ABSTRACT

The purpose of the present study was to examine the progress of sprint running velocity (SRV) during the initial and secondary acceleration phases in prepubescent (PPS), adolescent (ADS) and adult (AS) sprinters by comparing the progress of the magnitude of the stride length (SL) and stride frequency (SF). SRV, SL and SF progress for each 10-m interval of a 40-m sprinting test were examined with a video-analysis method for a total of thirty-one athletes. A 2 X 4 (age group X 10-m interval) ANOVA with repeated measures on the second factor revealed that SRV was developed similarly in ADS and AS (p > .05) and it was differentiated (p < .05) in PPS due to the limited distance acceleration phase. Pearson’s correlation analysis indicated that SRV and SL were highly correlated (r > .73, p < .05) for the entire distance of the sprinting test for AS and PPS. On the contrary, SF was the main contributor for SRV development in the 10-30m segment for ADS. In conclusion, SRV improvement seemed to be attributed to the increment of SL and SF, which were differently developed in prepubertal, adolescent and adult sprinters in the 40-m sprint.

KEY WORDS: maturity, motor development, spatio-temporal parameters, stride length, stride frequency, track and field, sprinting biomechanics.
INTRODUCTION

Sprint running velocity (SRV) constantly increases during childhood and adolescence (4, 21, 53, 57, 66, 70, 73, 80, 84). The most strenuous improvement in SRV, as noted in 30-50m sprinting tests, has being observed in untrained children aged 7-11 years old (4, 13, 56, 78, 87).

Based on a typical SRV curve of the 100-m sprint, the sprinting events are characterized by the acceleration phase, the maximum or constant SRV phase and the deceleration phase (62). A number of observations in various level sprinters, in combination with experimental data concerning trained and untrained subjects, agree that the length of each phase is approximately 0-40m, 40-80m and 80-100m respectively (1, 5, 15, 26, 28, 34, 36, 38, 45, 48, 55, 67, 68). A more detailed analysis (58) of the SRV curve revealed distinct sub-phases in each phase: the acceleration phase is composed by the initial (0-20m) and the extended (secondary) acceleration (20-40m), while the constant SRV phase is divided into the initial peak SRV (40-50 m), the SRV regulation (50-70) and the maximum SRV phase (70-80m). Differences between adult and adolescent athletes in a sprinting task, besides the greater values of SRV achieved by adults, is that the magnitude and the length of the acceleration phase are lower in adolescents (55). Research has shown that children can not maintain their maximum SRV after the 40-m mark of a maximal sprinting test (4) and that the secondary acceleration is completed after 20-30m (26, 52).

SRV is the product of stride length (SL) and stride frequency (SF) (41). Maximum SRV is the result of an optimal ratio between SF and SL (75). However, SF and SL values do not remain the same during the different phases of the sprint (1, 5, 7, 11, 15, 18, 22, 25, 36, 38, 48, 68, 83, 84). In general, despite the identification of individual patterns throughout a race (48), SF is maximized after 10-20m into the race (27, 39) and maintained during the constant SRV phase (44, 76), followed by a significant decrement in the last stages of the sprint due to fatigue (20, 61, 83). On the contrary, the maximum contribution of SL for SRV increment is noted in the 50-80m segment (38, 44, 68), despite the fact that the majority of the athletes enlarge their SL in the last meters of the race because of the decreased SF (62, 83). During the constant SRV phase, the effort for a concurrent maximization of both SF and SL could result in an improvement of SRV but it is not feasible because of the existence of a negative interaction between SF and SL (42). Additionally, it is uncertain if SL or SF is the most important contributor for the achievement of larger SRV. Previous researchers observed an equal or individualized contribution of both stride characteristics (7, 30, 48, 54, 59, 74), some detected SL dominancy (16, 27, 36, 42, 43, 53, 71, 72) and others proposed SF as the decisive factor for maximum SRV (8, 12, 23, 40, 48, 62, 63, 64, 69, 81, 84). Nevertheless,
it is well documented that body dimensions (i.e. body height, leg length) affects SL and SF (8).

During childhood and adolescence, SRV improvement is attributed to the increment of SL (20, 47), while SF is thought to remain independent of age (20, 86). The established relationship between SF and SL during childhood has found to be deranged between the ages of 11-15 years old (23, 47, 53, 77, 86). In specific, the period of maximal height growth affects SRV because SL increases and SF decreases due to the increment in body size and strength production caused by maturity (13, 19, 20). In general, the existence of limited information concerning the mechanical determinants of youth’s sprinting ability has being acknowledged (73).

The development of the SRV curve and the development of the stride characteristics (SF and SL) within the different phases of a sprinting task, unlike the extensive examination for adult and post-pubertal participants in a number of studies (1, 7, 15, 34, 36, 48, 55, 58, 67, 68), remains an issue which needs further investigation for trained and untrained prepubertal children. Additionally, the dominance of SL or SF for the maximization of SRV in the different phases of a sprinting task performed by athletes of different stages of maturity remains rather unexplored. Furthermore, it is of interest to compare the stride characteristics expressed relatively to body height among sprinters of different stages of maturity, because this comparison will provide information concerning force production effectiveness for the propulsion in order to perform a sprinting stride.

Based on the above, the purpose of the present study was to examine the development of SRV during the acceleration phase in prepubescent, adolescent and adult sprinters, by comparing the modification of SL and SF during a sprinting test with an allometric (i.e. SL and SF expressed relative to body height) perspective. It was hypothesized that SL will be differentiated among the age groups, since it is a factor affected by the increased body dimensions and strength because of the maturation process as mentioned above. It was also hypothesized that SF should not be differentiated among the different age groups because the neural system is developed very early in childhood. Results may possibly indicate the relationship between SL and SF with SRV in different stages of maturity. Additionally, information could be retrieved regarding the effectiveness of transforming the produced power into sprinting performance at different stages of maturity. The outcome of the present study could provide information concerning sprint performance improvement in prepubescent and adolescent sprinters.
MATERIAL AND METHODS

Participants

A total of thirty-one athletes were examined (Table 1). Group AS comprised of national and international level adult male sprinters. Groups PPS and ADS were formed by athletes classified as preadolescents (Stage I) and adolescents (Stage V) respectively, based to the technique of growth assessment described by Tanner (82). The selection of PPS athletes being about 11 years old was decided taking into consideration that mentionable changes occur in sprinting performance after this age (23, 47, 53, 80, 86, 88).

Table 1. Mean ± SD of the physical characteristics of the participants.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Age (yrs)</th>
<th>Body height (m)</th>
<th>Body mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS</td>
<td>11</td>
<td>22.3 ± 3.6</td>
<td>1.78 ± 0.08</td>
<td>72.1 ± 9.9</td>
</tr>
<tr>
<td>ADS</td>
<td>10</td>
<td>16.6 ± 0.5*</td>
<td>1.74 ± 0.03</td>
<td>66.2 ± 4.4</td>
</tr>
<tr>
<td>PPS</td>
<td>10</td>
<td>11.6 ± 0.8*§</td>
<td>1.54 ± 0.08*§</td>
<td>43.7 ± 8.8*§</td>
</tr>
</tbody>
</table>

*: p < .05 compared to AS; §: p < .05 compared to ADS

All participants had not an apparent or reported injury or disability and had a recorded regular participation to their training program. The investigation was conducted in accordance with the Helsinki Declaration and under the institutional research committee guidelines for the use of human subjects, which requires participants to be informed of the risks of contributing to the study and the acquisition of a signed consent document and/or parental approval prior to the experimental procedure.

Instrumentation

A JVC GR-D720E (Victor Co., Japan) digital video camera, operating with a sampling frequency of 50 fields/sec and with a shutter speed of 1/4000, was used for recording the sprinting tests.
Procedure

Measurements were conducted in late spring (at the beginning of the outdoor competitive season). Each participant executed a maximal sprinting test on a level 100-m indoor track with a rubber surface, which was preceded by a 40-minute warm-up. Warm up consisted of slow running for 8–10 minutes, stretching with emphasis on the leg muscles for 10–12 minutes, neuromuscular coordination drills (skipping and heel-to-butt kicks in particular), and four 80-m runs at gradually increasing speed for ADS and AS (60-m runs for PPS). The experimental test was a 40-m all out sprinting task, which was selected because research has shown that children cannot maintain their maximum SRV after the 40-m mark of a maximal sprinting test (4). The participants started the test from the standing starting position with their front foot’s toes just behind the start line. Participants were instructed to run as fast as possible from the beginning and to pass with maximum effort through the finish line. No “go” signal was given in order to avoid the effect of reaction time on performance.

Data acquisition and analysis

Sprinting performance was measured with a video-analysis method (3, 7, 14, 24, 26, 34, 36, 58, 71, 74). The video-camera was fixed on a tripod (height from ground level: 1.5m), which was positioned at the middle of the testing distance and at a distance of 15m from the middle of the lane. Markers positioned on both sides of the lane created 10-m zones. The camera was manually panned and zoomed in on the participants’ body during the entire sprinting test. The panning recording was done following the guidelines proposed by Gervais et al. (37). Video-recordings were used to assess sprinting performance (t) and the 10-m time-splits of the participants with an accuracy of ±0.01sec due to the recording rate. Start time was defined at the first field that the push-off leg had clearly took-off the ground and finish time was the instant where the athletes’ torso was over the finish line. Average SRV was calculated for the 10-m intervals based on the 10-m time splits as the ratio of distance to time for every 10m and over the entire running distance. SF was defined as strides per second. SL was the horizontal distance between the touchdown points of the feet recorded for two consecutive supports and it was calculated with the method described by Chow (18) using the A.P.A.S.-Wizard 2007 software (Ariel Dynamics Inc., Trabuco Canyon, CA). The use of this method consisted of computing the toe to the nearest 10-m marker distance by projecting the position of the toe onto a line between the two nearer 10-m marks and SL was extracted afterwards by the computed distances between two consec-
utive support phases. For better comparisons among the groups, the average stride frequency to body height ratio ($SF_{RATIO}$) and the average stride length to body height ratio ($SL_{RATIO}$) were included in the analysis. Finally, the $SN/h_{body}$ ratio (i.e., stride number divided by the body height) was used as an indicator of the magnitude of the force exerted on the ground for generating the propulsion for the stride (3).

Statistics

Data are presented as mean values ± standard deviation (SD) for each examined parameter. The anthropometric characteristics of the participants and the $SN/h_{body}$ ratio among groups were compared by one-way analysis of variance (ANOVA) with a Scheffe post hoc test. Differences concerning SRV, $t$, SL, $SL_{RATIO}$, SF and $SF_{RATIO}$ for each 10-m interval were compared by 2 X 4 (age group X 10-m interval) ANOVA with repeated measures on the second factor with Bonferroni adjustments. Significant differences were followed up with simple contrasts. The adequacy of the statistical power in order to execute the statistical analyses was examined using the G-Power 3.1.4 (©Franz Faul, Universität Kiel, Germany) software. The relationship between SRV with SF, $SF_{RATIO}$, SL and $SL_{RATIO}$ in each 10-m segment of the sprinting tests for each age group was examined by Pearson’s correlation analysis. Significance was accepted when $p < .05$. All statistical tests were conducted using the SPSS 10.0.1 software (SPSS Inc., Chicago, IL).

RESULTS

The SRV curve created by the participants’ performance revealed that maximum SRV for PPS was achieved in the 20-30m segment, followed immediately by a deceleration (Figure 1). On the contrary, ADS and AS accelerated up to the 20-30m and 30-40m interval, respectively.
AS was significantly faster ($p < 0.05$) than the other examined groups, with an increasing trend as the sprinting test was evolved (Table 2). SF reached its maximum value at the end of the secondary acceleration for AS, at the end of the initial acceleration for ADS and at the very first meters for PPS, thus revealing a different developing pattern among the examined groups ($F_{2, 28} = 111.798, p < 0.001, \eta^2 = .889$). SF$_{\text{RATIO}}$ for the entire sprinting distance was not significantly different ($p > 0.05$) among groups (Figure 2). No interaction was observed among the age groups and the 10-m segments of the sprinting test ($F_{2, 28} = 1.724, p = .197, \eta^2 = .460$).
Table 2. Mean ± SD of performance (t), average sprint running velocity (SRV), average stride frequency (SF) and average relative to body height stride length (SL Ratio) for the 10-m intervals and the entire 40-m sprinting test.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>0-10m</th>
<th>10-20m</th>
<th>20-30m</th>
<th>30-40m</th>
<th>0-40m</th>
</tr>
</thead>
<tbody>
<tr>
<td>t (sec)</td>
<td>AS</td>
<td>1.62 ± 0.06</td>
<td>1.16 ± 0.04*</td>
<td>1.02 ± 0.05†</td>
<td>4.86 ± 0.15</td>
<td>4.86 ± 0.15</td>
</tr>
<tr>
<td></td>
<td>ADS</td>
<td>1.67 ± 0.08</td>
<td>1.23 ± 0.06#*</td>
<td>1.09 ± 0.05#*†</td>
<td>5.13 ± 0.12#</td>
<td>5.13 ± 0.12#</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>2.12 ± 0.16‡‡</td>
<td>1.59 ± 0.14‡‡,*</td>
<td>1.54 ± 0.15‡,†</td>
<td>6.81 ± 0.61‡‡</td>
<td>6.81 ± 0.61‡‡</td>
</tr>
<tr>
<td>SRV (m/sec) AS</td>
<td>6.2 ± 0.2</td>
<td>8.7 ± 0.3</td>
<td>9.4 ± 0.4°</td>
<td>9.8 ± 0.5°‡,†</td>
<td>8.2 ± 0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ADS</td>
<td>6.0 ± 0.3</td>
<td>8.2 ± 0.4°*</td>
<td>9.2 ± 0.4°*†</td>
<td>7.8 ± 0.3°</td>
<td>7.8 ± 0.3°</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>4.7 ± 0.4#‡</td>
<td>6.3 ± 0.5#,#*</td>
<td>6.6 ± 0.6#,#*</td>
<td>5.9 ± 0.5#,#‡</td>
<td></td>
</tr>
<tr>
<td>SF (Hz)</td>
<td>AS</td>
<td>4.50 ± 0.16</td>
<td>4.49 ± 0.39</td>
<td>4.62 ± 0.37</td>
<td>4.50 ± 0.15</td>
<td>4.50 ± 0.15</td>
</tr>
<tr>
<td></td>
<td>ADS</td>
<td>4.55 ± 0.21</td>
<td>4.59 ± 0.38</td>
<td>4.43 ± 0.26</td>
<td>4.50 ± 0.20</td>
<td>4.50 ± 0.20</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>4.52 ± 0.30</td>
<td>4.10 ± 0.38§</td>
<td>3.92 ± 0.36§</td>
<td>4.15 ± 0.27‡§</td>
<td></td>
</tr>
<tr>
<td>SL Ratio</td>
<td>AS</td>
<td>76.4 ± 3.6</td>
<td>108.7 ± 6.7</td>
<td>119.3 ± 8.0</td>
<td>102.2 ± 3.6</td>
<td>102.2 ± 3.6</td>
</tr>
<tr>
<td>(% body height)</td>
<td>ADS</td>
<td>76.3 ± 4.8</td>
<td>103.3 ± 4.4†</td>
<td>120.1 ± 7.3†</td>
<td>100.1 ± 4.3</td>
<td>100.1 ± 4.3</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>70.4 ± 8.6</td>
<td>100.3 ± 7.1‡‡</td>
<td>109.0 ± 9.8‡‡,†</td>
<td>92.4 ± 6.7‡‡</td>
<td></td>
</tr>
</tbody>
</table>

#: p < .05 compared to AS; §: p < .05 compared to ADS; *: p < .05 compared to 0-10m; †: p < .05 compared to 10-20m; ‡: p < .05 compared to 20-30m.

Figure 2: Stride frequency expressed relative to body height (SL Ratio) in the respective 10-m segments of the sprinting tests for the examined age groups (ns: p > .05 within group compared to the previous 10-m interval and among groups in the same 10-m segment).
SL\textsubscript{RATIO} was significantly (p < 0.05) lower for PPS compared to ADS and AS in the entire sprinting task and in all 10-m intervals, with the exception of the first 10m. This trend was also observed when average SL was expressed in absolute values (Figure 3). SL was consecutively increased from a 10-m interval to the next in all groups. There was an interaction among the age groups and the 10-m intervals for SL (F\textsubscript{3, 81} = 5.144, p = .013, η\textsuperscript{2} = .971). A main effect was also observed for SL of the intervals (F\textsubscript{3, 81} = 309.444, p ≤ .000, η\textsuperscript{2} = .974).

Figure 3: Average absolute stride length (SL, in m) in the respective 10-m segments of the sprinting tests for the examined age groups (*: p < .05 within group compared to the previous 10-m interval; +: p < .05 among groups in the same 10-m segment).

Pearson correlation analysis revealed a strong relationship (r > .73, p < .05) between SRV and SL for the entire distance of the sprinting tests for groups AS and PPS (Table 3). However, SL\textsubscript{RATIO} was strongly correlated (r > .7, p < .01) with SRV only for the PPS group.
Table 3. Correlation coefficients of the relationship of the average absolute stride frequency (SF), the average stride frequency to body height ratio (SF\textsubscript{RATIO}), the average absolute stride length (SL), the average stride length to body height ratio (SL\textsubscript{RATIO}) with the average sprint running velocity (SRV) for the 10-m intervals and the entire 40-m sprinting test.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>0-10m</th>
<th>10-20m</th>
<th>20-30m</th>
<th>30-40m</th>
<th>0-40m</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF (Hz)</td>
<td>AS</td>
<td>.219</td>
<td>.465</td>
<td>.348</td>
<td>.156</td>
<td>-.111</td>
</tr>
<tr>
<td></td>
<td>ADS</td>
<td>.160</td>
<td>.919**</td>
<td>.856**</td>
<td>.525</td>
<td>.632*</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>-.011</td>
<td>.574</td>
<td>.696*</td>
<td>.455</td>
<td>.284</td>
</tr>
<tr>
<td>SF\textsubscript{RATIO} (SF/body height)</td>
<td>AS</td>
<td>-.050</td>
<td>.343</td>
<td>.126</td>
<td>-.021</td>
<td>-.222</td>
</tr>
<tr>
<td></td>
<td>ADS</td>
<td>.246</td>
<td>.938**</td>
<td>.860**</td>
<td>.572</td>
<td>.658*</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>-.038</td>
<td>.412</td>
<td>.475</td>
<td>.291</td>
<td>.181</td>
</tr>
<tr>
<td>SL (m)</td>
<td>AS</td>
<td>.643*</td>
<td>-.081</td>
<td>.406</td>
<td>.445</td>
<td>.676*</td>
</tr>
<tr>
<td></td>
<td>ADS</td>
<td>.629</td>
<td>-.597</td>
<td>-.254</td>
<td>.283</td>
<td>.373</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>.497</td>
<td>.388</td>
<td>.793**</td>
<td>.542</td>
<td>.738*</td>
</tr>
<tr>
<td>SL\textsubscript{RATIO} (SL/body height)</td>
<td>AS</td>
<td>.383</td>
<td>-.107</td>
<td>.255</td>
<td>.332</td>
<td>.614*</td>
</tr>
<tr>
<td></td>
<td>ADS</td>
<td>.719*</td>
<td>-.377</td>
<td>-.110</td>
<td>.301</td>
<td>.474</td>
</tr>
<tr>
<td></td>
<td>PPS</td>
<td>.553</td>
<td>.472</td>
<td>.766**</td>
<td>.487</td>
<td>.896**</td>
</tr>
</tbody>
</table>

*: p < 0.05; **: p < 0.01

Pearson correlation analysis indicated that SF was strongly correlated with SRV ($r > .86$, $p < .05$) in the 10-30m segment for ADS. On the opposite, SL\textsubscript{RATIO} was observed to be significantly correlated ($r > .72$, $p < .05$) with SRV in the first 10m for ADS and in the 20-30m segment for PPS. PPS achieved maximum SRV which was significantly correlated with of both SF and SL. Concluding, $S_N/h\text{body}$ ratio was significantly ($p < 0.05$) lower in PPS compared to the other age groups ($0.18 \pm 0.02$, $0.16 \pm 0.01$ and $0.15 \pm 0.01$ for PPS, ADS and AS, respectively).

**DISCUSSION**

Results indicated that the development of SRV during the sprinting tests had a similar pattern in adolescent and adult sprinters and it was slightly differentiated in prepubescent sprinters due to the absence of an extended secondary acceleration phase and due to the existence of a short constant SRV phase in the 40-m sprinting test. The hypothesis that SL than SF is a more influential factor of achieving larger SRV by athletes of different level
of maturity was in part verified, since a highly significant correlation was revealed between those parameters for the examined prepubertal and adult sprinters.

The time-analysis of the sprinting tests revealed that SRV peaked for the PPS group around the 30-m mark of the sprinting test, followed by a slight deceleration afterwards. These findings were in agreement with previous studies (4, 5, 28, 55) which, not surprisingly, have tested distances up to 40m in youth athletes (73). Additionally, the PPS examined in the present study had a similar in distance secondary acceleration phase compared to untrained individuals of similar age (51, 52). The faster sprinting times recorded by ADS and AS compared to PPS could be attributed to the fact that a longer acceleration phase was observed for the older participants. This was in agreement with the suggestion that the longer the acceleration phase, the better the performance in a sprinting task is (55). Another notable finding was that the pre-last 10-m interval was marginally faster than the last for PPS. This could be explained by the decreased SF that allowed PPS to coordinate the actions of their body segments in order to accomplish the technique requirements of the finish as shown in the video-recordings.

SL was constantly increased from one 10-m segment to the next in all groups as it has been noted elsewhere (7, 8, 84). SRV and SL were revealed to be highly correlated for the entire distance of the sprinting tests for groups AS and PPS, being in accordance with results of previous research (16, 27, 36, 42, 43, 53, 71, 72). This was not the case for ADS, which had a strong correlation between SF and SRV during the secondary acceleration phase of the sprinting test. The larger values for SRV, SL, SF and $S_{V/h_{body}}$ ratio for adolescent sprinters compared to prepubertal athletes were in agreement with previous studies (17, 20, 21, 23, 47, 53, 77, 80, 86). As expected, SRV and the stride characteristics for AS was lower compared to elite international level sprinters (1, 15, 34, 38, 48, 68, 89), but within reasonable agreement with participants examined in a number of studies (5, 7, 10, 11, 22, 25, 46, 71, 83). Furthermore, it is worth mentioning that the SF and SL values recorded at the 30-40m segment for group PPS were almost identical to those previously reported elsewhere (26). The absence of an increasing trend for SF and the existence of a concurrent increment of SRV as the sprinting task unfolded have led researchers to the conclusion that SL is the major factor for SRV development through the sub-phases of acceleration and constant SRV (25, 48, 53). The suggestion that is of importance to stabilize SF during the acceleration phase as a prerequisite to achieve maximum SRV (25) could be supported by the present data only for ADS. The lack of a strong correlation coefficient between SRV and the stride characteristics may be an indication of the existence of individualized optimum combinations of SF and SL for maximizing SRV (7,
It has being proposed that the modifications of the stride characteristics in each phase could be attributed to the differences in the nervous regulation of the movements but also in the functional role of the muscles involved (29), but both factors are assumed to be different between childhood, adolescence and adult life (65). Nevertheless, despite differences in stride characteristics such as SF and SL, most of the spatio-temporal parameters of the support leg were found to be not different in adult and preadolescent sprinters at the constant SRV phase (17).

With regard to the stride characteristics expressed relatively to body height, SF$_{\text{RATIO}}$ was not different among groups and its development was not modified due to the different level of maturation. However, SF$_{\text{RATIO}}$ was significantly correlated with SRV during the acceleration phase for ADS, a result that confirms previous suggestions that SF$_{\text{RATIO}}$ is a good indicator for sprinting potential in young athletes (23). On the other hand, SL$_{\text{RATIO}}$ was significantly lower in PPS than the other examined groups. This finding could be explained by the $S_N/h_{\text{body}}$ ratio decrement as age increased, revealing that more distance was covered during a single push-off (3). This finding composes an indication for the greater force exertion capabilities (3) of the adult sprinters. Additionally, it has being suggested that taller people execute a sprinting task with larger SL and lower SF (6, 84). Under this perspective, it is logical that PPS had significantly smaller SL and SL$_{\text{RATIO}}$ since they were significantly shorter in body height than the other examined groups. Despite the fact that prepubertal and adolescent sprinters tested here were faster than trained and untrained age-matched subjects tested in other studies (47, 51, 52, 70, 71, 86), the $S_N/h_{\text{body}}$ ratio recorded for PPS was larger than reported for Afro-Caribbean prepubescent boys (3). This finding could be interpreted as an indicator of limited effectiveness for force exertion capabilities of the examined PPS in the present study.

The importance of strength regarding SRV performance has being noted in adults (2, 12, 14, 32, 63, 64, 79). In detail, maximum SRV is suggested to be achieved by developing the explosive strength of the muscles, which could eventually contribute to longer SL (49, 76). However, a strong relationship between them was not established in adults (33) and prepubertal boys (9). More research is needed in order to clarify this controversy. Nevertheless, sprint performance improvement during maturity has being attributed to a variety of factors such as the increase of body dimensions, the increase of body mass, the constant transformations of slow to fast twitch muscle fibres, the increased muscle activation, the increased hormonal stimulation, the decreased muscle co-contraction and the increased power production, which is important for the acceleration phase (31, 35, 50, 55, 60, 65, 85). Participation in training programs, even at the age of 10-11 years old, has found to improve SRV as an effect of the increased SL (71). The controversy noted in the literature is that sprint training improves the accel-
eration phase but not the constant SRV phase (52). It is recommended that future research should explore the influence of maturation on the development of the neuromuscular parameters that affect the stride characteristics in the acceleration phase. It is also proposed that future research concerning the trainability and optimal stimulation of those parameters during childhood and adolescence should take under consideration the progress of SF and SL in the acceleration phase as shown in the present study.

CONCLUSION

The main finding of the present study was that adolescent athletes developed their sprint running velocity within the sprinting test in a different manner than the other age-groups tested, in which speed improvement seemed to be attributed to the increment of stride length. Additionally, it was found that prepubertal boys have a very short constant sprint velocity phase around the 30-m mark of the 40-m sprinting test and their $SL_{RATIO}$ and $S_{N/h_{body}}$ ratio values were found to be lower than the other groups tested. Furthermore, stride frequency was differently developed among the prepubertal, adolescent and adult sprinters examined in the present study. Research should emphasize on the sprinting mechanics and training methods for developing acceleration and maximum speed in circumbertal athletes and untrained individuals.

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