Is the Relationship Between Sprinting and Maximal Aerobic Speeds in Young Soccer Players Affected by Maturation?

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The purpose of this study was to investigate the relationship between maximal sprinting (MSS) and aerobic (MAS) speeds in a cohort of highly-trained young male soccer players with the influence of body mass controlled for using allometric scaling. MSS and MAS were obtained in 14 pre-age at peak height velocity (APHV) players (12.3 ± 0.7 years), 21 circum-APHV players (14.3 ± 0.9 year) and 26 post-APHV players (16.9 ± 0.7 years). The three groups showed similar positive correlations between MSS and MAS ($r = 0.73$ to $0.52$; $p < .01$). In conclusion, our results suggest that the relationship between MSS and MAS is not affected by maturation.

Morphological and physiological considerations suggest that sprinting ability and aerobic function (e.g., aerobic power and endurance capacity) put conflicting demands on the design of a human’s locomotor apparatus and therefore cannot be maximized simultaneously (31). The intuitive basis of this performance trade-off probably stems from the observation that elite specialist sprinters and marathon runners differ substantially in size and shape, and no athlete excels in both events. In addition to cardiorespiratory attributes, individual differences in the proportion of fast, powerful muscle fibers to slow more fatigue-resistant fibers are believed to be the primary physiological basis of this performance trade-off (34). Consistent with this suggestion, short-distance human sprinters possess a greater proportion of fast-twitch muscle fibers than do endurance athletes, and vice versa for the slower more fatigue-resistant muscle fibers (7,12). A genetic-based trade-off between sprint and endurance phenotypic traits has been suggested such as that an individual is inherently predisposed toward performance in either sprint/power or endurance events (19,35). However, team sports such as soccer require a more complex (mixed) phenotypic trait, as both qualities (i.e., speed and aerobic function) influence high-level soccer performance (22,28). Thus, successful young soccer players are expected to be selected and systematically trained to develop both qualities (i.e., speed and aerobic fitness; 23). Accordingly, the presence of functional trade-offs...
between speed and endurance can impose important constrains on the development of these two game-related fitness traits (22).

Children appear to have an “optimal” phenotypic profile for team sports like soccer since their ability to demonstrate this locomotor specialization is less apparent (26). That is, children who perform well in sprinting tasks also perform well in endurance activities, and vice versa (27). Nevertheless, it appears that this “optimal” locomotor profile is transient as it has been suggested that specialization into endurance or sprinting profiles occurs during late-puberty stages (8,16). However, few studies have assessed the association between sprinting and aerobic-related performances in children and adolescents of different maturational levels spanning a wide circum-pubertal spectrum. In addition, to the best of our knowledge, the ability to demonstrate this postpuberty specialization has been only examined in nonspecifically trained children (4,8,16). Whether children trained to develop both qualities (i.e., speed and aerobic fitness), as it happens in soccer, would still show a similar specialization is presently unknown.

A tool that might offer valuable information on the child locomotor profile is the calculation of the ratio of maximal sprinting speed (MSS) to maximal aerobic speed (MAS), which is similar to the ratio of anaerobic to aerobic power previously described (2,30). The proposed speed ratio (i.e., MSS to MAS) can help to better understand how these two locomotor qualities develop in relation to each other within an individual and can be useful in assessing the degree of physiological adaptation in specific populations (2,30). Available studies suggest that in nonspecifically trained children, the anaerobic to aerobic ratio increases during pubertal development, levels off during adolescence and remains stable into early adulthood (16). However, factors other than growth, development and maturation, such as disease, medication and exercise training are likely to affect this ratio (2,30). Despite acknowledged confounders, the MSS to MAS ratio could be used as a sensitive tool to assess differences in an individual’s relative sprinting and aerobic exercise capacity.

It is well known that in children, performances in various physical tests are affected by growth. For example, while improvements in running speed may result from a training program, they may also be simply related with changes in body size as a consequence of growth and maturation (16). Thus, to accurately assess changes or differences in “intrinsic” physical performance parameters, size-adjusted rather than absolute values have been suggested to be more appropriate (33). Controlling for any confounding influence of morphological attributes (e.g., body mass or height) via allometric analyses allows sample and test-specific size adjustment to be achieved, enabling comparisons of performance measures between different groups or timepoints (33). We are not aware of any studies that have examined the effects of age and maturation on the relationship between body size and locomotor performances (i.e., MSS and MAS) as determined by allometric scaling.

Examining the relationships between MSS and MAS performance across different levels of age and maturation has the potential to provide useful insights into the evolution of important soccer match fitness-related factors (22). Information in this context would be valuable for profiling young soccer players (14), adapting the training to their abilities (5) and identifying highly talented youngsters (29). Thus, the purpose of this study was to examine relationships among MSS and MAS in highly-trained young soccer players with the influence of body mass controlled
for using allometric scaling. We first hypothesized to observe essentially “mixed” profiles (i.e., similar levels for both MSS and MAS, as evidenced by large correlations between both attributes) in the prepubertal group. Conversely, as a result of the anticipated specialization (8,16), more “specialized” profiles (i.e., either high MSS or MAS, as evidenced by poor correlations between both attributes) could be observed in pubertal and especially postpubertal players. However, it is also possible that the soccer selection/training process, which put constant emphasis on both qualities, might systematically exclude “specialized” profiles. This would result in the persistence of “mixed” profiles even in the older group.

Materials and Methods

Participants
A total of 61 young male soccer players (11.5–17.8 yr) participated in this study. Only outfield players (i.e., there were no goalkeepers in the sample) were tested. Written informed consent was obtained from the parents and from the players. All the players were training in a high-performance soccer academy and participated in » 14 hr of combined soccer training and competitive play per week on average. The experimental protocol was approved by the Institutional Ethical Committee.

Experimental Measures
All measurements were taken at the beginning of the annual training season (approximately after 2 weeks of training) to limit differences in training status between players. All players followed a similar training program with the supervision of their respective coaches. All performance tests were performed on two separate occasions with at least one day between the two testing sessions. Speed tests were completed on the first day, while the anthropometrical assessment and MAS tests were performed in the second testing session. Test sessions were undertaken between 07:00 and 9:00 hr (anthropometrical and MAS) and between 16:00 and 18:00 (speed) at least 8 hr after the last training session. All performance tests were performed in an indoor facility maintained at standard environmental conditions. Speed testing began after 20 min of standardized warm-up, which consisted of low-intensity forward, side-ways and backward running, acceleration runs, skipping and hoping exercise, and jumps at increasing intensity. Players were fully familiar with all test procedures.

Anthropometric measurements: All the anthropometrical measurements were taken in the morning before the MAS test was performed. Dimensions included height, body mass, seated height and 7 skinfolds (triceps, subscapular, biceps, suprailiac, abdominal, thigh and medial calf). Height was measured with a fixed stadiometer (± 0.1 cm; Holtain Limited, Crosswell, UK), seated height with a fixed sitting height table (± 0.1 cm; Holtain Limited, Crosswell, UK), body weight with a digital balance (ADE Electronic Column Scales, Hamburg, Germany) and skinfold thickness with a Harpenden skinfold caliper (Baty International, Burgess Hill, UK). The exact positioning of each skinfold measurement was in accordance with procedures described by Norton et al. (20). The same anthropometer carried out all the measurements.
Pubertal timing was estimated according to the estimated biological maturity age of each individual as described by Mirwald et al. (18). The age of peak linear growth (age at peak height velocity, APHV) is an indicator of somatic maturity representing the time of maximum growth in stature during adolescence. A biological maturity age (years) was calculated by subtracting the chronological age at the time of measurement from the chronological APHV. Thus, a maturity age of -1.0 indicates that the player was measured 1 yr before APHV; a maturity of 0 indicates that the player was measured at the time of APHV; and maturity age of +1.0 indicates that the subject was measured 1 yr after APHV (3). On that basis, players were accordingly subdivided into three nonoverlapped maturational groups: before the estimated APHV (Pre-APHV) players (> -3.0 yrs to PHV to < -1.5 years to PHV; \( n = 14 \)), around the estimated APHV (Circum-APHV) players (> -1 yrs to PHV to < +1 yrs from PHV; \( n = 21 \)) and after estimated the APHV (Post-APHV) players (> + 1.5 yrs from PHV to < 3.0 yrs from PHV; \( n = 26 \)). Ethnicity of the players was Arab (Middle East and North Africa backgrounds). The effect of ethnicity on the validity of the biological maturity estimates (i.e., APHV) using the procedures described above is unknown. Thus the equation was deemed to be valid in the present population.

Maximal Sprinting Speed (MSS): The running speed of players was evaluated with a 40-m sprint effort by using dual-beam electronic timing gates (Swift Performance Equipment, Lismore, Australia) with slip times at 10 m, 20 m and 30 m. Players were instructed to run as quickly as possible along the 40-m distance from a standing start. MSS was assessed using the fastest 10-m split time during the 40-m test. Speed was measured to the nearest 0.01 s. Subjects performed two trials with at least 3 min of rest between them. The best performance of the 2 tests was used for the analysis.

Maximal Aerobic Speed (MAS): In a separate day, players performed an incremental field test to assess MAS. The incremental field test was a modified version of the University of Montreal Track Test (15; i.e., the VAMEVAL maximal incremental running test). The VAMEVAL test begins with a running speed of 8 km·h\(^{-1}\) with a consecutive speed increase of 0.5 km·h\(^{-1}\) each minute until exhaustion. The players adjusted their running speed to auditory signals at 20-m intervals, delineated by cones around a 200-m long athletics track. The end of the test was taken to be when participants twice failed to reach the next cone in the required time. During the test, players were verbally encouraged by testers and coaches. The velocity of the last 1-min stage completed by the subjects was retained as the players’ MAS (km·h\(^{-1}\)). If the last stage was not completed entirely, the MAS was calculated using the formula of Kuipers et al. (13): \( \text{MAS} = S_t + (t/60 - 0.5) \), where \( S_t \) was the last completed speed in km·h\(^{-1}\) and \( t \) in the time in seconds of the uncompleted stage.

MSS/MAS ratio: From the data of the MSS and the MAS tests, a maximal sprinting speed-to-maximal aerobic speed ratio was calculated as follows:

\[
\text{MSS/MAS ratio} = \frac{\text{MSS}}{\text{MAS}}
\]

### Allometric Scalling Model

MSS and MAS were used as the dependent variables. Body mass (kg), height (cm) and leg length (cm) served as independent variables to construct three different regression models and to identify the scaling exponents. The following steps outline
the procedures used to construct the model (36). First, normality of the dependent variables was assessed in the entire cohort. Second, a log-linear regression analysis was performed on the independent and dependent variables. The slope of the regression line was used as the allometric scaling exponent. Third, distribution of residuals and the assumption of homoscedasticity were tested by the Anderson-Darling normality test and visual inspection of the residuals. The residual errors should demonstrate a constant variance (homoscedasticity) and a normal distribution, indicating that the model fits all individuals across the entire range. Fourth and last, independence of the power ratio (i.e., allometrically-scaled MSS and MAS) and independent variable (i.e., body mass, height and leg length) was assessed. For an allometric model to be deemed appropriate there should be no significant correlation between the allometrically-scaled MSS and MAS measurement and the independent variable.

Statistical Analyses

Descriptive statistics are means ± Standard deviation (SD). Maturity group differences in anthropometric variables and performance measurements expressed in raw and allometrically-scaled values were examined using one-way ANOVA. If the first test provided a significant difference, then each group was compared with the other two using post hoc Bonferroni tests. To determine the relationship between MSS and MAS we conducted linear regression analysis using values (both raw and allometrically scaled) of MSS and MAS. 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 (11). To estimate maturity-related differences on the MSS/MAS ratio of individual players, we estimated a standard deviation representing individual responses (the square root of the difference in the variances in the performance scores in each pair of maturity groups; 10). The precision of our estimates of outcome statistics are shown as 90% confidence intervals (90% CI), which define the likely range of the true value in the population from which the sample was drew. For all statistical analyses significance was set al p < .05.

Results

Physical and Performance Data

The physical characteristics of each group are shown in Table 1. All physical and anthropometrical variables, except the sum of the seven skinfolds, were significantly different among the three groups.

Allometric Scaling Exponent

The use of the three independent variables (i.e., body mass, height and leg length) as scaling variables was successful in meeting all of the statistical criteria. As such, all the variables were positively correlated with MSS and MAS. Body mass yielded larger correlations with performance variables than height and leg length. Moreover, given the high level of interrelatedness between the three variables and
body mass being the most commonly used allometric scaling variable, only results of body mass are reported.

Data were normally distributed. Log-linear regression analysis using body mass as the independent variable was applied to the entire group, resulting in scaling exponents of 0.33 and 0.22 for MSS and MAS, respectively. These exponents were later on used to compute allometrically-adjusted ratios (MSS and MAS expressed in km·h⁻¹ divided by body mass raised to the appropriate exponent). The Breusch–Pagan/Cook–Weisberg test for heteroscedasticity was performed, and the residual errors from the body mass model were found to be randomly distributed or homoscedastic (p > .05). The independence test of the power ratio was nonsignificant (p > .05) for both parameters (i.e., MSS and MAS; p > .05). Visual inspection of residuals showed no apparent systematic variation. In addition, the Anderson-Darling normality test of the residuals revealed a normal distribution (p > .05).

### Mean Performance Differences Between Groups

Unsurprisingly, post-APHV players were significantly faster (i.e., higher MSS in raw values) than circum-APHV and pre-APHV players (p < .001; Table 2). In addition, pre-APHV players were slower than circum-APHV (p < .001). Similar to MSS, raw MAS was significantly influenced by age (p < .001). Post-APHV players had significantly higher MAS than pre- and circum-APHV players, while circum-APHV players were better than pre-APHV (Table 2). Mean maturity-related differences in the MSS/MAS ratio are shown in Table 3. The MSS/MAS ratio (raw values) was significantly lower (p < .05) in post-APHV players as compared with both pre- and circum-APHV players with no differences between the two latter

### Table 1  Player’s Physical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Pre-APHV</th>
<th>Circum-APHV</th>
<th>Post-APHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 14)</td>
<td>(n = 21)</td>
<td>(n = 26)</td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>12.3 ± 0.7</td>
<td>14.3 ± 0.9*</td>
<td>16.9 ± 0.7†‡§</td>
</tr>
<tr>
<td>Height (m)</td>
<td>145.9 ± 4.4</td>
<td>160.7 ± 6.3*</td>
<td>173.3 ± 4.4†‡§</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>35.4 ± 3.7</td>
<td>47.7 ± 5.2*</td>
<td>62.1 ± 6.9†‡§</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>16.6 ± 1.5</td>
<td>18.4 ± 1.2*</td>
<td>20.6 ± 1.9†‡§</td>
</tr>
<tr>
<td>Leg Length (m)</td>
<td>71.7 ± 3.9</td>
<td>78.6 ± 4.6*</td>
<td>83.1 ± 3.8†‡§</td>
</tr>
<tr>
<td>Sum Skinfolds (mm)</td>
<td>48.6 ± 11.5</td>
<td>49.1 ± 18.4</td>
<td>48.7 ± 10.6</td>
</tr>
<tr>
<td>Years to/from PHV</td>
<td>-2.1 ± 0.4</td>
<td>-0.2 ± 0.7*</td>
<td>2.3 ± 0.4†‡§</td>
</tr>
</tbody>
</table>

Values are means ± SD; n, number of subjects. Pre-APHV, before the estimated age at peak height velocity; Circum-APHV, around the estimated age at peak height velocity; Post-APHV, after the estimated age at peak height velocity. BMI, body mass index; Sum Skinfolds calculated from adding up the skinfold thicknesses of biceps, triceps, subscapular, supraspinale, abdomen, thigh, and calf muscles; PHV, peak height velocity. * Significant difference (P < 0.05) between circum-APHV and pre-APHV players; † Significant difference (P < 0.05) between post-APHV and pre-APHV players; § Significance difference (P < 0.05) between post-APHV and circum-APHV players.
Locomotor Tradeoffs in Youth Soccer

Individual Performance Differences Between Groups

The standard deviation of the MSS to MAS ratio scores was almost identical in the three groups for both raw and allometrically scaled values (Table 3). This homogenous between-subject variation indicates that individual differences in the MSS/MAS ratio as a result of different maturity status were similar. Individual differences, expressed as standard deviations, for both raw and allometrically scaled scores are presented in Table 4.
Correlations Between MSS and MAS

Raw MSS scores for individuals plotted against MAS scores are shown in Figure 1A. Both pre-APHV and circum-APHV groups showed a positive, large relationship between MSS and MAS ($r = .71–0.66$, $p < .01$). A small, nonsignificant positive correlation between MSS and MAS was found in the post-APHV group ($r = .22$, $p = .29$) was found in this group. When the same linear regression analysis was performed on allometrically scaled scores (Figure 1B), the three groups showed a positive, large to very large relations between scaled MSS and MAS ($r = 0.52–0.73$; $p < .01$).

<table>
<thead>
<tr>
<th></th>
<th>Pre-APHV (n = 14)</th>
<th>Circum-APHV (n = 21)</th>
<th>Post-APHV (n = 26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSS/MAS ratio (Raw values)</td>
<td>0.01 (-0.09–0.09)</td>
<td>0.04 (-0.08–0.10)</td>
<td>0.04 (-0.07–0.09)</td>
</tr>
<tr>
<td>MSS/MAS ratio (Scaled values)</td>
<td>0.02 (-0.06–0.06)</td>
<td>-0.02 (-0.06–0.05)</td>
<td>-0.03 (-0.06–0.05)</td>
</tr>
</tbody>
</table>

Values are means (90% CI). Pre-APHV, before the estimated age at peak height velocity; Circum-APHV, around the estimated age at peak height velocity; Post-APHV, after the estimated age at peak height velocity.

Discussion

The primary aim of this investigation was to determine whether the relationship between MSS and MAS was affected by maturation in a cohort of highly-trained young soccer players. Present results show that both locomotor attributes (i.e., MSS and MAS) improve with the transition from pre- to post-APHV stages, resulting in unchanged, size-corrected MSS/MAS ratio scores. We also found positive, large correlations between size-corrected MSS and MAS among each maturity group. Thus, our results do not support the notion of a maturity-related trade-off between MSS and MAS in developmental soccer players.

Allometric Model

Locomotor performances evaluated in the current study were positively correlated with body mass, reflecting the size-dependency of both performance measurements. Thus, the application of allometric scaling attempted to remove the confounding influence of body mass on MSS and MAS (33), which allowed us to better
Figure 1 — Relationship between maximal sprinting speed (MSS) and maximal aerobic speed (MAS) in three groups of young soccer players differing in physical maturity status (estimated by the years to/from the age at peak height velocity). Individual values are shown in absolute (A) and allometrically scaled (B) terms.
examine the athletic capacities of players differing in age and maturation levels. Allometric scaling of MSS and MAS produced different scaling exponents (0.33 vs. 0.22, respectively). These exponents are, by definition, the slope of the log-linear regression lines and indicate that body mass and associated factors in response to growth, maturation and training, exert more influence on MSS than on MAS. To the best of our knowledge, this is the first study applying allometric scaling models to locomotor performance data in a cohort of well-trained young soccer players; thus, direct comparison with the existing literature cannot be made.

Performance Differences Between Groups

The MSS and MAS were significantly different between pre- and circum- and post-APHV players. Raw MSS/MAS ratio was significantly higher in the circum-APHV group compared with the pre-APHV players, while no differences were found when comparing circum- and post-APHV players. This increment in the MSS/MAS ratio in the transition from pre- to circum-APHV stages arises from the more marked increase in MSS in comparison with MAS (13% and 8%, respectively). However, from circum- to post-APHV the increases in MSS and MAS were comparable, 10% in both parameters, so that the ratio was no more affected. This suggests that the transition from pre-APHV to circum-APHV represents an area of a more marked increase in MSS as compared with the transition from circum- to post-APHV stages. These findings are in agreement with Philippaerts and coworkers (21) who have previously reported peak development in running sprinting speed at the age of peak height velocity in youth soccer players. Moreover, these authors reported further running speed gains after peak height velocity but at slower rates (21). However, the same authors reported that aerobic power performance peaked at peak height velocity to drop after it (21). In contrast, our results showed differences in MAS (10%) when circum- and post-APHV groups were compared, suggesting further improvements in aerobic power in our players. The fact that our football players were subjected to an intensive soccer training regimen might explain the maturity-related differences in aerobic power (i.e., MAS) compared with results reported by Philippaerts et al. (21), as it has been suggested that additional training hours influence the “sustainability” of improvements in endurance performance observed in elite post-APHV field hockey players (6). The similar MASs observed in the post-APHV players in the current study (17.3 ± 1.0 km·h⁻¹) in comparison with top-level soccer players (17.7 ± 0.9 km·h⁻¹; 22) provides further support for this hypothesis. Moreover, it is also possible that selection bias within the soccer players may indeed factor out players without the capacity to concurrently train and maintain MSS and MAS.

Most of these increases in MSS and MAS occurring in the transition from pre-APHV to circum-APHV are likely to be related to the parallel changes in body mass (see Table 1). This is supported by the body mass-corrected values reported in Table 2, where it can be seen that both allometrically scaled MSS and MAS of pre- and circum-APHV players were not statistically different. As skinfolds did not differ among the three groups, changes in body mass were presumably more a reflection of increases in lean body mass or muscle. On the contrary, when MSS and MAS were body mass-corrected, both parameters were still higher in the post-APHV group in comparison with the pre-APHV group. This suggests that other
maturity-induced factors not causally related with changes in body (or muscle) mass can independently impact MSS and MAS. These factors might be related to a series of maturity-induced improvements in neural function, multijoint coordination, increases in muscle power associated with the rise in circulating levels of testosterone and growth hormone and changes in both oxidative and nonoxidative metabolism (9,32). Therefore, our results suggest that some factors operating at different maturity stages might simultaneously regulate concurrent improvements in MSS and MAS in proportion to player’s body mass (i.e., pre- and circum-APHV) or at a greater rate to their body mass (i.e., post-APHV; 1).

Another novel aspect of the current study was that, in addition to the mean effects of maturation on the MSS/MAS ratio (discussed above), the analysis of the individual differences indicates that this mean effect of maturation on the MSS/MAS ratio (both on raw and allometrically scaled values) does characterize the effect in individual players adequately. In this regard, the standard deviation representing individual differences was small and of similar magnitude in the three groups of players, suggesting that all individual players displayed a rather homogenous ratio. Again, this could be related to the selection/training process that puts similar emphasis on both qualities and therefore, tends to normalize players’ athletic profile. Potential factors accounting for individual differences in the MSS/MAS ratio such as genetic endowment, physical training loads and nutritional status were also likely to be similar among players in the different groups. Despite this relatively low variability, it is important to consider the individual MSS/MAS ratio to give recommendations as to whether endurance training or specific speed and power training should be emphasized in an individualized training perspective.

**Trade-Offs Between MSS and MAS**

A negative correlation between speed and aerobic function is generally thought to be a fundamental trade-off in locomotor performance that occurs virtually in all animal species because, among other factors, of the physiology of skeletal muscle and the biomechanics of the mature skeleton-muscular system (24,25,31). While very little direct evidence for this trade-off at the level of whole organism performance has been provided in humans (31), data in (nonspecifically trained) children indicate that this locomotion specialization into more sprinting or aerobic profiles does not occur before puberty (8,16). For the first time, we investigated here the possible associations between MSS and MAS in a cohort of young, developmental highly-trained soccer players. The small nonsignificant correlation between nonallometrically scaled MSS and MAS values in the post-APHV group (r = .22) gives support to the notion that some locomotion specialization might occur at late pubertal stages. Differences were also found in the slope of the MSS-MAS relationships between groups, with post-APHV players specifically showing lower relative increases in MSS with increasing MAS than the pre-APHV and circum-APHV players (Figure 1A). Sprinting performances in the post-APHV players were in line with those previously reported in adult male soccer players (23,28). Data on 40-m sprinting times in pre-APHV and circum-APHV children were also comparable to those previously reported in similar (well-trained) boys (17). Clearly, the participants of the current study were as fast as other similar athletes (17). This suggests that the observed trend of post-APHV players toward showing
a somehow more endurance profile when raw MSS and MAS values were evaluated was not achieved at expenses of sacrificing sprinting speed, further supporting the lack of maturity-related trade-offs in our sample of well-trained young soccer players. Training studies on concurrent training in this specific population should however be conducted before definitive conclusions can be made. After adjusting for body mass (i.e., allometric scaled data), a large ($r = .68$) MSS-MAS correlation was found in the post-APHV group, which was in the range of the correlations observer in pre- ($r = .73$) and circum- ($r = .52$) APHV players. Similarly, the slopes of the body-mass corrected MSS-MAS relationship between the three groups were remarkably similar (Figure 2B). From this larger MSS-MAS correlation observed when allometric scaled values were examined (in comparison with raw values) it can be inferred that body mass was a relevant modifying factor of the MSS-MAS relationship in our group of postpubertal players and should be taken into account. Albeit speculative, these results also suggest that some body mass-independent factors such as muscle architecture, muscle stiffness and motor coordination might be common determinants of performance in both qualities (i.e., MSS and MAS).

Limitations

The present work in a sample of young soccer players, as with any other cross-sectional study, only provide suggestive evidence concerning the causal relationship between concurrent changes in MSS and MAS during growth. The current study only characterizes average MSS and MAS developmental patterns displayed by young soccer players differing in estimated maturity timing and age. Accordingly, the true magnitude of performance changes that might effectively occur between and within individuals with growth and maturation cannot be described. Although estimates of maturity in the current study have merit in that they do not require invasive procedures, care is warranted in utilizing predicting APHV from anthropometrical factors (18). Lastly, only male soccer players were evaluated here. Thus, caution should be taken when applying the present results to a similar group of female players.

Conclusions

We conclude that, in our sample of highly-trained young soccer players, there is a positive association between MSS and MAS regardless of the maturity status. Although training studies are required to draw definitive conclusions, the equivalent mass-corrected MSS/MAS ratio in the three groups differing in physical maturity levels and age suggests that improvements in sprinting speed could be achieved without compromising these of maximal aerobic speed or vice versa. The fact that these two performance traits (i.e., MSS and MAS) covary during puberty might also suggest that they could be optimized at the same time during growth, at least to a certain extent. These findings have implications for training prescription during puberty in talented soccer players. Detailed analyses of performance capacities and behavior of young soccer players are required to fully understand how development (growth, maturation and training) may shape their locomotor systems.
References