS, Langesund, Norway) and ended when the player ran through the light gate (Muscle Lab, Ergotest Technology AS, Langesund, Norway). The fastest time of three measurements was used for analyses. This test had an ICC of 0.83 (95% CI: 0.58 to 0.94).

Anthropometry and biological maturity

A single observer measured each player's height and body mass following standard procedures (Kramer et al., 2016; Lohman et al., 1988). The players wore shirts and shorts, but removed their socks and shoes. Height was measured to the nearest 0.1 cm (SECA, model 206, Seca Instruments, Ltd, Hamburg, Germany) and body mass to the nearest 0.1 kg (UWE, model ATM B150, Universal Weight Enterprise Co., Ltd, Taiwan). Years from age at PHV were estimated by using the equation proposed by Moore et al. (2015) using the recorded age and height:

$$\mathrm{Maturityoffset} = -7.709133 + (0.0042232\mathrm{x}(\mathrm{age} * \mathrm{height}(\mathrm{cm})))$$

The maturity offset shows how far the players were before or beyond their age of PHV. A negative maturity offset means that the maximal age of PHV still has to come. For the multilevel analysis, we created two groups based on the split-half value of the maturity offset per age group: "earliest maturing players" and "latest maturing players".

Lower limb explosive strength

To measure lower limb explosive strength (LLES), players were asked to perform a countermovement jump (Bosco et al., 1983). The researchers instructed them to keep their hands on their hips during the entire test. Scores were electronically measured using an infrared light mat (Muscle Lab, Ergotest Technology AS, Langesund, Norway). The best jump of three attempts, measured in centimetres, was used for analysis. This test had an ICC 0.964 (95% CI: 0.88 to 0.99).

Procedures

The KNLTB invited young players identified as talented by the coaches' expert opinions to take part in the KNLTB development programme. Parents/legal guardians were informed about all the programme's aspects and measurements and provided written informed consent for the players prior to participation. All the players were informed about the programme's objectives and aspects, including tests, and also gave their consent. This research project has been conducted according to the guidelines for ethical standards for sports medicine research (Harriss & Atkinson, 2011).

Players in the programme underwent the physical measurements twice a year: at the start of the season and halfway through the season. Measurements were executed during the physical training programme. Players had no intensive physical activity 24 hours before the measurements. The tests were performed on an indoor hard-surface tennis court during the competition season. Anthropometric measurements were taken before the standardized warming-up session. The warm-up included: i) a shuttle run test, up to stage seven for players aged under 12 years and up to stage eight for players aged 12 and over; and ii) acceleration sprints and stretches. After the warm-up, players performed the sprint test and the jump test.

Statistical analysis

The researchers calculated mean scores and standard deviations for chronological age, height, body mass, maturity offset, LLES and sprint time, separately for each performance level (elite and sub-elite) and for the six standardized age groups (10–15 years). The multilevel modelling program MLwiN 2.02 (Rasbash et al., 1999) was used to investigate longitudinal developmental changes in the 5 m sprint. A simple two-hierarchy model was defined in this longitudinal dataset: level 1 represents the repeated measurements and level 2 represents the individual players. Age is the first step in building a model explaining sprint performance and its development. Chronological age was used to analyse longitudinal changes instead of stepwise changes in age groups. Chronological age is a variable in the model: age increased the variance in level 2. To overcome this, age was shifted by centring on the mean value (11.96 years), this value is now named "centred age" (Baxter-Jones & Mirwald, 2004). Possible explanatory variables were added to the regression model in a stepwise manner in the following order: centred age, centred age^2, performance level, maturity group, BM, height, LLES and performance level*centred age. The power function of age (centred age^2) was used to allow for the nonlinearity of developmental changes in the 5 m sprint, because improvement per year is expected to be less marked at older ages. Random intercepts and random slopes were considered. Random intercepts allow sprint performance to differ between the players. Random slopes allow the explanatory variable to have a different effect for each player.

Changes in the – 2 Log Likelihood (deviation) statistic indicated whether the improvement or reduction in the statistical fit of the multilevel model was significant after variable inclusion. Variables were accepted as significant when the estimated mean coefficient was greater than twice the standard error of the estimate ($p< .05$) and if the deviance in – 2 Log Likelihood was significant ($p < .05$). The variable was discarded if the retention criterion was not met. The final model only included variables that were significant contributors (T. Kramer et al., 2016). Moreover, a comparison was made between the predicted 5 m sprint times to the measured times to investigate the fit of the predicted model.

In addition independent T-tests were conducted on the predicted sprint performance per age (based on the multilevel models) to analyse mean differences between elite versus sub-elite players. The *Cohen's d* effect sizes were calculated and interpreted according to published thresholds (0.2, 0.6, 1.2, 2.0, 4.0 for trivial, small, moderate, large, very large, and extremely large, respectively), as recommended for sports sciences (Hopkins, Marshall, Batterham, & Hanin, 2009).

Results

Table 2 presents the means and standard deviations for elite and sub-elite female tennis players by age. On average, all players became heavier, taller, jumped higher and ran faster on the 5 m sprint test as they got older. The mean age of PHV for the total group was around 11.7. Elite players are taller and heavier than sub-elite players. Elite players score higher on the countermovement jump scores than the sub-elite players. Elite players were 33 ms faster at age 10 and 10 ms faster at age 15 than sub-elite players (see Table 2).

Table 3 shows the multilevel model which predicted the developmental changes in 5 m sprint test. The difference in deviance from the empty model to the final model was 462.135 ($p < .001$). Elite and sub-elite players had significantly different development curves, as shown by two significant parameters: performance level and performance level*centred age. All variables significantly improved the model, except for maturity groups ($p = .285$) and body mass ($p = .975$); consequently, these were not included in the final model.

The results of the multilevel analyses in Table 3 show that elite players are predicted to be faster than sub-elite players (β_1 (performance level) = 20.272). Sub-elite players are predicted to develop more over age (β_2 (performance level x age) = −13.309). Taller players are predicted to be faster (β_3 (height) = −1.359), and the higher a player can jump, the faster her predicted time on the 5 m sprint test (β_4(CMJ height) = −5.142). Figures 1 and 2 show the lines of development based on the multilevel model. Elite players started with faster sprint times, but exhibited no significant improvement from age 13. From age 14 no significant differences between performance levels were found. Figure 2 shows no significant differences between the measured and predicted 5 m sprint test.

Table 4 shows the predicted scores on the 5 m sprint test for elite and sub-elite players for each age, as well as the effect sizes between performance groups per age. Elite girls were faster than sub-elite girls up to age 14. From age 14 and older, we found no significant differences in sprint performance. The effect sizes were very large up to age 14; for ages 14 and 15, they were small and trivial (Table 4).

Based on Table 4, the mean development from age 10 to 13 and for older than 13 was calculated. The mean development from ages 10 to 13 is 16 ms per year for elite players and 22 ms per year for sub-elite players. From age 13 and older, the mean development per year is 0 ms for elite players and 15 ms for sub-elite players.

Table 2. Descriptive data per age group and performance level in young female tennis players ($N = 167$).

	Elite		Sub-elite	
	Mean	SD	Mean	SD
Age group 10 (number of players)	15		41	
Age (years)	10.30	0.16	10.26	0.19
Maturity offset (years)	−1.37	0.30	−1.42	0.31
Body mass (kg)	34.38	4.02	34.57	5.04
Height (cm)	145.75	5.99	145.08	6.91
LLES (cm)	24.58	1.68	23.47	3.81
5 m sprint (ms)	1036	54	1069	65
Age group 11 (number of players)	40		132	
Age (years)	11.04	0.27	10.96	0.28
Maturity offset (years)	−0.67	0.39	−.86	0.39
Body mass (kg)	38.22	4.65	36.64	5.63
Height (cm)	150.80	6.12	147.94	6.52
LLES (cm)	25.26	3.60	24.04	3.75
5 m sprint (ms)	1016	48	1051	59
Age group 12 (number of players)	43		71	
Age (years)	11.98	0.32	11.99	0.26
Maturity offset (years)	0.20	0.40	0.09	0.39
Body mass (kg)	41.85	4.39	40.71	7.60
Height (cm)	156.35	5.72	154.14	6.30
LLES (cm)	27.43	3.91	25.21	3.85
5 m sprint (ms)	992	56	1016	50
Age group 13 (number of players)	50		30	
Age (years)	12.95	0.32	12.92	0.31
Maturity offset (years)	1.24	0.39	0.91	0.44
Body mass (kg)	50.07	4.77	44.38	6.58
Height (cm)	163.52	4.83	157.93	6.23
LLES (cm)	29.07	4.38	26.17	2.54
5 m sprint (ms)	976	52	1000	39
Age group 14 (number of players)	37		15	
Age (years)	13.94	0.28	13.89	0.26
Maturity offset (years)	2.17	0.32	1.92	0.40
Body mass (kg)	55.29	4.14	51.35	6.90
Height (cm)	167.74	4.39	164.21	5.33
LLES (cm)	29.30	4.15	27.71	2.17
5 m sprint (ms)	959	45	985	27
Age group 15 (number of players)	16		12	
Age (years)	14.82	0.25	14.79	0.27
Maturity offset (years)	2.89	0.28	2.68	0.27
Body mass (kg)	59.02	3.84	55.37	5.94
Height (cm)	169.33	3.81	166.30	4.09
LLES (cm)	30.79	4.29	28.26	4.50
5 m sprint (ms)	956	50	966	33

LLES = Lower limb explosive strength

Discussion

This mixed-longitudinal study examined the longitudinal development of sprint performance in young female tennis players aged 10 to 15, and investigated differences between performance levels. Also potentially explanatory variables were investigated. This study in girls was important because male and female tennis players follow the same rules, but play in completely different ways. For example, females play shorter matches and have longer rallies and the serve is of less importance (Fernandez et al., 2006). The results show that the older the player gets, the more superior their sprint performance. However, this development is not linear; sprint performance development levels out at older ages. We found that, overall, elite players were faster until age 14. After age 14, no differences were found between elite and sub-elite players on the 5 m sprint test. However, sub-elite players developed their sprint speed to a greater extent between the ages of 10 and 15. The predicted model is a good fit for the measured sprint performance; coaches can see how players are likely to develop and which aspects affect sprint performance development (e.g. LLES, which can be trained).

Development levelled off as players aged, explained by the significant contribution of age^2. For elite players, development levels off from age 13, whereas in sub-elite players this occurred at age 14. We also found that sprint speed increased more at younger ages than in late adolescence, this is shown as non-linear development for sprint performance (Table 4). Lloyd and Oliver (2012) showed that speed develops more at age 10 than

Table 3. Multilevel regression analysis of 5 m sprint test adjusted for age, maturation, body size and performance level (502 measurements) in young female tennis players.

Step	Fixed explanatory variables	Log Likelihood	p	Final step Coefficient	Final step SE
1	Constant	5582.069	<.001	1342.522	73.633
2	Centred age	5229.183	<.001	1.386	3.778
3	Centred age^2	5214.180	<.001	2.201	0.979
4	Performance level (elite = 0)	5199.070	<.001	20.272	6.953
5	Maturity groups (earliest maturing players = 0)	5197.926	.285		
6	Body mass	5199.069	.975		
7	Height	5192.381	<.001	−1.359	0.453
8	Lower limb explosive strength	5143.079	<.001	−5.142	0.647
9	Performance level * centred age	5126.120	<.001	−13.309	3.204
Variance-covariance of random variables			SE		
Level 1 (within individuals) Constant		1067.730	81.509		
Level 2 (between individuals) Constant		1032.633	170.724		

Table 4. Mean differences and effect sizes for predicted 5 m sprint time in ms by performance level and age in young female tennis players.

	Elite		Sub-elite							
Age	Mean (ms)	SD	Mean (ms)	SD	mean difference	95% Confidence interval of difference		*Cohen's d*		*p*-value
10	1024	16	1073	13	−49	−62	−36	3.36	very large	<.001
11	1009	14	1054	11	−45	−54	−37	3.57	very large	<.001
12	989	13	1025	11	−36	−44	−27	2.99	very large	<.001
13	977	14	1006	13	−29	−37	−20	2.15	very large	<.001
14	979	15	986	16	−7	−19	5	0.45	small	.243
15	976	19	976	22	0	−17	18	0	trivial	.963

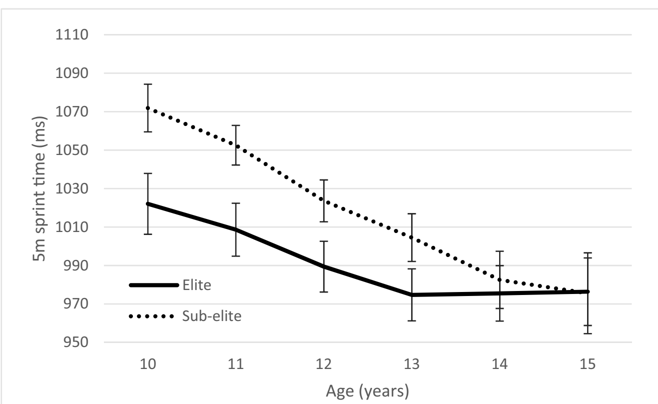

Figure 1. Predicted sprint times over age for elite and sub-elite female tennis players.

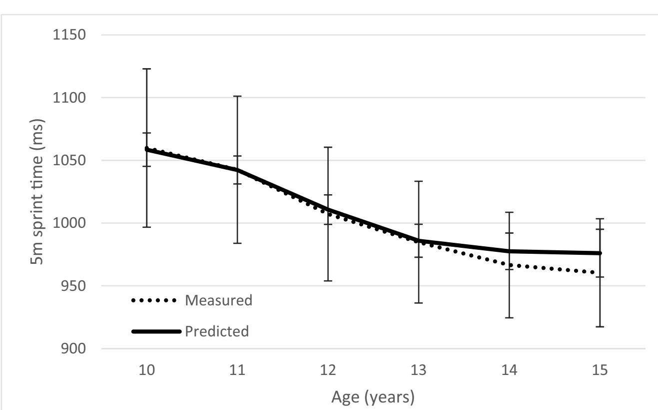

Figure 2. Predicted and measured sprint times for young female tennis players.

at age 15, our results are in line with their findings. This faster development at younger age may be the consequence of biological maturation in which muscle mass increases (Lloyd & Oliver, 2012; Lloyd et al., 2014). More muscle mass results in a better CMJ score, which is needed for sprint performance. Furthermore, players get taller enabling them to take longer steps, thereby improving sprint performance (Salonikidis & Zafeiridis, 2008; Torres-Luque et al., 2011). Altogether, height and countermovement jump improve with age as the players mature biologically.

Sub-elite players catch up with elite players on sprint performance from age 14, and develop their sprint performance faster as has been shown in other studies (Girard & Millet, 2009; Kramer et al., 2016; Munivrana et al., 2015). However, elite players still performed better on court (better ranking). A possible explanation could be the speed-accuracy trade-off: while sub-elite players improve their speed, they are less accurate when performing at this high speed and therefore make more mistakes than elite players. More recent work on young Dutch tennis players (Kolman et al., 2017) found that elite players had better developed speed-accuracy trade-offs. Elite players were better at hitting the ball hard and precisely, while sub-elite players made more mistakes (Kolman et al., 2017). Physical performance seems to give advantages at younger ages, but the advantage of physical performance disappears as players' age and other advantages arise. A recommendation for future research is to further unravel performance characteristics in young tennis players, such as technical and tactical skills (Elferink-Gemser et al., 2004, 2018; Kolman et al., 2019).

Elite players are faster at younger ages and therefore have more opportunities to develop an all-round game. The players can then spend their (training) time focusing on other aspects than developing speed (Powers & Howley, 2008), for example their psychological, tactical and technical skills. Sub-elite players may need to invest more (training) time in sprint performance development, while elite players can take advantage of the speed-accuracy trade-off and thus build technical skills. This speed-accuracy trade-off is measured by the speed of the ball and how precisely a player can play the ball in a prespecified box. This trade-off can be well developed from age 14 and older (Huijgen et al., 2013). Kolman et al. (2019) also showed that players with a higher performance level have better developed technical and tactical skills. Therefore, these skills may explain differences in performance level from age 14, but more research is needed on other physical skills.

No differences were found in biological maturity between the performance groups. The mean age of PHV in the current study was similar to the average mean age of PHV for girls: 11.9 years (Malina et al., 2004). The researchers expected that maturity may play a role in the differences between elite and sub-elite players as identified in other studies (Loffing et al., 2010; Myburgh et al., 2016; Ulbricht et al., 2010). In our study, we used Moore and colleagues' method (Moore et al., 2015) to measure maturity; even though this is a reliable and valid measure, it is still only a prediction of PHV. The tested players were aged between 10 to 15, years in which growth varies in velocity and players can change in group from earlier to later matured, or the other way around. This switch is possible because we used a split-half method to create the groups. A player with a PHV around this split-half could change group because the measurements are less accurate the greater the years before or after the PHV. This PHV difference may have led to players switching between groups. The more homogenous group of players and group switches in maturity status may explain why maturity is not significant in the equations in this study.

This study only included players who were either elite or sub-elite players at time of measurement; players whose performance level changed were excluded; a total of 35 players switched performance level. An advantage of this choice was that the groups were more homogenous, so comparison was not biased by players who changed groups. This gave us clear insights into the group differences. On the other hand, a disadvantage is that it is not clear whether players who changed from sub-elite to elite levels (or vice versa) did so because of their improvement (or lack thereof) in sprint performance. Furthermore, it has to be acknowledged that this study is not cross- validated yet, so caution is warranted when applying the model. Moreover, the model does not predict whether a player will become a professional player; we did not follow up on the players' career development. More research is needed to clarify which aspects are more important in talent development than sprint performance from age 14 and older, and what else is needed to become a professional player (e.g. psychological skills). Future research should further unravel underlying performance characteristics which distinguish elite and sub-elite players at various stages in their development. Monitoring not only sprint performance but also technical (for example the D4T of Kolman et al., 2017), tactical and psychological skills can help in increased understanding of windows of opportunity for performance development. A multidimensional, longitudinal approach analysing individual development is advocated (Elferink-Gemser et al., 2018; Till et al., 2011)

To conclude, the current study showed that elite female players are faster than their sub-elite counterparts from age 10 until 14, but the speed advantage disappears thereafter. Moreover, it seems possible to predict sprint performance (5 m) based on chronological age, body size given by height, and lower limb strength performance. Better sprint performance can result in using different strokes and having more choices to make during the rally because the player has more time to prepare a shot. Although sub-elite players become as fast as their elite counterparts from age 14, elite players continue to perform better on court. Therefore, sprint performance is an important characteristic of young female tennis players and seemed to depend on growth and maturation in parallel to physical fitness.

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References

Baxter-Jones, A., & Mirwald, R. (2004). Multilevel modeling. In R. C. Haupsie, N. Cameron, & L. Molinari (Eds.), *Methods in human growth research* (pp. 306–330). Cambridge University Press.

Bloomfield, J., Polman, R., O'Donoghue, P., & McNaughton, L. (2007). Effective speed and agility conditioning methodology for random intermittent dynamic type sports. *The Journal of Strength and Conditioning Research*, *21*(4), 1093–1100. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3778701

Bosco, C., Luhtanen, P., & Komi, P. V. (1983). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupational Physiology*, *50*(2), 273–282. doi:10.1007/BF00422166

Chelly, S. M., & Denis, C. (2001). Leg power and hopping stiffness: Relationship with sprint running performance. *Medicine and Science in Sports and Exercise*, *33*(2), 326–333. doi:10.1097/00005768-200102000-00024

Deprez, D. N., Fransen, J., Lenoir, M., Philippaerts, R. M., & Vaeyens, R. (2015). A retrospective study on anthropometrical, physical fitness, and motor coordination characteristics that influence dropout, contract status, and first-team playing time in high-level soccer players aged eight to eighteen years. *The Journal of Strength & Conditioning Research*, *29*(6), 1692–1704. doi:10.1519/JSC.0000000000000806

Elferink-Gemser, M. T., Te Wierike, S. C. M., & Visscher, C. (2018). Multidisciplinary longitudinal studies: A perspective from the field of sports. In K. A. Ericsson, R. R. Hoffman, A. Kozbelt, & A. M. Williams (Eds.), *Cambridge handbooks in psychology. The Cambridge handbook of expertise and expert performance* (p. 271–290). Cambridge University Press.

Elferink-Gemser, M., Visscher, C., Lemmink, K., & Mulder, T. (2004). Relation between multidimensional performance characteristics and level of performance in talented youth field hockey players. *Journal of Sports Sciences*, *22*(11–12), 1053–1063. doi:10.1080/02640410410001729991

Elferink-Gemser, M. T., Visscher, C., Lemmink, K. A. P. M., & Mulder, T. (2007). Multidimensional performance characteristics and performance level in talented youth field hockey players: A longitudinal study. *Journal of Sports Sciences*, *25*(4), 481–489. doi:10.1080/02640410600719945

Fernandez, J., Mendez-Villanueva, A., & Pluim, B. M. (2006). Intensity of tennis match play. *British Journal of Sports Medicine*, *40*(5), 387–391. doi:10.1136/bjsm.2005.023168

Gale-Watts, A. S., & Nevill, A. M. (2016). From endurance to power athletes: The changing shape of successful male professional tennis players. *European Journal of Sport Science*, *16*(8), 948–954. doi:10.1080/17461391.2016.1192690

Girard, O., & Millet, G. P. (2009). Physical determinants of tennis performance in competitive teenage players. *The Journal of Strength and*

Conditioning Research, *23*(6), 1867–1872. doi:10.1519/JSC.0b013e3181b3df89
Harriss, D. J., & Atkinson, G. (2011). Update – Ethical standards in sport and exercise science research. *International Journal of Sports Medicine*, *32*(11), 819–821. doi:10.1055/s-0031-1287829
Hayes, M. J., Spits, D. R., Watts, D. G., & Kelly, V. G. (2018). The relationship between tennis serve velocity and select performance measures. *The Journal of Strength and Conditioning Research*, 1-29. doi:10.1519/JSC.0000000000002440
Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise*, *41*(1), 3. doi:10.1249/MSS.0b013e31818cb278
Huijgen, B. C., Elferink-Gemser, M. T., Ali, A., & Visscher, C. (2013). Soccer skill development in talented players. *International Journal of Sports Medicine*, *34*(8), 720–726. doi:10.1055/s-0032-1323781
Huijgen, B. C., Elferink-Gemser, M. T., Post, W., & Visscher, C. (2010). Development of dribbling in talented youth soccer players aged 12–19 years: A longitudinal study. *Journal of Sports Sciences*, *28*(7), 689–698. doi:10.1080/02640411003645679
Huijgen, B. C. H., Elferink-Gemser, M. T., Post, W. J., & Visscher, C. (2009). Soccer skill development in professionals. *International Journal of Sports Medicine*, *30*(8), 585–591. doi:10.1055/s-0029-1202354
Johnston, K., Wattie, N., Schorer, J., & Baker, J. (2018). Talent identification in sport: A systematic review. *Sports Medicine*, *48*(1), 97–109. doi:10.1007/s40279-017-0803-2
Keiner, M., Sander, A., Wirth, K., & Schmidtbleicher, D. (2014). Long-term strength training effects on change-of-direction sprint performance. *The Journal of Strength and Conditioning Research*, *28*(1), 223–231. doi:10.1519/JSC.0b013e318295644b
Kolman, N., Huijgen, B., Kramer, T., Elferink-Gemser, M., & Visscher, C. (2017). The Dutch technical-tactical tennis test (D4T) for talent identification and development: Psychometric characteristics. *Journal of Human Kinetics*, *55*(1), 127–138. doi:10.1515/hukin-2017-0012
Kolman, N. S., Kramer, T., Elferink-Gemser, M. T., Huijgen B. C., & Visscher C. (2019). Technical and tactical skills related to performance levels in tennis: A systematic review. *Journal of Sports Sciences*, *37*(1), 108–121. doi: 10.1080/02640414.2018.1483699
Kovacs, M. S. (2006). Applied physiology of tennis performance. *British Journal of Sports Medicine*, *40*(5), 381–385. doi:10.1136/bjsm.2005.023309
Kovacs, M. S. (2007). Tennis physiology: Training the competitive athlete. *Sports Medicine*, *37*(3), 189–198. doi:10.2165/00007256-200737030-00001
Kovalchik, S. A., & Reid, M. (2017). Comparing matchplay characteristics and physical demands of junior and professional tennis athletes in the era of big data. *Journal of Sports Science & Medicine*, *16*(4), 489–497. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5721178/
Kramer, T., Huijgen, B. C., Elferink-Gemser, M. T., Lyons, T., & Visscher, C. (2010). Physical development of young talented tennis players. In M. Coelho e Silva, A. J. Figueiredo, M. T. Elferink-Gemser, & R. M. Malina (Eds.), *Youth sports participation, trainability and readiness* (pp. 93–114). Coimbra University Press.
Kramer, T., Huijgen, B. C., Elferink-Gemser, M. T., & Visscher, C. (2017). Prediction of tennis performance in junior elite tennis players. *Journal of Sports Science & Medicine*, *16*(1), 14–21. https://www.ncbi.nlm.nih.gov./pmc/articles/PMC5358024/
Kramer, T., Valente-Dos-Santos, J., Coelho-E-Silva, M. J., Malina, R. M., Huijgen, B. C., Smith, J., Elferink-Gemser, M. T., & Visscher, C. (2016). Modeling longitudinal changes in 5 m sprinting performance among young male tennis players. *Perceptual and Motor Skills*, *122*(1), 299–318. doi:10.1177/0031512516628367
Leyhr, D., Kelava, A., Raabe, J., & Höner, O. (2018). Longitudinal motor performance development in early adolescence and its relationship to adult success: An 8-year prospective study of highly talented soccer players. *PloS One*, *13*(5), e0196324. doi:10.1371/journal.pone.0196324
Leyhr, D., Raabe, J., Schultz, F., Kelava, A. & Höner, O. (2020). The adolescent motor performance development of elite female soccer players: A study of prognostic relevance for future success in adulthood using multilevel modeling. *Journal of Sports Sciences*, *38*(11-12), 1342–1351. doi: 10.1080/02640414.2019.1686940
Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. *Strength and Conditioning Journal*, *34*(3), 61–72. doi:10.1519/SSC.0b013e31825760ea
Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Myer, G. D., & Croix, M. B. D. S. (2014). Chronological age vs. biological maturation: Implications for exercise programming in youth. *The Journal of Strength & Conditioning Research*, *28*(5), 1454–1464. doi:10.1519/JSC.0000000000000391
Loffing, F., Schorer, J., & Cobley, S. P. (2010). Relative age effects are a developmental problem in tennis: But not necessarily when you're left-handed!. *High Ability Studies*, *21*(1), 19–25. doi:10.1080/13598139.2010.488084
Lohman, T. G., Roche, A. F., & Martorell, R. (1988). *Anthropometric standardization reference manual*. Human Kinetics Books.
Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity* (2nd ed.). Human Kinetics Books.
Malina, R. M., & Kozieł, S. M. (2014). Validation of maturity offset in a longitudinal sample of Polish girls. *Journal of Sports Sciences*, *32*(14), 1374–1382. doi:10.1080/02640414.2014.889846
Matthys, S. P., Vaeyens, R., Fransen, J., Deprez, D., Pion, J., Vandendriessche, J., Vandorpe, B., Lenoir, M., & Philippaerts, R. (2013). A longitudinal study of multidimensional performance characteristics related to physical capacities in youth handball. *Journal of Sports Sciences*, *31*(3), 325–334. doi:10.1080/02640414.2012.733819
Meyers, R. W., Oliver, J. L., Hughes, M. G., Cronin, J. B., & Lloyd, R. S. (2015). Maximal sprint speed in boys of increasing maturity. *Pediatric Exercise Science*, *27*(1), 85–94. doi:10.1123/pes.2013-0096
Meyers, R. W., Oliver, J. L., Hughes, M. G., Lloyd, R. S., & Cronin, J. B. (2017). Influence of age, maturity, and body size on the spatiotemporal determinants of maximal sprint speed in boys. *Journal of Strength and Conditioning Research*, *31*(4), 1009–1016. doi:10.1519/JSC.0000000000001310
Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise*, *34*(4), 689–694. https://www.researchgate.net/profile/Adam_Baxter/publication/310049139_
Moore, S. A., McKay, H. A., Macdonald, H., Nettlefold, L., Baxter-Jones, A. D., Cameron, N., & Brasher, P. M. (2015). Enhancing a somatic maturity prediction model. *Medicine and Science in Sports and Exercise*, *47*(8), 1755–1764. doi:10.1249/MSS.0000000000000588
Munivrana, G., Filipčić, A., & Filipčić, T. (2015). Relationship of speed, agility, neuromuscular power, and selected anthropometrical variables and performance results of male and female junior tennis players. *Collegium Antropologicum*, *39*(Suppl. 1), 109–116. www.collantrolpol.hr/antropo/article/view/1343
Myburgh, G. K., Cumming, S. P., Coelho, E., Silva, M., Cooke, K., & Malina, R. M. (2016). Growth and maturity status of elite British junior tennis players. *Journal of Sports Sciences*, *34*(20), 1957–1964. doi:10.1080/02640414.2016.1149213
Parsons, L. S., & Jones, M. T. (1998). Development of speed, agility and quickness for tennis athletes. *Strength and Conditioning*, *20*(3), 14–19. doi:10.1519/1073-6840(1998)020<0014:DOSAAQ>2.3.CO;2
Powers, S. K., & Howley, E. T. (2008). Exercise prescription for health and fitness. In E. T. H. S. K. Powers (Ed.), *Exercise physiology: Theory and application to fitness and performance* (pp. 325–342). McGraw-Hill.
Rasbash, J., Browne, W., Goldstein, H., Yang, M., Plewis, I., Draper, D., … Woodhouse, E. (1999). *A user's guide to MLwiN*. Institute of Education.
Roetert, E. P., Piorkowski, P. A., Woods, R. B., & Brown, S. W. (1995). Establishing percentiles for junior tennis players based on physical fitness testing results. *Clinics in Sports Medicine*, *14*(1), 1–21. doi:10.1016/S0278-5919(20)30254-4
Rowland, T. W. (2005). The importance of body size. In T. W. Rowland (Ed.), *Children's exercise physiology* (pp. 1–41). Human Kinetics Books.
Salonikidis, K., & Zafeiridis, A. (2008). The effects of plyometric, tennis-drills, and combined training on reaction, lateral and linear speed, power, and strength in novice tennis players. *The Journal of Strength and Conditioning Research*, *22*(1), 182–191. doi:10.1519/JSC.0b013e31815f57ad

Till, K., Cobley, S., O'Hara, J., Brightmore, A., Cooke, C., & Chapman, C. (2011). Using anthropometric and performance characteristics to predict selection in junior UK Rugby League players. *Journal of Science and Medicine in Sport*, *14*(3), 264–269. doi:10.1016/j.jsams.2011.01.006

Torres-Luque, G., Cabello-Manrique, D., Hernandez-Garcia, R., & Garatachea, N. (2011). An analysis of competition in young tennis players. *European Journal of Sport Science*, *11*(1), 39–43. doi:10.1080/17461391003770533

Ulbricht, A., Fernandez-Fernandez, J., & Ferrauti, A. (2010). Conception for fitness testing and individualized training programs in the German tennis federation. *Sports Orthopedics and Traumatology*, *29*(3), 180–192. doi:10.1016/j.orthtr.2013.07.005

Valente-dos-Santos, J., Coelho-e-Silva, M. J., Severino, V., Duarte, J., Martins, R. S., Figueiredo, A. J., … Malina, R. M. (2012). Longitudinal study of repeated sprint performance in youth soccer players of contrasting skeletal maturity status. *Journal of Sports Science & Medicine*, *11*(3), 371. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3737923