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Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players

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Abstract

We investigated age-related differences in the relationships among acceleration, maximum running speed, and repeated-sprint performance in 61 highly trained young male soccer players (Under 14, $n = 14$; Under 16, $n = 22$; Under 18, $n = 25$). We also examined the possible influence of anthropometry (stature, body mass, fat-free mass) and biological maturation (age at peak height velocity) on performance in those three sprint-running qualities. Players were tested for 10-m sprint (acceleration), flying 20-m sprint (maximum running speed), and 10×30-m sprint (repeated-sprint performance) times. Correlations between acceleration, maximum running speed, and repeated-sprint performance were positive and large to almost perfect ($r = 0.55$–0.96), irrespective of age group. There were age-based differences both in absolute performance in the three sprint-running qualities (Under 18 > Under 16 > Under 14; $P < 0.001$) and when body mass and fat-free mass were statistically controlled ($P < 0.05$). In contrast, all between-group differences disappeared after adjustment for age at peak height velocity ($P > 0.05$). The large correlations among acceleration, maximum running speed, and repeated-sprint performance in all age groups, as well as the disappearance of between-group differences when adjusted for estimated biological maturity, suggest that these physical qualities in young highly trained soccer players might be considered as a general quality, which is likely to be related to qualitative adaptations that accompany maturation.

Keywords: *Maturation, high-speed running, repeated sprints, team sports football*

Introduction

The ability to perform high-speed running actions during a soccer match is an important prerequisite for successful participation in the sport (Reilly, Bangsbo, & Franks, 2000). Several studies with adults have reported that components of high-speed running such as acceleration (Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001; Reilly, 2005), maximum running speed (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010b; Little & Williams, 2005), and repeated-sprint ability (Aziz, Mukherjee, Chia, & Teh, 2008; Rampinini et al., 2007) are related to match performance and competitive standard. Acceleration, maximum running speed, and repeated-sprint ability are considered by many researchers and practitioners to be determined by a combination of specific physiological, metabolic, biomechanical, and morphological factors and therefore require different training techniques (Glaister, 2005; Ross, Leveritt, & Riek, 2001). It is generally considered that acceleration is influenced by the development of concentric forces, impulse and knee extensor activity, whereas maximum speed is related more to the stretch–shortening cycle, lower-limb stiffness, and hip extensor activity (Sleivert & Taingahue, 2004). Research in adults has also indicated that the ability to perform repeated sprints is closely related to other aspects of metabolism, such as muscle phosphocreatine degradation/resynthesis, muscle buffer capacity, maximal oxygen uptake, and oxygen kinetics (Glaister, 2005; Spencer, Bishop, Dawson, & Goodman, 2005). However, correlations between acceleration and maximum running speed are typically reported to be large to very large ($r > 0.70$) (Harris, Cronin, Hopkins, & Hansen, 2008), and a large correlation ($r = 0.66$) between repeated-sprint ability and short-sprint qualities (i.e. 20-m sprint time) has also been reported (Pyne, Saunders, Montgomery, Hewitt, & Sheehan, 2008).

The human locomotor system undergoes age-related changes that influence motor function, so

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that the physical performance of prepubescent children improves with age (Malina, Bouchard, & Bar-Or, 2004). This improvement has been exemplified via maximal running speed in children (Papaiakovou et al., 2009). In contrast, the ability to reproduce sprint running performance in subsequent efforts (e.g. repeated-sprint ability) appears to deteriorate as children age (Ratel, Duche, & Williams, 2006). Thus, it might be hypothesized that the relationships among acceleration, maximum running speed, and repeated-sprint performance are age-dependant, with repeated-sprint performance being more dependent on running speed qualities in younger children (as evidenced by a stronger correlation between performance in a repeated-sprint test and maximum running speed). However, to date no data are available on the strength of association among these three speed qualities in children and adolescents.

Several studies have examined the contribution of chronological age, biological maturation, and different anthropometric characteristics to sprinting performance in young soccer players (Malina et al., 2004; Mujika, Spencer, Santisteban, & Bishop, 2009; Philippaerts et al., 2006; Wong, Chamari, Dellal, & Wisloff, 2009). While characteristics such as stature, body mass, and maturity status have been reported to be determinants of sprint-running performance (Malina et al., 2004), their specific contribution to acceleration, maximum running speed, and repeated-sprint ability in young soccer players is unknown. For example, leg muscle volume is likely to account largely for the increase in maximal-intensity exercise capability in multi-joint tasks such as jumps or sprints that occurs with maturation (O'Brien, Reeves, Baltzopoulos, Jones, & Maganaris, 2009). In contrast, the decline in maximal-intensity exercise capability reported during repeated-sprint cycle ergometry was positively correlated with lean leg volume in children, adolescents, and adults (Ratel et al., 2006). Little is known, however, about the possible effects of maturation on repeated-sprint running (Ratel et al., 2006). Thus, it is likely that different growth- and maturity-related factors influence acceleration, maximum running speed, and repeated-sprint ability in different ways throughout growth and maturation.

Thus, the purpose of this study was to investigate possible age-related variations in different high-speed running qualities in a group of highly trained young soccer players. Specifically our aims were to: (1) investigate the relationship between performance in the three speed-related qualities in different age-groups of young players, and (2) examine the influence of anthropometry and biological maturation on performance of these three high-speed running tasks.

Methods

Participants

A total of 61 young male soccer players (aged 12.0–17.8 years) were recruited. Only field players were tested with goalkeepers excluded. Written informed consent was obtained from the players and their parents. All participants were training in a high-performance soccer academy and completed on average $\sim$14 h of combined soccer training and competitive play per week. The players were grouped on the basis of chronological age into 2-year age categories: under 14 (U14: 12.0–13.9 years), under 16 (U16: 14.0–15.9 years), and under 18 (U18: 16.0–17.9 years). The experimental protocol received approval from the institutional ethics committee.

Outcome measures

All measurements were taken at the beginning of the annual training season (after 2 weeks of training) to limit differences in training status between players. All players followed a similar training programme under the supervision of their respective coaches. All performance tests were conducted on the same day. Test sessions were undertaken between 07:00 and 09:00 h (anthropometry) and between 16:00 and 18:00 (speed) at least 8 h after the last training session. All performance tests were performed in an indoor facility maintained at standard environmental conditions. Speed testing followed 20 min of standardized warm-up, which consisted of low-intensity forward, sideways, and backward running, acceleration runs, skipping and hopping exercises, and jumps at increasing intensity. Players were fully accustomed to all test procedures.

Anthropometry. All measurements were taken in the morning. Dimensions included stature, body mass, sitting height, and seven skinfolds (triceps, subscapular, biceps, supraspinale, abdominal, front thigh, and medial calf). Height was measured with a fixed stadiometer ($\pm$0.1 cm, Holtain Ltd., Crosswell, UK), sitting height with a purpose-built table ($\pm$0.1 cm, Holtain Ltd., Crosswell, UK), body mass with a digital balance ($\pm$0.1 kg, ADE Electronic Column Scales, Hamburg, Germany), and skinfold thickness with a Harpenden skinfold caliper ($\pm$0.1 mm, Baty International, Burgess Hill, UK). The exact positioning of each skinfold measurement was in accordance with procedures previously described (Norton et al., 2000). All skinfold measurements were taken on the right side of the body. Body fat percentage was calculated from skinfold thicknesses (triceps and subscapular) using Slaughter's equations (Slaughter et al., 1988). These equations have been suggested to be the most accurate equations for estimation of body fat percentage from skinfold thickness in an adolescent population (Rodriguez et al., 2005). Fat-free mass (kg) was derived by subtracting body fat mass from total body mass. The same anthropometrist conducted all the measurements.

Maturity status. Pubertal timing was estimated according to the biological age of maturity of each individual as described by Mirwald and colleagues (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). The age of peak linear growth (age at peak height velocity) is an indicator of somatic maturity representing the time of maximum growth in stature during adolescence. Biological age of maturity (years) was calculated by subtracting the chronological age at the time of measurement from the chronological peak-velocity age (Baxter-Jones & Sherar, 2007). Thus, a maturity age of -1.0 indicates that the player was measured 1 year before this peak velocity; a maturity of 0 indicates that the player was measured at the time of this peak velocity; and a maturity age of $+1.0$ indicates that the participant was measured 1 year after this peak velocity. Ethnicity of the players was Arab (Middle East and North Africa backgrounds). The effect of ethnicity on the validity of biological maturity estimates using the procedures described above is unknown. Thus the equation was assumed to be valid in the present sample.

Acceleration and maximum running speed. The running speed of players was determined using a 40-m sprint effort with dual-beam electronic timing gates (Swift Performance Equipment, Lismore, NSW, Australia) with split times at 10 m, 20 m, and 30 m. Time was measured to the nearest 0.01 s. Players were instructed to run as quickly as possible over the 40-m distance from a standing start (crouched start positioned 0.5 m behind the timing lights). Acceleration was evaluated using the time to cover the first 10 m of the 40-m test. Maximum running speed was assessed using a flying 20-m sprint (i.e. last 20 m of the 40-m sprint effort) as previously reported (Little & Williams, 2005). The intraclass correlation coefficient in a flying 20-m sprint has been shown to be 0.98 (Winchester, Nelson, Landin, Young, & Schexnayder, 2008). Participants performed two trials with at least 3 min of rest between them. The best performance of the two tests was used for analysis.

Repeated-sprint performance test. All players performed this test after a 10-min rest break after the 40-m sprint test. The repeated-sprint performance consisted of ten repeated straight-line 30-m sprints separated by 30 s of active recovery (i.e. jogging back to the starting line within $\sim$25 s to allow 4–5 s of passive recovery before the start of the next sprint repetition). This test is similar to other repeated-sprint performance tests previously used with team-sport athletes (Glaister et al., 2007; Pyne et al., 2008; Spencer et al., 2005). Time was recorded to the nearest 0.01 s using two sets of electronic timing gates (Swift Performance Equipment, Lismore, NSW, Australia). Players used a standing start 0.5 m behind the timing lights. Players were given verbal encouragement to run as quickly as possible for each of the ten sprints and constant verbal feedback was provided during the recovery run. Mean sprint time was subsequently determined as a measure of repeated-sprint performance. Percent sprint decrement, a common index of fatigue in repeated-sprint performance tests, was not calculated here because of its poor reliability (Glaister, 2005; Oliver, 2009).

Statistical analyses

Descriptive statistics (means $\pm$ standard deviations) are reported. All analyses of variance (ANOVA) were performed on log-transformed data; for the sake of clarity, however, they are reported non-transformed. Age-group-based comparisons of anthropometry were made with one-way between-groups ANOVA (with three levels: U14, U16, and U18). When ANOVA showed a significant group effect, between-group differences were allocated by using *post hoc* Bonferroni tests. Between-groups differences in acceleration, maximum running speed, and repeated-sprint performance were assessed using analysis of covariance (one-way ANCOVA) and in four successive steps. First, no covariate was taken into account, then body mass, fat-free mass, and finally age at peak height velocity were separately entered into the model as covariates. Given the high level of interrelatedness between body mass, height, and leg length, only body mass was used as a covariate in the present study. The magnitude of the differences of each covariate effect was assessed (pairwise comparisons) using standardized mean differences (Cohen effect size, ES) on the adjusted means (least squared means) provided by the ANCOVA. The criteria to interpret the magnitude of the effect size were: $\leq$0.2 trivial, $>$0.2–0.6 small, $>$0.6–1.2 moderate, $>$1.2–2.0 large, and $>$2.0–4.0 very large (Batterham & Hopkins, 2006). Relationships between performance on the acceleration, maximum running speed, and repeated-sprint performance tests were determined using correlation analysis. The corresponding strength was assessed using Pearson's correlation coefficient (r). The following criteria were adopted for interpreting the magnitude of correlation (r) between test measures: ≤0.1 trivial, >0.1–0.3 small, >0.3–0.5 moderate, >0.5–0.7 large, >0.7–0.9 very large, and >0.9–1.0 almost perfect (Hopkins, Marshall, Batterham, & Hanin, 2009). Inference about the true (large-sample) value of a correlation was based on uncertainty in its magnitude (Batterham & Hopkins, 2006): if the 90% confidence limits overlapped small positive and negative values, the magnitude was deemed unclear; otherwise, the magnitude was deemed to be the observed magnitude. In addition, the standard error of the estimate of the previous correlations expressed as a percentage of the predicted variable was also calculated.

Results

Table I shows the physical characteristics of the players according to age group. All anthropometric variables, except the sum of seven skinfolds and the percentage of body fat, showed age differences (U18 > U16 > U14; $P < 0.001$).

Table I. Physical characteristics for U14, U16, and U18 soccer players (mean ± s).

Variable	U14 (n = 14)	U16 (n = 22)	U18 (n = 25)
Age (years)	12.7 ± 0.7*	14.9 ± 0.6*#	17.0 ± 0.6
Height (m)	1.50 ± 0.07*	1.65 ± 0.08*#	1.73 ± 0.05
Body mass (kg)	38.6 ± 5.5*	51.0 ± 7.6*#	61.9 ± 6.6
Body mass index (kg · m^{-2})	17.2 ± 1.5*	18.6 ± 1.6*#	20.8 ± 1.7
Leg length (cm)	73.2 ± 4.0*	80.4 ± 4.5*#	83.1 ± 4.0
Sum of skinfolds (mm)[a]	52.2 ± 18.8	45.9 ± 7.62	47.5 ± 11.1
Percent body fat	9.7 ± 3.5	9.2 ± 1.6	10.0 ± 2.4
Fat-free mass (kg)	35.0 ± 4.4*	46.2 ± 6.5*#	55.6 ± 5.2
Years to/from APHV	–1.7 ± 0.7*	0.4 ± 0.9*#	2.2 ± 0.6

[a]Sum of skinfold thicknesses of the following sites: biceps, triceps, subscapular, supraspinale, abdomen, front thigh, and medial calf. APHV = age at peak height velocity.
*Significant difference ($P < 0.05$) vs. U16 players. #Significant difference ($P < 0.05$) vs. U18 players.

Under 18 players had faster ($P < 0.01$) 10-m (ES = 0.93 and 2.56), flying 20-m (ES = 1.08 and 3.02), and mean sprint (ES = 1.12 and 3.15) times than U16 and U14 players (Table II), while U16 players were faster ($P < 0.01$) than U14 players in all sprint running performances (ES range of 1.49–2.09; Table II). Correlation coefficients, 90% confident limits, and the standard errors of the estimate for the different sprint running performances are presented in Table III. Correlations were positive and ranged from large to almost perfect (r = 0.55–0.96) with relatively low (less than 4%) standard errors of the estimate.

Age differences (U18 > U16 > U14; $P < 0.05$) in the three sprint running tests still persisted when body mass and fat-free mass were statistically controlled for. After adjustment for age at peak height velocity, all between-group differences disappeared ($P > 0.05$, for all sprint running performances). Results of the between-groups pairwise comparisons are presented in Figure 1. With the exception of the U18 vs. U16 comparison for the 10-m and flying 20-m sprints, between-group effect sizes were substantially lower when age at peak height velocity was included as a covariate compared with body mass or fat-free mass (Figure 1). Compared with no adjustment, the mean reduction in between-groups effect sizes with body mass as a covariate was 65.1 ± 7.9%, 62.6 ± 8.5%, and 46.2 ± 12.6% for 10-m, flying 20-m, and mean sprint time, respectively. Inclusion of fat-free mass as a covariate resulted in a reduction in effect size of 76.8 ± 8.8%, 72.9 ± 8.6%, and 60.7 ± 6.4% for 10-m, flying 20-m, and mean sprint time, respectively. When age at peak height velocity was entered as a covariate, the effect size was reduced by 88.1 ± 12.0 %, 91.1 ± 7.4%, and 82.7 ± 8.5% for 10-m, flying 20-m, and mean sprint time, respectively.

Discussion

Sprint running performance in children and adolescents depends on several factors mediated by growth

Table II. Times for 10-m sprint, flying 20-m sprint, and repeated-sprint exercise mean sprint time (MST) for the U14, U16, and U18 soccer players (mean ± s), together with effect size differences[a].

	Age groups			U16 vs. U14 ES	U18 vs. U14 ES	U18 vs. U16 ES
Variable	U14 (n = 14)	U16 (n = 22)	U18 (n = 25)	(magnitude of difference)	(magnitude of difference)	(magnitude of difference)
10-m sprint (s)	1.93 ± 0.11	1.80 ± 0.06*	1.73 ± 0.06#^	1.49 (Large)	2.56 (Very large)	0.93 (Moderate)
20-m flying (s)	2.85 ± 0.23	2.53 ± 0.11*	2.34 ± 0.08#^	1.96 (Large)	3.02 (Very large)	1.08 (Moderate)
RSE MST (s)	5.04 ± 0.28	4.62 ± 0.17*	4.39 ± 0.12#^	2.09 (Large)	3.15 (Very large)	1.12 (Moderate)

*Significant difference ($P < 0.05$) between U16 and U14 players. #Significant difference ($P < 0.05$) between U18 and U14 players. ^Significance difference ($P < 0.05$) between U18 and U16 players.
[a]ES = effect size differences. Thresholds for magnitude of difference are: ≤ 0.2 trivial, > 0.2–0.6 small, > 0.6–1.2 moderate, > 1.2–2.0 large, > 2.0–4.0 very large.

and maturation. The main aim of the present study was to determine the relationship among different speed qualities relevant for soccer performance at different ages. A secondary aim was to examine possible factors determining running speed performances. The strong correlations observed between acceleration, maximum running speed, and repeated-sprint performance in all age groups, as well as the disappearance of between-group differences in sprint running performances when adjusted for estimated biological maturity (i.e. age at peak height velocity) suggest that high-speed running in young highly trained soccer players can be considered a general quality, which is likely to be related to qualitative muscular adaptations that occur with maturation.

Table III. Within-group correlation matrix for 10-m time, flying 20-m time, and mean repeated-sprint performance in U18, U16, and U14 soccer players.

	10-m sprint time	20-m flying time
U18 ($n=25$)		
10-m sprint time	–	
20-m flying time	0.79 (0.62–0.89, ±2.1%)	–
RSE (MST)	0.66 (0.42–0.82, ±2.6%)	0.74 (0.54–0.86, ±2.5%)
U16 ($n=14$)		
10-m sprint time	–	
20-m flying time	0.56 (0.14–0.81, ±2.8%)	–
RSE (MST)	0.55 (0.12–0.81, ±2.8%)	0.96 (0.90–0.98, ±1.3%)
U14 ($n=22$)		
10-m sprint time	–	
20-m flying time	0.79 (0.60–0.90, ±3.3%)	–
RSE (MST)[a]	0.76 (0.55–0.88, ±3.5%)	0.91 (0.82–0.96, ±3.3%)

Note: Data are presented as correlation coefficients, with the 90% confidence limits and the estimated error of the estimate (expressed as a percentage of the predicted variable) in parentheses.
[a]RST (MST) = repeated sprint test (mean sprint time).

In the adult literature, sprinting ability over short (<10 m) and longer distances (>30 m) is considered by many researches and practitioners to require separate and specific biomechanical and neuromuscular qualities and therefore training techniques (Harris et al., 2008; Little & Williams, 2005). When considering the U18 and U14 groups, we found very large positive correlations between 10-m and flying 20-m sprint times ($r=0.79$ for both groups). A weaker but nevertheless large and positive correlation ($r=0.56$) was found for the U16 group. The fact that the U16 group included mainly circumpubertal boys around the age at peak height velocity might partly explain this weaker correlation. The standard deviation of age at peak height velocity (representing individual differences) was higher in the U16 group of players than in the U14 and U18 groups (Table I), which suggests a relatively heterogeneous biological maturity status in the U16 group. In addition, large inter-individual variability in maturation of the

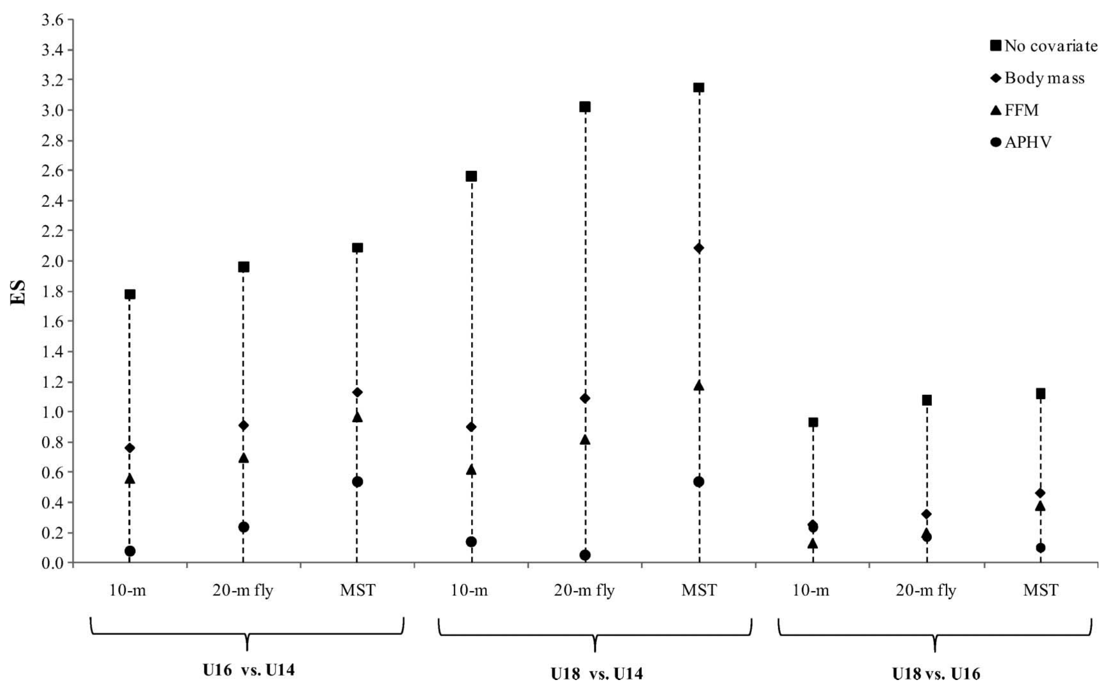

Figure 1. Standardized between-group differences (ES) in 10-m time, 20-m flying time, and repeated-sprint exercise mean sprint time (MST) both including and not including body mass, fat free-mass (FFM), and estimated biological maturity status (APHV = age at peak height velocity) as covariates.

different physiological and biomechanical factors likely to determine both sprinting qualities has been reported previously in children at similar developmental stages (Blimkie & Sale, 1998). Nevertheless, while correlation does not imply causality, these results suggest that indices of acceleration and maximal running speed in young soccer players might share common factors. The preoccupation of soccer researchers and practitioners of treating and training these variables as separate qualities could thus be overemphasized (Harris et al., 2008).

Repeated-sprint performance is believed to be a significant predictor of match physical performance in professional adult soccer players (Rampinini et al., 2007). However, no previous study has addressed the relative importance of different running sprint qualities in repeated-sprint exercise in young soccer players. Our results show that with our repeated-sprint performance test protocol, mean sprint time was more strongly related to maximum running speed (i.e. flying 20-m sprint: *r*-values ranging from 0.74 to 0.96) than to acceleration (i.e. 10-m sprint: *r*-values ranging from 0.55 to 0.76). The weaker correlation between maximum running speed and mean repeated-sprint sprint time in the U18 group versus with the U14 and U16 groups (Table III) might be expected. Previous investigations have shown that with increasing age, the ability to repeat short-term maximal efforts (such as the repeated sprint running exercise employed in the present study) declines (Ratel et al., 2006). Furthermore, it has been also suggested that some locomotor specialization into more sprinting or aerobic profiles can occur around or after puberty (Falk & Bar-Or, 1993; Rowland, 2002). Thus, it is possible that some of our U18 players have evolved towards a more sprinting type profile, which might have led to a reduced ability to resist fatigue during repeated sprints as previously shown in adults (Ratel et al., 2006). However, it has recently been reported that performance decrement during a repeated-sprint ability test similar to the one employed here was not negatively affected by age in a sample of well-trained soccer player aged 11–18 years (Mujika et al., 2009). Albeit speculative, the differences between the results obtained in non-specifically trained children (Ratel et al., 2006) and highly specialized soccer players (Mujika et al., 2009) might partially be explained by the effects that training may have on the factors responsible for the improved repeated-sprint ability, namely faster phosphocreatine resynthesis, greater oxidative capacity, and better acid–base regulation (Ratel et al., 2006). It can thus be hypothesized that soccer training might have balanced out the age-related deterioration in fatigue resistance during repeated-sprint exercise. However, the 3- to 6-fold larger coefficient of variation reported for the speed decrements (Glaister et al., 2007; Impellizzeri et al., 2008) compared with the typical speed decrements experienced by well-trained soccer players (Mujika et al., 2009) prevent definitive conclusions in this regard (Hopkins et al., 2009; Oliver, 2009); the presence of a type II error in Mujika's study cannot be excluded (Atkinson & Nevill, 1998). Alternatively, it is also possible that selection bias within the soccer players may also dismiss players without the capacity to concurrently train and maintain repeated sprint performance and maximum running speed. Nevertheless, the very large to almost perfect correlation between maximal running speed and repeated-sprint ability and the low prediction error (standard error of the estimate <3.5%) is consistent with a previous study of well-trained junior Australian Rules Football players (Pyne et al., 2008). Overall, these results suggest that repeated-sprint ability in trained team-sport athletes might be mainly related to running speed qualities. Despite the fact that other factors related to repeated-sprint exercise performance were not analysed in the present study, our results indicate the need to develop maximum running speed during training to maximize repeated-sprint ability in young team-sport athletes (Buchheit, Mendez-Villanueva, Quod, Quesnel, & Ahmaidi, 2010a). It should be acknowledged, however, that the repeated-sprint protocol (number of sprints, recovery duration, recovery type and intensity) is likely to influence mean sprint time and therefore should be taken into account when testing and training to improve repeated-sprint ability (Spencer et al., 2005).

The development of sprinting speed in the age range investigated in the present study (12–17 years) is influenced by growth and maturation (Malina et al., 2004). Growth refers to the increase in size from conception to adulthood: it refers to so-called muscular quantitative factors (e.g. muscle volume) (Martin et al., 2004). Maturation, on the other hand, refers to the tempo and timing of progress towards the mature biological state (Malina et al., 2004); it refers to muscular qualitative factors (e.g. muscle fibre type, anaerobic energy production, and neural adaptation). While growth and maturation are unified processes, and factors that influence these processes are interrelated and interdependent (Malina et al., 2004), previous studies have evaluated the influence of both quantitative and qualitative muscular factors on short-term external power output (mainly using sprint cycling) only (Martin et al., 2004; Ratel et al., 2006)); the present study is the first to analyse the possible role of these factors on different running speed qualities relevant to soccer performance. Overall, while between-group differences in acceleration, maximum running speed, and repeated-sprint ability were clear with no adjustment (i.e. effect size rated as very large, Figure 1), substantial reductions in the magnitude of these differences were observed when either body mass or fat-free mass were entered as covariates. This is in line with previous studies that reported positive associations between anthropometric characteristics (e.g. body mass and stature) and both single-sprint performance (Mero, 1998) and repeated-sprint ability (Mujika et al., 2009). However, the inclusion of the estimates of maturity status (i.e. age at peak height velocity) as a covariate rendered the body mass and fat-free mass terms redundant, as they further reduced the magnitude of the effect size (Figure 1). This suggests that the age-related differences in sprint running performances in the present study were more (and almost completely) related to differences in maturation rather than to differences in anthropometric factors *per se*. This finding is consistent with previous studies on short-term external power output on a cycle ergometer (Armstrong, Welsman, & Chia, 2001; Martin, Dore, Hautier, Van Praagh, & Bedu, 2003; Martin et al., 2004) that reported that in addition to anthropometric attributes (i.e. body mass and fat-free mass), factors related to maturity itself can exert additional effects on the age-related differences in sprint running performance. The substantial effects of maturity over and above those due to anthropometric covariates (i.e. growth) on the age-related differences in the three speed qualities examined could be mediated (among others) by: enhancements in neural function, multi-joint coordination, muscle stiffness, changes in muscle architecture, and increases in muscle power associated with the rise in circulating concentrations of testosterone and growth hormone from childhood to adolescence (Malina et al., 2004). However, the similar (flying 20-m sprint) and higher (10-m time sprint) effect of fat-free mass compared with that of maturity for the U18 vs. U16 comparison indicates that fat-free mass is still important for sprinting qualities in post-pubertal boys.

Conclusions

The very large correlations reported between acceleration, maximum running speed, and repeated-sprint ability and the low standard error of the estimate suggest that running speed can be considered as a general quality, irrespective of players' age or maturity status. Our results also suggest that the positive effects of age on running speed qualities during growth in our sample of well-trained soccer players are likely to be more related to biological maturation than to anthropometric characteristics only. These factors should therefore be taken into account when comparing and interpreting speed tests results in child and adolescent players. These results led us to speculate that maturity-related aspects should be targeted during speed-oriented training sessions in developmental soccer players (Buchheit et al., 2010a; Venturelli, Bishop, & Pettene, 2008).

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