TITLE:

THE NATURAL DEVELOPMENT OF MAXIMAL SPRINT SPEED IN BOYS WITH ADVANCING MATURATION

Abstract

The purpose of this study was to examine the natural development of the mechanical features of sprint performance in relation to maturation within a large cohort of boys. Three hundred and thirty-six boys (11-15 years) were assessed for sprint performance and maturation. Maximal speed, stride length (SL), stride frequency (SF), flight time (FT) and contact time (CT) were assessed during the sprint. Five maturation groups (G1-5) were established based on age from peak height velocity (PHV). G1 were early pre-PHV, G2 pre-PHV, G3 approaching-PHV, G4 around-PHV and G5 post-PHV. There was no difference in maximal speed between G1-3 but those in G4 and G5 were significantly faster ($p<0.05$) than G1-3. Significant increases ($p<0.05$) in SL were observed across G1-3, but no significant ($p>0.05$) improvements in SL were observed between boys G4-5. SF decreased whilst CT increased (both $p<0.05$) between G1-2, but no changes were observed for either variable between boys in G3-5. While boys pre-PHV (G1-3) improved their SL concomitant decreases in SF and increases in CT prevented them from improving maximal speed. Maximal sprint speed appears to develop around and post-PHV as SF and CT begin to stabilize, with improvements in maximal sprint speed in maturing boys underpinned by improving SL.

Key Words

Boys, speed, stride length, stride frequency, contact time, maturation.

Sprinting and running are key fundamental movement skills that are considered to be the building blocks for many sporting activities (1,38,44) and are common forms of locomotion performed by children during playground games and activities (8). Furthermore, sprinting performance appears to be an important determinant of success in many adult (11,34,41,53) and youth sports (26,29), and assessments of maximal speed are commonly included in batteries of talent identification tests (29,37).

Sprint speed in boys is known to develop in a non-linear fashion throughout childhood and adolescence (25), with accelerated periods of development observed during both a pre-adolescent and adolescent spurt in performance (25,47). Whilst the majority of published data in the literature have been expressed with reference to chronological age, it has been suggested that the adolescent spurt in sprint performance coincides with peak height velocity (PHV) (35). Therefore, natural improvements in sprint performance may be maturity-related however, this is yet to be fully explored.

Maturation is known to influence many aspects of physical performance including sprint speed, however, previous large cohort studies have used plate tapping and shuttle run tests as a form of speed assessment (2,20), and very few studies have actually used sprint tests (52). Previous youth studies that have used relevant test protocols failed to collect data to reflect the maturation status of the participants (29) or have focused on populations involved in systematic long-term training (46). Catley and Tomkinson (6) have recently reported percentile sprint times for a large cohort (n= 85347 tests) of 9-16 year old children, however, consideration was not given to the impact of maturation on sprint performance. This may be of particular importance for studies where male participants span the period of adolescence, as the timing of adolescence and PHV is known to be highly variable in boys (25) and has been proposed to have an impact upon selection in elite youth sport (31,45). Physiologically, boys around the period of PHV may experience a 10-fold increase in testosterone concentrations (47) and concomitant increases in muscles mass (24). The development of these muscular and hormonal characteristics (3) has been suggested to result in improved expression of both concentric strength and power (23) and is likely to influence sprint speed.

Whilst it is accepted that running speed is the product of stride length and stride frequency (14), there is sparse literature that specifically focuses on the development of these characteristics throughout childhood and adolescence. It is also known that other mechanical stride characteristics may influence stride length and stride frequency (13), and in adults it has been reported that faster runners achieve longer strides through greater application of ground reaction forces during a reduced ground contact period (48,49). In adults, improvements in strength and power have been associated with improved stride length and speed (48,50), and it has been suggested that a similar relationship may be evident in children (28), especially around the period of PHV when physiological characteristics linked to improved neuromuscular function (25) and greater limb length (7) are reported to occur.

There is evidence that the development of sprint speed from early childhood to adulthood is associated with an increased stride length, but the study of Schepens et al. (43) used only 6-8 participants per age group and did not account for maturation status. Therefore the aim of this study was to examine the natural development of the mechanical features of maximal sprint speed in relation to maturation within a large cohort of boys. On the basis of the literature available, it is hypothesized that improvements in stride length will explain gains in sprint speed with advancing maturation, and that no change in stride frequency would be evident with advancing maturation.

Materials and Methods

Participants

Three hundred and thirty-six school boys aged 11-15 years old (13.22±1.37 years, range 4.91 years) volunteered to participate in the study. Participants were assessed within normal Physical Education class groups then separated into maturational groups for the purposes of analysis. The maturation groups were determined by the predicted years from PHV derived from anthropometric assessments (30). Mean (±SD) values for group characteristics are provided in table 1. All participants were regularly engaged in Physical Education classes from the same curriculum and were free of injury at the time of testing. Ethical approval for the study was granted from the Institutional Research Ethics Committee, and subsequently, parental consent and participant assent were collected.

***** table 1 here******

Procedures

All participants were required to complete a sprint test and an assessment of maturation. All assessments took place over a two-week period, and were conducted in the same indoor sports hall during Physical Education classes. Test apparatus were set up with the same orientation in the facility for all testing sessions. All participants were instructed to wear the same clothing and footwear and asked to refrain from physical activity 24 hours before testing and to refrain from eating one hour prior to testing. All participants were provided with the opportunity to familiarize themselves with the test equipment and the protocol used prior to each testing session.

Sprint test. The assessment of sprinting speed required participants to perform a maximal sprint over a 30m track. A finish line was established at 35m to encourage participants to continue sprinting throughout the 15-30m zone of the sprint where measurements were recorded. These distances were selected based on previous data highlighting maximal speed being achieved within 35m for the majority of youth games players (5). Participants were given two trials for the sprint test, and were instructed to start from a split stance position with one foot on a line positioned 50cm behind the starting line. Participants were given the instructions “Ready” and “Go”, and verbal encouragement was given throughout the test to encourage maximal effort. A minimum of four minutes rest was given between trials to ensure sufficient recovery between trials.

Sprint test variables. The assessment of sprint characteristics was made via an optical measurement system (Optojump, Microgate, Italy) positioned at floor level in the 15-30m section of the sprint track. Data for the sprint characteristics were instantaneously collected using a Windows XP laptop via specialist Optojump software (Microgate, Italy) and subsequently exported to Microsoft Excel for data processing. Strong intra-class correlations (ICC) and low coefficient of variations (CV) have previously been reported for the optical measurement system during the assessment of jump height (ICC: 0.982-0.989, CV: 2.7%; [12]) and also measurement of stride characteristics (ICC: 0.87-0.98, CV: 0.6-5.5%; [33]) in adult populations.

Data obtained from the optical measurement system automatically calculated the following variables:

- *Speed:* Calculated by dividing the distance (m) between alternate foot contacts (stride length) and the time taken (s) between these contacts (flight time + contact time). Units are expressed as distance per unit time ($m.s^{-1}$).
- *Stride length (SL):* The distance (m) travelled between alternate foot contacts.
- *Stride frequency (SF):* The rate (Hz) of lower limbs movements as defined by the number of strides taken per second.
- *Contact time (CT):* The amount of time (s) the participant spends during the stance phase of the sprint, where the foot is in contact with the floor
- *Flight time (FT):* The amount of time (s) between foot contacts, where the participant is not in contact with the floor.

Sprint test data processing. All data were collected from the two fastest consecutive strides for each participant over their two 30m sprints. The SL, SF, CT and FT corresponding to these fastest strides were used for subsequent analysis. If a participant was deemed to have obtained their fastest stride from the last or first foot contact recorded in the 15-30m data collection zone, then these data were excluded from the analysis. This exclusion was enforced to remove those partciapnts who had already achieved maximal speed prior to the data collection zone, and also those who were still accelerating at the end of data collection zone, thereby resulting in data from only those partcipants achieving maximal speed between 15-30m.

Assessment of maturity. Maturity was estimated from anthropometric measurements using the protocol proposed by Mirwald et al. (30[equation. 1]) in which standing height, sitting height, leg length, chronological age and the interaction between these variables are used in order to predict the number of years from peak height velocity (maturity offset). This method was chosen due to the non-invasive nature of the assessment and the satisfactory levels of measurement accuracy (30). This method for estimating maturity has previously been deemed suitable for research with children (23).

Maturity offset = – [9.236 + 0.0002708*Leg Length and Sitting Height interaction] – [0.001663*Age and Leg Length interaction] + [0.007216·Age and Sitting Height interaction] + [0.02292·Weight by Height ratio]

[equation 1]

Participants were grouped into maturational intervals according to their maturity offset, whereby Group 1: more than 2.5 years before PHV, Group 2: -2.49 to -1.5 years from PHV, Group 3: -1.49 to -0.5 years from PHV, Group 4: -0.49 to 0.5 years from PHV, Group 5: 0.51 to 1.5 years from PHV. Further breakdown of participant maturation offset values is provided in table 1.

Statistical Analyses

Descriptive statistics (mean ± SD) were produced for all sprint performance characteristics for each maturation group. Subsequently a one-way analysis of variance was conducted between each maturation group to determine differences between groups. Homogeneity of variance was assessed via Levene's statistic and where violated, Welch's adjustment was used to correct the F-ratio. The location of significant difference was identified by either using Tukey's HSD or Games-Howell post-hoc analysis, where equal variances were and were not assumed, respectively. Pearson's correlations were also conducted to assess the relationship between test variables. All significance values were accepted at $p<0.05$ and all statistical procedures were conducted using SPSS v.17 for Windows.

Results

The data in table 1 highlights the participant characteristics, with significant increases in standing height, mass and leg length seen between groups of boys of advancing maturation ($p<0.05$). The results in figures 1 and 2 indicate there was no significant change in maximal speed across the pre-PHV groups (G1-3), but each of these groups were significantly ($p<0.05$) slower than those boys around (G4) and post (G5) PHV. There were significant ($p<0.05$) increases in SL across those boys pre-PHV, approaching-PHV and those around-PHV (G1-4); however no significant differences in SL were observed between those boys around (G4) and post (G5) PHV. There were significant ($p<0.05$) decreases in SF between the early pre-PHV, pre-PHV and approaching PHV groups (G1-3); however significant differences were not evident in SF for boys in groups approaching (G3), around (G4) and post (G5) PHV. A similar pattern was also observed for CT, where significant ($p<0.05$) increases in CT were observed across the early pre-PHV groups (G1-3); however there were no significant differences in SF between boys in groups approaching (G3), around (G4) and post (G5) PHV. No significant differences ($p<0.05$) were observed in FT across all maturation groups.

**** Figures 1 and 2 here****

Figures 3, 4 and 5 present Pearson's correlations between speed and stride characteristics; demonstrating that speed was more strongly related with SL than SF (R=.752, p<0.01, R^2=0.564, and R=.407, p<0.01, R^2=0.165, respectively) and SL and SF had a weak negative relationship (R=-.291, p<0.01, R^2=0.084). Table 2 highlights the relationships between sprint and descriptive data. Standing height and leg length demonstrated the strongest relationships with SL (R=.626, p<0.01, R^2=.391 and R=.609, p<0.01, R^2=.370, respectively). It should also be noted that a significant relationship was evident between standing height and leg length (R=.944, p<0.01, R^2=.891).

****Table 2 and Figures 3, 4 and 5 here****

Discussion

The aim of this study was to examine the natural development of the mechanical determinants of maximal sprint speed in relation to maturation in a large sample of boys. Increasing maturation was reflected in significant increases in somatic dimensions across all groups. However, a similar pattern was not observed with sprint speed. A combination of decreasing SF and increasing SL resulted in speed remaining unchanged across the pre-PHV groups. Boys became significantly faster around the time of PHV. The stabilization of SF and continued increase in SL explained the subsequent increase in speed around and after PHV.

Philippaerts et al. (35) reported negative performance changes in sprint speed in the 12 months prior to PHV, but in agreement with the present study, reported most significant changes around the PHV period. Yague and De La Funte (52) reported improvements in speed in the 12 months post PHV, however they also noted improvement in speed 16 months prior to PHV that was not observed in this study. The lack of improvement in speed amongst the pre-adolescent groups in the present study would seem to be in contrast with the consistent improvements in leg length and SL as well as the strong association reported between these variables in the current study; however these improvements seem to have been mitigated by decrements in SF (14) and increased CT observed in the pre-PHV groups. Philippaerts et al. (35) reported on a similar phenomenon whereby decrements in speed in boys approaching PHV was speculated to be caused by temporary disruption in motor co-ordination, termed adolescent awkwardness.

The results of the current study report decreasing SF and increased CT in the pre-adolescent groups. Data from Schepens et al. (43) also reported a trend for decreased SF. This trend was non-significant but is likely to have been limited by small group sample size (n = 6-8). It would appear that pre-adolescent boys in the present study may lack the necessary motor co-ordination and strength to effectively orientate, stabilize and apply force through their lower limbs. Boys at or post PHV seem to be able to utilise the additional leg and stride length more effectively as both CT and SF stablise around this time. It is speculated that maturity-related improvements in strength and power output observed around the time of PHV (9,36,39) may facilitate the improvement in technical efficiency and force application, resulting in improved speed in those boys around and post PHV.

The results of the study revealed significant changes in leg length, standing height and mass across all maturation groups. Such growth related changes would be expected as part of natural growth and development (25). The changes in mass seen across the maturation groups could not only be associated with growth related changes in stature, but also changes in the relative proportions of fat-free mass seen in boys during the adolescent period (47). However, in this study, increased mass was associated with longer CT, and therefore as children mature, additional body mass may cause them to spend more time on the ground, although they may compensate for this by achieving a longer SL. The increases in leg length with advancing age are of particular relevance as it has been suggested that such changes have an influence upon maximal sprint speed (26,27,35,43) due to the resultant increases in SL. The association between leg length and SL could result from improved contact length (49), which is the distance covered during the contact phase, as well as extra distance covered during the aerial phase of the sprint stride. Data from this study suggests that the time in the air remains consistent across all maturation groups. This implies that more mature boys were covering more distance over the same duration of aerial phase, and therefore the force generating capacity of the lower limbs may have an influence upon the association between maturation and SL, in addition to changes in leg length. The lack of change in FT in the present study is consistent with literature relating to adult sprinters of different abilities (48,49). This may also reinforce the notion that repositioning of the limbs during the flight phase of sprinting has limited impact upon overall performance (48).

Furthermore, Weyand et al. (48) stated that faster running speed in adults may be achieved by applying greater ground reaction forces during reduced ground contact periods, reflecting a higher rate of force development during the stance phase of a sprint. However, from the present results it is clear that CT does not naturally improve with maturation, instead increasing in the early part of the growth spurt before stabilising. These data suggest that young boys may not naturally decrease CT but instead learn to develop greater forces during the same timeframe, resulting in increased SL and eventually speed.

Favourable natural adaptation in preactivation and stretch-reflexes during rebounding have been reported to occur prior to PHV (22), however in the current study speed does not increase until post-PHV. Consequently it may be speculated that the increases in SL are more likely attributed to alterations in muscle-tendon characteristics during maturation. This may include increased muscle cross-sectional area (32), fascicle length (16), pennation angle (4,17), muscle-tendon junction size (18) and stiffness (21,40). It has also been reported that myelination of motor neurons is only completed post-puberty (15), and co-contraction of the agonist-antagonist muscles may reduce (10) at the same time that neural firing rates (51), and twitch times (21) may also improve favourably. It is speculated that these factors combine to result in the highest level of motor skill development being observed around the period of PHV (47), resulting in the potential for improved maximal sprint speed.

Some recent research in elite adult sprinters by Salo et al. (42) has suggested that contrasting strategies (i.e improved SL, improved SF or both) may be optimal for different adult sprint athletes to bring about an enhanced sprint performance. From the current study it seems that boys who are pre-PHV may be considered to be SF-reliant, and therefore be more dependent on neural factors to facilitate a high SF. Conversely it seems that boys around and post PHV may be termed more SL-reliant, whereby they become more dependent upon their developing levels of strength and power, resulting in improved application of force during ground contact and therefore improvements in SL.

A limitation of this study may be the estimation of maturation from somatic measures (30) rather than using a measure of biological maturation. However, the standard error of estimates for this equation has been reported as 0.57 years which may be considered satisfactory when balancing the reliability of the measure against the practicality of assessing large scale samples of children in a non-invasive manner. The consistent significant increases in all somatic measures across groups supports the prediction of maturation and subsequent grouping in the present study. Should the reader wish to apply a more conservative approach then the results of groups 1, 3 and 5 could be used to gain a clear assessment of sprint performance in boys who are early pre-PHV, approaching PHV, and post-PHV. Previous research has also suggested the use of age as a covariate when considering maturation (46), however, as age was used in the prediction of maturation such an approach is not appropriate in the current study.

The results of this study indicate that the time around PHV is a key point in the improvement in speed in boys. In this large cohort study, SF has been shown to decrease during the pre-PHV period. Furthermore whilst reduced CT is often reported as desirable for sprint performance, it appears from natural development that CT actually increases during childhood. SL increases with maturation, and this is likely due to increased limb length and improved relative force production. It has been suggested that natural development during childhood may help inform training (41). Findings from this study would suggest that pre-PHV boys should focus on the development of neuronal parameters to facilitate improved SF and CT. Improved neural factors may result in increased technical competency and assist in coping with the growth-related anthropometric changes observed at this time. Whilst neural training should continue for boys around and post-PHV, the focus of training should shift towards improved SL with the development of strength and rate-of-force development to make optimal use of the maturity-related changes in circulating androgens and increased muscle mass. However, it may also be that to further improve maximal speed, adolescents will need to train to improve factors, such as reduced ground contact and increased SF, that do not naturally develop with maturation. Future studies should focus on the collection of longitudinal data to validate the observations in this study regarding the natural development of speed with advancing maturation, and also consider the interaction of maturation with training.

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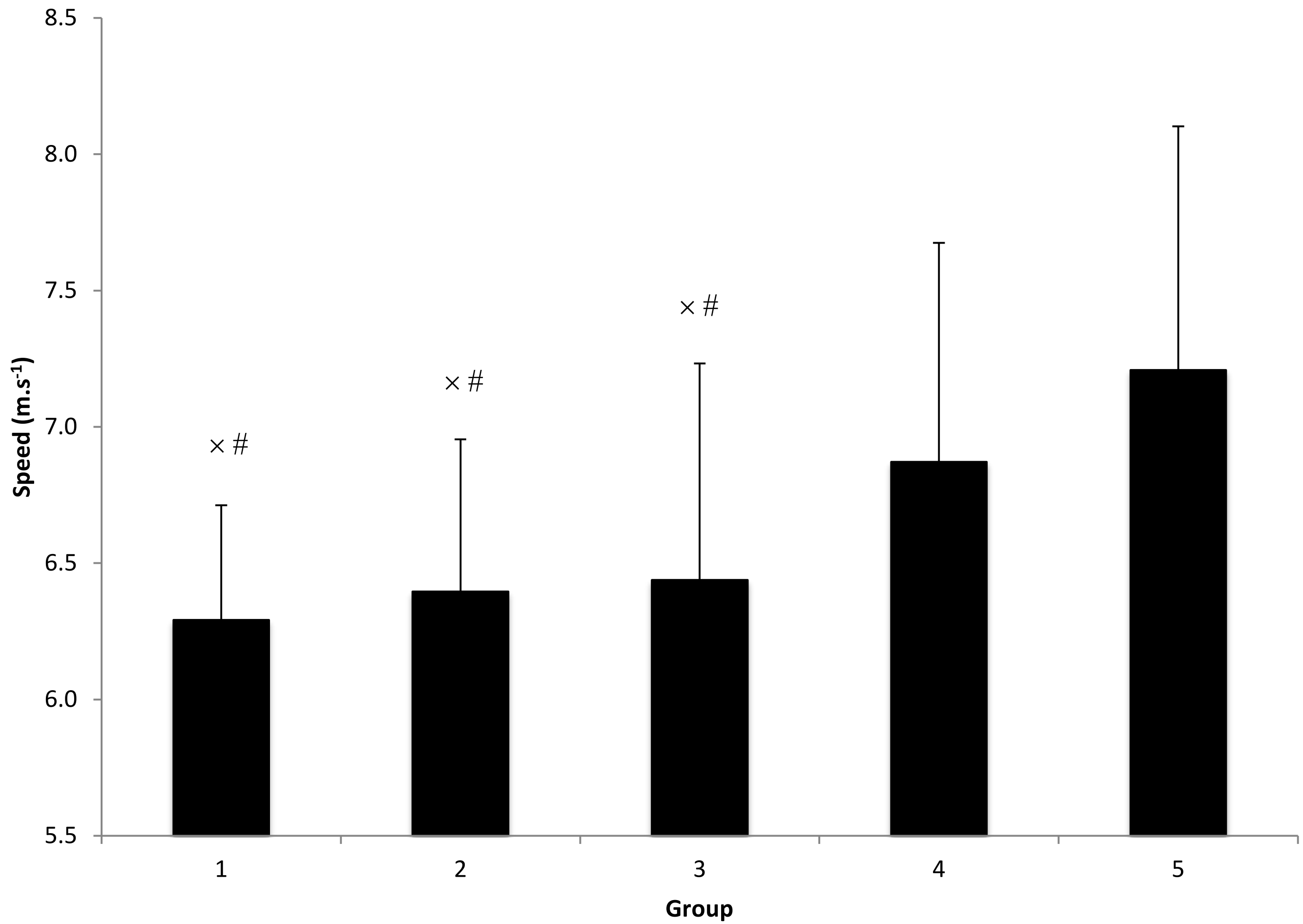

Figure 1. Maximal speed in a 30m sprint across different maturation groups.
* Significantly different to P1, $p<0.05$; ^ Significantly different to P2, $p<0.05$; + Significantly different to P3, $p<0.05$; × Significantly different to P4, $p<0.05$; # Significantly different to P5, $p<0.05$.

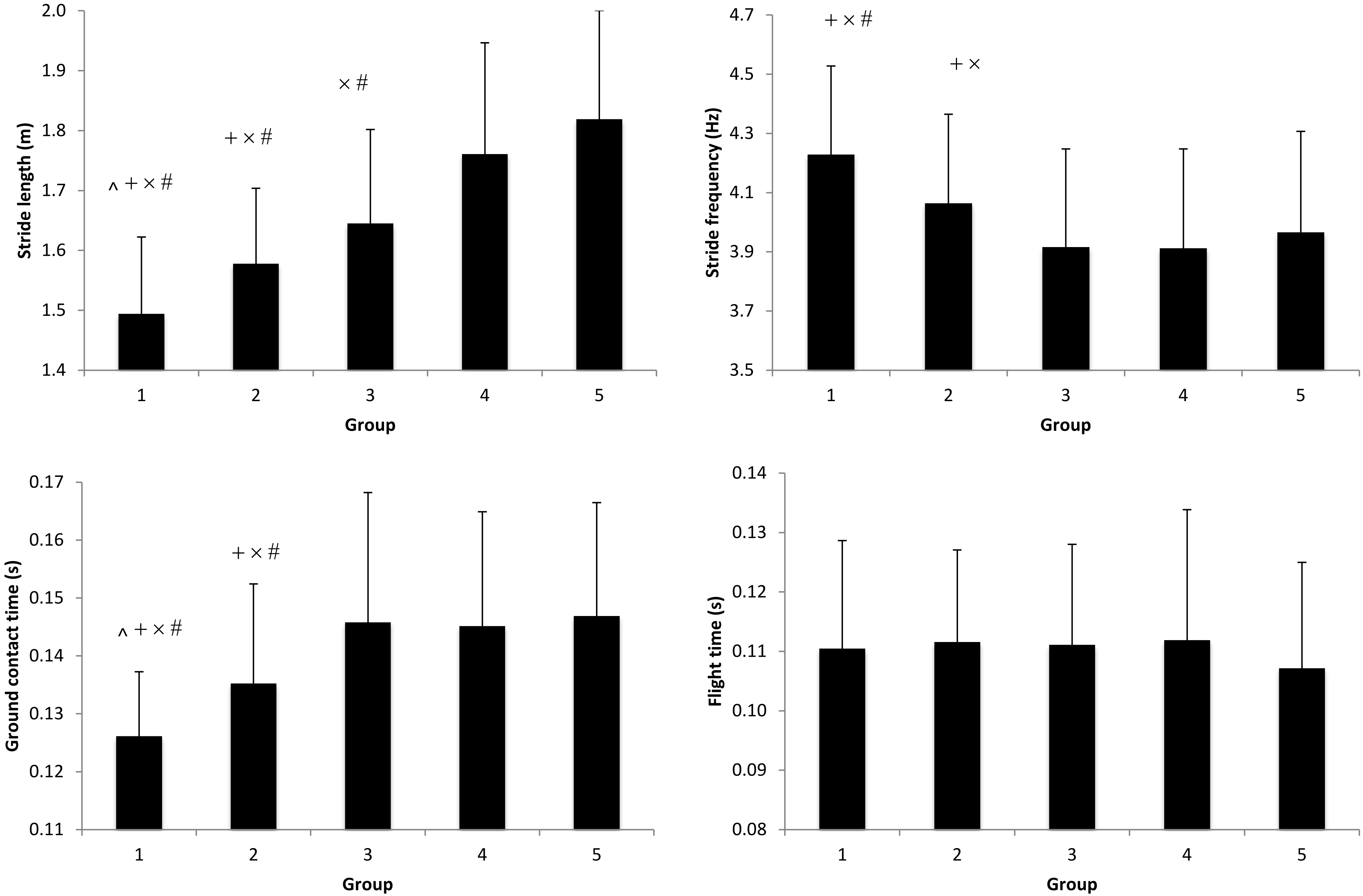

Figure 2. Data for stride length (SL), stride frequency (SF), contact time (CT) and flight time (FT) during the 15-30m zone of sprint test for the maturational groups. * Significantly different to P1, $p<0.05$; ^ Significantly different to P2, $p<0.05$; + Significantly different to P3, $p<0.05$; × Significantly different to P4, $p<0.05$; # Significantly different to P5, $p<0.05$.

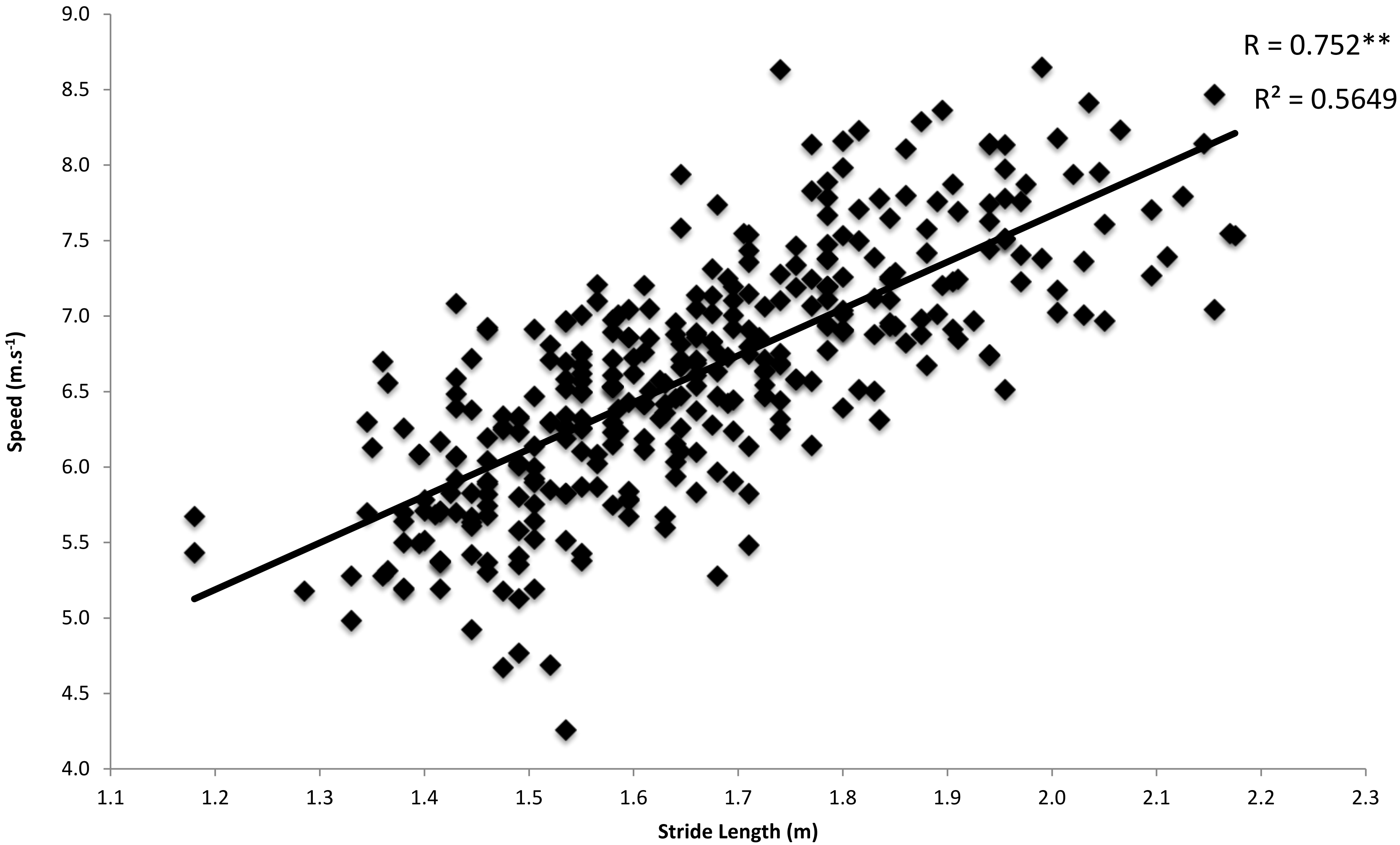

Figure 3. Pearson's correlation for Speed and Stride length. * Significant at p<0.05. ** Significant at p<0.01.

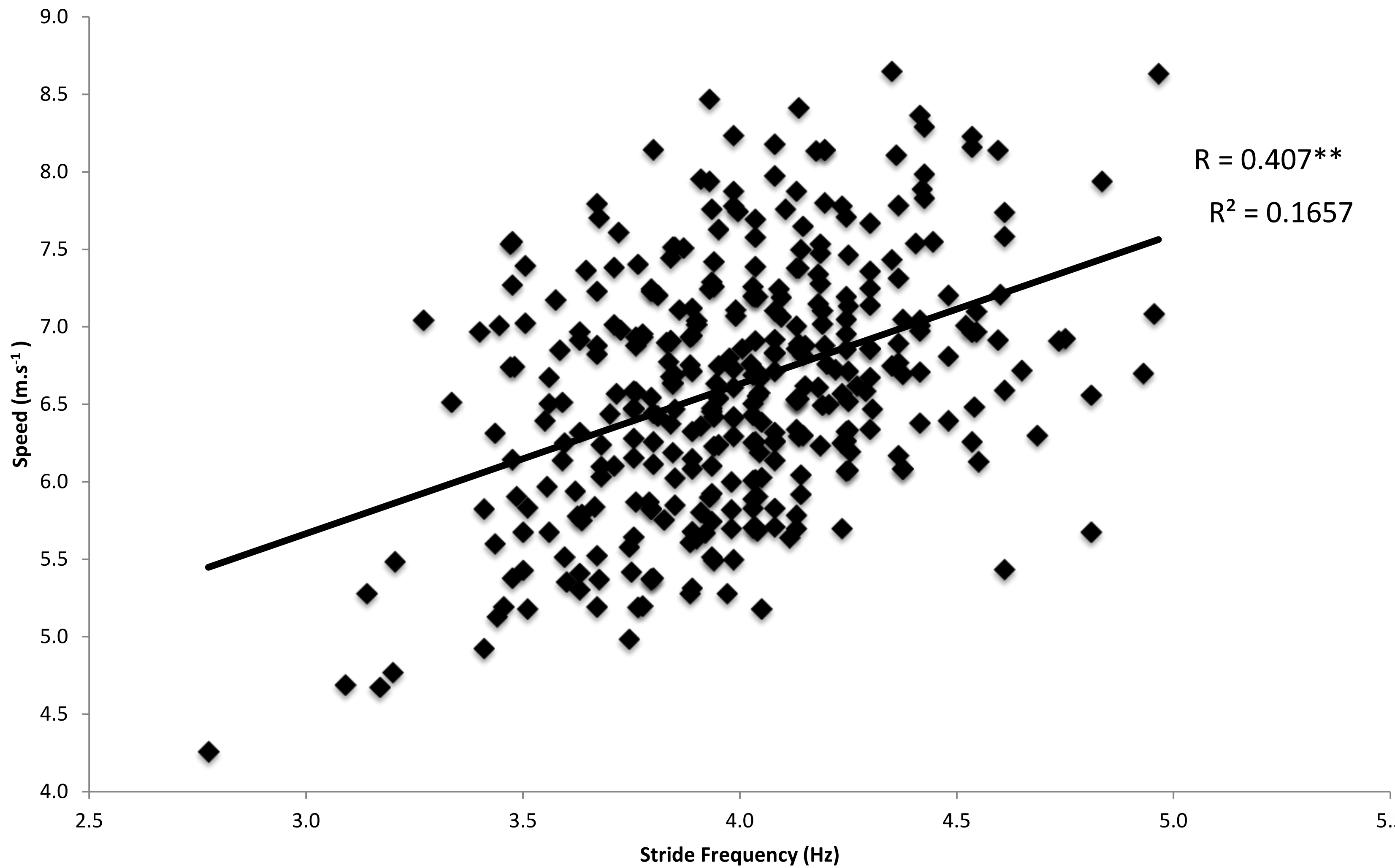

Figure 4. Pearson's correlation for Speed and Stride frequency. * Significant at p<0.05. ** Significant at p<0.01.

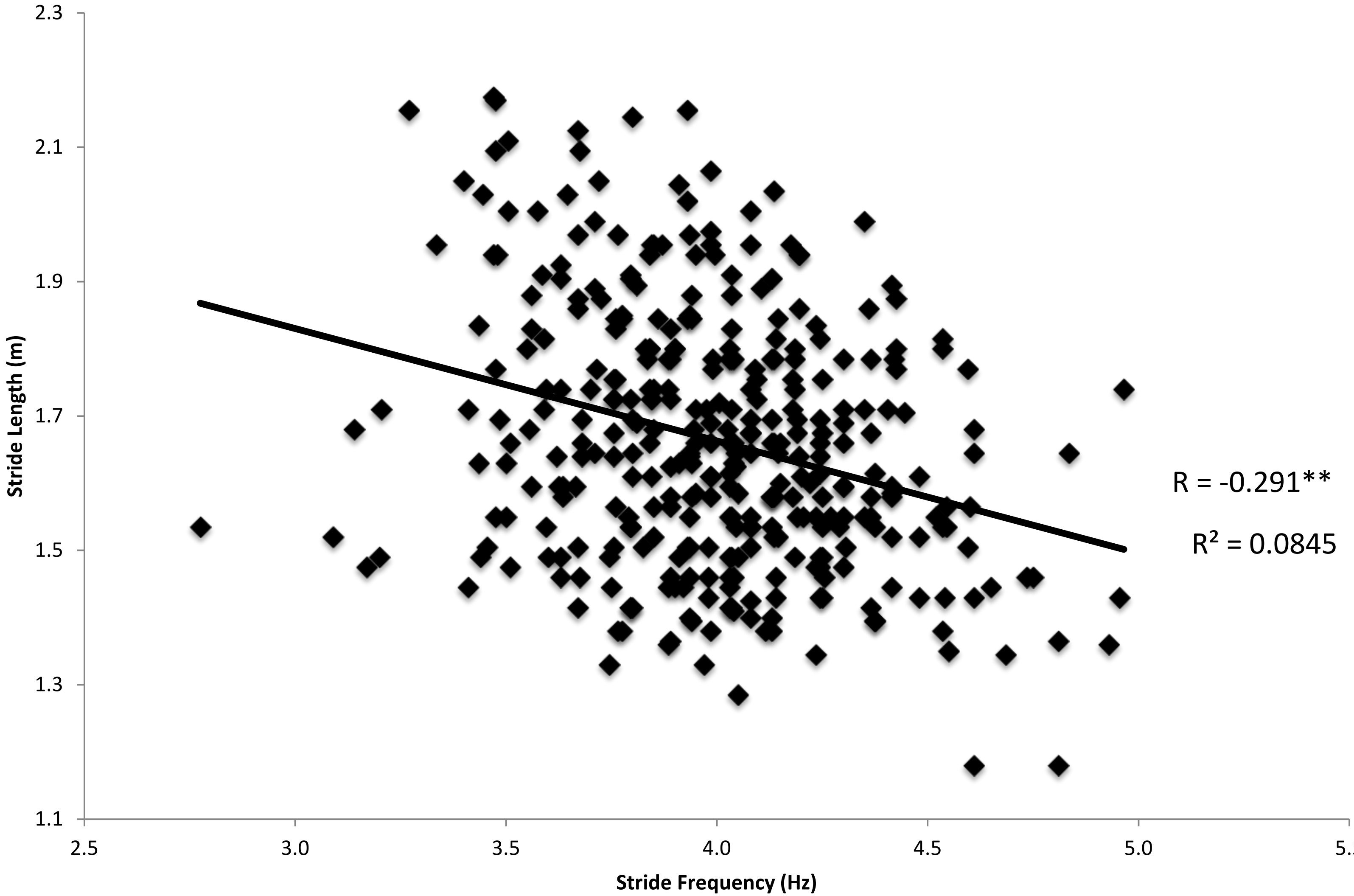

Figure 5. Pearson's correlation for Stride length and Stride frequency. * Significant at p<0.05. ** Significant at p<0.01.

Table 1. Descriptive characteristics of participants for the maturational groups (mean±SD).

Group	n	Age (years)	Age from Predicted PHV (years)	Standing Height (cm)	Mass (kg)	Leg Length (cm)
1	37	11.47 ± 0.35**	-2.80 ± 0.26**	139.1 ± 5.0**	33.8 ± 4.5**	68.2 ± 4.0**
2	106	12.17 ± 0.68**	-2.00 ± 0.28**	148.5 ± 4.7**	42.9 ± 7.6**	73.6 ± 4.1**
3	86	13.23 ± 0.76**	-0.99 ± 0.27**	157.4 ± 5.5**	51.6 ± 9.5**	78.3 ± 4.4**
4	61	14.28 ± 0.71**	0.00 ± 0.28**	164.7 ± 5.3**	59.9 ± 10.1**	82.0 ± 3.9**
5	48	14.98 ± 0.65**	0.97 ± 0.31**	171.8 ± 4.3**	68.4 ± 13.3**	84.6 ± 3.9*

* Significantly different to all other groups p<0.05.
** Significantly different to all other groups p<0.01.

Table 2. Pearson's correlations (r) between anthropometric characteristics, maturation and age with sprint characteristics

	Speed	Stride length	Stride Frequency	Contact Time	Flight Time
Standing Height	.379**	.626**	-.341**	.379**	-.017
Leg length	.343**	.609**	-.365**	.395**	-.013
Mass	.024	.215**	-.294**	.542**	-.262**
Age Predicted from PHV	.388*	.572**	-.254**	.334**	-.062

* Significantly different to all other groups p<0.05.
** Significantly different to all other groups p<0.01.