TITLE:

RELIABILITY OF THE SPATIOTEMPORAL DETERMINANTS OF MAXIMAL SPRINT SPEED IN ADOLESCENT BOYS OVER SINGLE AND MULTIPLE STEPS

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Abstract

The purpose of this study was to examine the reliability of the spatiotemporal determinants of maximal sprinting speed in boys over single and multiple steps. Fifty-four adolescent boys (age = 14.1 ± 0.7 years [range=12.9-15.7 years]; height = 1.63 ± 0.09 m; body mass = 55.3 ± 13.3 kg; -0.31 ± 0.90 age from Peak Height Velocity (PHV) in years; mean ± s) volunteered to complete a 30 m sprint test on three occasions over a two-week period. Speed, step length, step frequency, contact time and flight time were assessed via an optical measurement system. Speed and step characteristics were obtained from the single-fastest step and average of the two- and four-fastest consecutive steps. Pairwise comparison of consecutive trials revealed the coefficient of variation (CV) for speed was greater in 4-step (CV=7.3 & 7.5%) compared to 2-step (CV=4.2 & 4.1%) and 1-step (CV=4.8 & 4.6%) analysis. The CV of step length, step frequency and contact time ranged from 4.8-7.5% for 1-step, 3.8-5.0% for 2-step and 4.2-7.5% for 4-step analyses across all trials. An acceptable degree of reliability was achieved for the spatiotemporal and performance variables assessed in this study. Two-step analysis demonstrated the highest degree of reliability for the key spatiotemporal variables, and therefore may be the most suitable approach to monitor the spatiotemporal characteristics of maximal sprint speed in boys.

Key words

Step characteristics, Step length, Step frequency, Contact time, Adolescent.

Introduction

Sprint performance may be considered an important determinant of sporting success (8,33,26) and is also considered a fundamental component of athletic development programmes for youth athletes (1,22). Furthermore, sprinting is considered a fundamental movement skill that underpins successful and healthy physical development (24). For these reasons, assessments of sprint performance are common in talent identification batteries in youth sports and have been used to distinguish between elite and non-elite youth athletes (33,26).

Speed is the product of step length and step frequency (15), and whilst some debate exists regarding the interaction between these variables (9,15,37,39), the exploration into these factors is important for understanding of optimal sprint performance (5). In adults, it has been suggested that faster sprinters exhibit increased stride lengths through the application of greater ground reaction forces during shorter periods of ground contact (39). However, only a limited number of studies (25,34,38) have explored the spatiotemporal determinants of sprint performance in youth populations, with none exploring the reliability of these characteristics and how such data might be applied for tracking changes in performance. Meyers et al. (25) suggested that maturation may influence the relative importance of the determinants of speed. Specifically, they showed that sprint speed in young boys (pre peak height velocity) may be related to stride frequency while in older boys (post peak height velocity) performance is more related to stride length.

Methods for assessing sprinting speed in the literature have included over-ground running, non-motorised and torque treadmill techniques (35), with the literature suggesting that over-ground assessment of speed are the most reliable and commonly used method in youth populations (35). However, these data are often derived from electronic timing gate systems that measure only sprint time with no reference to the components of sprint performance. The use of optical measurement systems (21,5,25,40), and retrospective video analysis (15,4,37) are common methods to allow more detailed analysis of spatiotemporal sprint characteristics, yet only limited data are available from youth populations (25). The use of non-motorised treadmills may allow for determination of sprint kinetics and asymmetry in these variables (36) but methodological constraints seem to reduce their validity in paediatric populations due to the treadmill inertia; influence of body mass; elasticity of tethers used and ultimately the lower velocities achieved in youths compared to over-ground running (35,34,20).

While previous research has examined the reliability of sprint performance in youth populations (3,6,18,19), to the authors' knowledge no previous research has examined the reliability of spatiotemporal sprint mechanics at maximal speed in adolescent boys. Adolescence is a period of rapid change and sprint characteristics have been shown to fluctuate around this period (25). The time around the growth spurt can be associated with temporarily disrupted co-ordination (31) which may influence the reliability of sprint step characteristics. Optical measurement systems have been shown to produce reliable results for assessing jump height (11), motorized treadmill running performance (30), and for the measurement of step length and rate with elite male and female sprinters using a 40 m track (5). However, to the authors' knowledge no data exist to assess the reliability of this method in youth populations. Data pertaining to the reliability of the spatiotemporal characteristics of youth males would be important in order to establish appropriate magnitudes of change that allow for effective monitoring of sprint performance in boys (12).

Given the limited research into the reliability of sprint characteristics in youth, the aim of this study was to examine the reliability of the spatiotemporal determinants of maximal sprint speed in a population of boys.

Methods and Materials

Participants

Fifty-four school-aged boys (mean ± *s* [range]: age 14.1 ± 0.7 [12.9 - 15.7] yrs, height 1.64 ± 0.92 [1.42 - 1.82] m, mass 55.3 ± 13.3 [36.5 - 94.3] kg) agreed to participate in the study. Age from peak height velocity (PHV) was -0.31 ± 0.90 (range: -2.0 - +1.8) years, as predicted from anthropometric measures (27). Participants reported no injuries upon enrolling into the study and all regularly participated in twice-weekly physical education classes that were 60 minutes in duration. Data pertaining to habitual and sporting activities of the participants outside of school curriculum time were not collected. The project received ethical approval by the University's Research Ethics committee and both participant assent and parental consent were obtained prior to testing.

Procedures

Testing took place over a two-week period and required participants to attend three scheduled testing sessions, separated by a minimum of 24 hrs. All testing sessions took place during physical education classes, in the same indoor facility. All participants were instructed to wear the same clothing and footwear, asked to refrain from physical activity 24 hours before testing and to refrain from eating one hour prior to testing. Participants were provided with the opportunity to familiarize themselves with the test equipment and the protocol used prior to the first testing session.

Sprint test. The sprint test was administered using procedures previously reported for assessing adolescent boys (25), whereby participants performed a maximal sprint over a 30 m track. A finish line was established at 35 m to encourage participants to continue maximal sprinting throughout the 15-30 m data collection zone of the sprint where measurements were recorded. This distance was selected based on evidence that the majority of trained youth soccer players achieved maximal speed inside 35 m (2). 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 50 cm behind the starting line. Participants were given the instructions “Ready” and “Go”, and verbal encouragement was given throughout the test to encourage maximal effort. All tests were undertaken individually and a minimum of four minutes rest was given between trials to ensure sufficient recovery.

Sprint test variables. The assessment of sprint characteristics was made via an optical measurement system (Optojump, Microgate, Italy) positioned at floor level in the 15-30 m data collection zone of the sprint track. Data for the sprint characteristics were instantaneously collected to an accuracy of 1/1000 s using a Windows XP laptop via specialist Optojump software (Microgate, Italy), and subsequently exported to Microsoft Excel for data processing. High levels of reliability and validity have previously been reported for the use of optical measurement systems during the assessment of jump performance [ICC: 0.982-0.989, CV: 2.7%;(11)] and also the measurement of spatiotemporal running characteristics

[ICC: 0.87-0.98, CV: 0.6-5.5%;(30)] 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 (step length) and the time taken (s) between these contacts (flight time + contact time). Units are expressed as distance per unit time ($m.s^{-1}$).
- *Step length:* The distance (m) between the foot tip of alternate foot contacts (i.e. the distance between left and right foot contacts).
- *Step frequency:* The rate (Hz) of lower limbs movements as defined by the number of steps taken per second.
- *Contact time:* 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:* The amount of time (s) between alternate foot contacts, where the participant is not in contact with the floor.

Sprint test data processing. Data for all steps completed within the 15-30 m data collection zone were recorded for participants over their two sprint trials. Subsequently all data corresponding to the single fastest step over the two trials was extracted for the 1-step analysis. Similarly, all data corresponding to the two fastest and four fastest consecutive steps were extracted for 2-step and 4-step analysis, respectively. If a participant was deemed to have obtained their fastest steps from the last or first foot contact recorded in the 15-30 m data collection zone, then their data were excluded from the analysis. This exclusion was enforced to remove those participants who had already achieved maximal speed prior to the data collection zone, and also those who were still accelerating at the end of the data collection zone, thereby resulting in data from only those participants achieving maximal speed between 15-30 m. Sixty-six participants were originally tested, with 12 removed as a result of these criteria, resulting in 54 participants being taken forward for statistical analysis. No statistical differences in physical characteristics or maturity existed between those included and those excluded based on these criteria.

Statistical Analyses

Means and standard deviations were calculated for all variables over 1, 2 and 4-steps, with a repeated-measures analysis of variance (ANOVA) used to assess if there were differences between the 1, 2 and 4 step data. Where required, Tukey's HSD test was used to highlight significant pair-wise differences. Mauchly's test for sphericity was used to ensure non-violation of the respective assumptions and, where violated, a Greenhouse-Geiser adjustment was implemented. Test-to-test reliability was assessed for all variables through change-in-the-mean, intra-class correlation and the co-efficient of variation. Ninety-five percent confidence intervals were reported for all test variables. The typical error and smallest worthwhile effect were also calculated and the ratio between the two used to represent the sensitivity of each variable as a noise:signal ratio (41). The smallest worthwhile effect was calculated as 0.2 of the between-participant standard deviation either between consecutive trials or across all trials to provide an overall value (13). Change in mean, coefficient of variation, typical error and limits of agreement were calculated for consecutive trials using an online spreadsheet (14) using Microsoft Excel for Mac 2011. This spreadsheet also provided a mean typical error across all three trials to allow calculation of the noise:signal ratio. The repeated measures ANOVA was processed using IBM SPSS statistics v20, with all significance values accepted where $p < 0.05$.

Results

Mean and standard deviations for all variables assessed during the 1, 2- and 4-step analyses over the three testing occasions are presented in Table 1. The highest speed was observed in the 1-step analysis, with significant decreases in the 2-step and 4-step analysis across tests 1, 2 and 3 ($F_{2,106} = 197.37$, $p < .05$; $F_{2,106} = 58.74$, $p < .05$; $F_{2,106} = 114.52$, $\mathrm{p} < .05$, respectively). Furthermore, for the 1-step analysis there was no observed systematic bias in speed ($F_{2,106} = 0.02$, $p > .05$), step length ($F_{2,106} = 2.07$, $p > .05$) and step frequency ($F_{2,106} = 1.87$, $p > .05$), with no significant differences observed between tests 1, 2 and 3. For the two-step analysis, significantly lower speed and shorter stride length were noted between tests 1-2 ($p < .05$), although no significant differences were observed in test 3 compared to all other tests ($p > .05$). No significant differences were observed during the 2-step analysis for stride frequency ($F_{2,106} = 0.75$, $p > .05$), contact time ($F_{2,106} = 2.92$, $p > .05$) and flight time ($F_{2,106} = 1.35$, $p > .05$) across all testing occasions. A similar pattern was observed for the 4-step analysis, where significantly lower speed and shorter step length were observed from tests 1-2 ($p < .05$) before significant increases in both variables between tests 2-3 ($p < .05$).

Table 1. Mean and standard deviation data from Optojump tests analysed over 1-, 2- and 4-steps.

	Mean $\pm$ Standard Deviation		
	Test 1	Test 2	Test 3
One step			
Speed ($m.s^{-1}$)	7.290 ± 0.752	7.295 ± 0.822	7.284 ± 0.730
Step Length (m)	1.80 ± 0.17	1.78 ± 0.16	1.76 ± 0.14
Step Frequency (Hz)	4.06 ± 0.28	4.11 ± 0.34	4.13 ± 0.33
Contact Time (s)	0.137 ± 0.015	0.138 ± 0.018	0.133 ± 0.016$^{*\wedge}$
Flight Time (s)	0.110 ± 0.014	0.106 ± 0.014	0.110 ± 0.016
Two step			
Speed ($m.s^{-1}$)	7.076 ± 0.728	6.939 ± 0.743*	7.038 ± 0.700
Step Length (m)	1.79 ± 0.16	1.74 ± 0.14*	1.76 ± 0.15
Step Frequency (Hz)	3.96 ± 0.26	3.98 ± 0.33	4.00 ± 0.30
Contact Time (s)	0.140 ± 0.015	0.141 ± 0.016	0.138 ± 0.014
Flight Time (s)	0.114 ± 0.015	0.111 ± 0.016	0.114 ± 0.013
Four step			
Speed ($m.s^{-1}$)	6.991 ± 0.725	6.617 ± 0.827*	6.925 ± 0.704$^{*\wedge}$
Step Length (m)	1.78 ± 0.15	1.69 ± 0.18*	1.75 ± 0.14$^{*\wedge}$
Step Frequency (Hz)	3.93 ± 0.25	3.92 ± 0.34	3.96 ± 0.28
Contact Time (s)	0.142 ± 0.014	0.144 ± 0.018	0.140 ± 0.015$^{\wedge}$
Flight Time (s)	0.114 ± 0.013	0.113 ± 0.014	0.113 ± 0.014

* Significantly different to test 1 ($p \leq 0.05$), ^ Significantly different to test 2 ($p \leq 0.05$).

The change in the mean, intra-class correlation, coefficient of variation and limits of agreement across all tests of the step analyses can be observed in Table 2. The between-test differences observed in Table 1 are reflected in the change of mean presented in Table 2. Notably there were negligible changes in the mean across the three testing occasions for the 1-step analysis and substantial changes in the mean in the 4-step analysis, which were two-three fold greater than the changes observed for the 2-step analysis. The coefficient of variation for speed over the three tests was similar for both the 1- and 2-step analyses (4.1-4.8%), yet greater in the 4-step analysis (7.3-7.5%). Overall the 2-step analysis was found to have the lowest coefficient of variation for speed, step length, and step frequency (3.8-4.6%), with 1-step analysis showing a similar range (4.6-5.4%) and clear overlap in the 95%

confidence intervals between the 1- and 2-step analyses. The 95% confidence intervals for speed during the 4-step analysis were outside the ranges of the same variable during the 1- and 2-step analyses. Overall the 2-step analysis was found to have the highest intra-class correlations for speed, stride length and contact time variables ($r = .79$-$.86$). Furthermore, 1-step analysis also demonstrated good levels of consistency for speed, step length and contact time ($r = .66$-$.81$). Step frequency, contact time and flight time were most consistent variables during the 4-step analysis ($r = .52$-$.86$).

The noise/signal ratio data in Table 3 highlights that speed in the 2-step analysis was the only variable to achieve a ratio <2 over all tests (1.89-1.92), with all other variables in the 2-step analysis from all other analyses ranging from 2.19-4.33.

Table 2. Change in the Mean, coefficient of variation, intra-class correlations (95% confidence intervals in brackets) and limits of agreement from Optojump tests analysed over 1-, 2- and 4-steps.

	Change in Mean		Coefficient of Variation (%)		Intra-class Correlation		95% Limits of Agreement	
	T2-1	T3-2	T2-1	T3-2	T2-1	T3-2	T2-1	T3-2
One step								
Speed (m.s^{-1})	0.008 (-0.128:0.139)	-0.012 (-0.143:0.120)	4.8 (4.0:6.0)	4.6 (3.9:5.8)	0.81 (0.70-0.89)	0.81 (0.70:0.89)	0.005 ± 0.958	-0.012 ± 0.944
Step Length (m)	-0.02 (-0.06:0.01)	-0.01 (-0.04:0.02)	4.8 (4.1:6.0)	4.9 (4.1:6.1)	0.74 (0.59:0.84)	0.67 (0.49:0.79)	-0.02 ± 0.24	-0.01 ± 0.24
Step Frequency (Hz)	0.05 (-0.03:0.14)	0.02 (-0.06:0.10)	5.6 (4.7:6.9)	5.4 (4.5:6.7)	0.51 (0.28:0.68)	0.61 (0.41:0.75)	0.05 ± 0.62	0.02 ± 0.59
Contact Time (s)	0.001 (-0.003:0.005)	-0.005 (-0.009:-0.001)	6.9 (5.7:8.5)	7.5 (6.3:9.3)	0.69 (0.52:0.81)	0.66 (0.48:0.79)	0.001 ± 0.026	-0.005 ± 0.028
Flight Time (s)	-0.004 (-0.008:0.001)	0.004 (-0.001:0.009)	11.9 (9.9:14.9)	12.2 (10.1-15.2)	0.29 (0.03:0.52)	0.28 (0.02:0.51)	-0.004 ± 0.034	0.004 ± 0.036
Two step								
Speed (m.s^{-1})	-0.137 (-0.246:-0.028)	0.099 (-0.006:0.204)	4.2 (3.5:5.2)	4.1 (3.4:5.0)	0.86 (0.77:0.91)	0.86 (0.77:0.92)	-0.137 ± 0.782	0.099 ± 0.756
Step Length (m)	-0.05 (-0.07:-0.02)	0.02 (0.00:0.05)	3.9 (3.3:4.9)	3.8 (3.2:4.7)	0.80 (0.67:0.88)	0.79 (0.67:0.88)	-0.05 ± 0.19	0.02 ± 0.18
Step Frequency (Hz)	0.02 (-0.04:0.09)	0.01 (-0.05:0.07)	4.6 (3.9:5.7)	4.0 (3.3:4.9)	0.66 (0.48:0.79)	0.77 (0.63:0.86)	0.02 ± 0.49	0.01 ± 0.42
Contact Time (s)	0.001 (-0.002:0.004)	-0.003 (-0.006:0.000)	5.0 (4.2:6.3)	4.8 (4.0:5.9)	0.80 (0.68:0.88)	0.81 (0.69:0.88)	0.001 ± 0.020	-0.003 ± 0.019
Flight Time (s)	-0.003 (-0.008:0.002)	0.003 (-0.001:0.007)	12.6 (10.5:15.8)	10.4 (8.7:13.0)	0.28 (0.01:0.51)	0.49 (0.26:0.67)	-0.003 ± 0.036	0.003 ± 0.029
Four step								
Speed (m.s^{-1})	-0.374 (-0.547:-0.200)	0.308 (0.127:0.488)	7.3 (6.1:9.1)	7.5 (6.3:9.4)	0.67 (0.50:0.80)	0.64 (0.45:0.77)	-0.374 ± 1.247	0.308 ± 1.294
Step Length (m)	-0.09 (-0.13:-0.05)	0.06 (0.02:0.10)	6.6 (5.5:8.2)	7.2 (6.0:9.0)	0.63 (0.44:0.77)	0.52 (0.29:0.69)	-0.09 ± 0.28	0.05 ± 0.31
Step Frequency (Hz)	-0.01 (-0.07:0.05)	0.04 (-0.02:0.10)	4.2 (3.5:5.3)	4.3 (3.6:5.3)	0.72 (0.57:0.83)	0.74 (0.60:0.84)	-0.01 ± 0.44	0.04 ± 0.44
Contact Time (s)	0.002 (-0.001:0.005)	-0.004 (-0.006:-0.001)	4.6 (3.8:5.7)	4.3 (3.6:5.3)	0.83 (0.72:0.90)	0.86 (0.77:0.92)	0.002 ± 0.019	-0.004 ± 0.017
Flight Time (s)	-0.001 (-0.005:0.003)	0.000 (-0.003:0.004)	8.4 (7.0:10.5)	8.5 (7.1:10.6)	0.52 (0.29:0.69)	0.55 (0.33-0.71)	-0.001 ± 0.027	0.000 ± 0.026

Table 3. Typical error, smallest worthwhile change and noise:signal ratio from Optojump tests analysed over 1-, 2- and 4-steps.

	Typical Error *(Noise)*			Smallest Worth While Change *(Signal = 0.2*SD)*			Noise/Signal Ratio		
	T2-1	T3-2	Mean	T2-1	T3-2	Overall	T2-1	T3-2	Overall
One step									
Speed ($m.s^{-1}$)	0.345	0.341	0.343	0.157	0.155	0.153	2.20	2.20	2.24
Step Length (m)	0.09	0.09	0.09	0.03	0.03	0.03	2.71	3.00	2.85
Step Frequency (Hz)	0.22	0.21	0.22	0.06	0.07	0.06	3.51	3.15	3.47
Contact Time (s)	0.009	0.010	0.010	0.003	0.003	0.003	2.65	2.94	2.94
Flight Time (s)	0.012	0.013	0.013	0.003	0.003	0.003	4.29	4.33	4.33
Two step									
Speed ($m.s^{-1}$)	0.282	0.273	0.277	0.147	0.144	0.144	1.92	1.89	1.92
Step Length (m)	0.07	0.07	0.07	0.03	0.03	0.03	2.33	2.45	2.36
Step Frequency (Hz)	0.18	0.15	0.16	0.06	0.06	0.06	3.04	2.40	2.71
Contact Time (s)	0.007	0.007	0.007	0.003	0.003	0.003	2.19	2.33	2.19
Flight Time (s)	0.013	0.011	0.012	0.003	0.003	0.003	4.33	3.67	4.00
Four step									
Speed ($m.s^{-1}$)	0.450	0.467	0.458	0.159	0.156	0.153	2.83	2.99	2.99
Step Length (m)	0.10	0.11	0.11	0.03	0.03	0.03	2.91	3.35	3.40
Step Frequency (Hz)	0.16	0.16	0.16	0.06	0.06	0.06	2.72	2.59	2.76
Contact Time (s)	0.007	0.006	0.007	0.003	0.003	0.003	1.88	2.19	2.19
Flight Time (s)	0.010	0.009	0.009	0.003	0.003	0.003	3.57	3.21	3.21

Discussion

It would seem from the results of this study that both speed and its spatiotemporal determinants obtained via an optical measurement system exhibit acceptable levels of reliability, with all variables in 1-, 2- and 4-step analysis, except flight time, possessing coefficients of variation below the 10% level often used to determine test reliability (16,23). Such findings are important owing to the lack of published data related to the measurement error using optical measurement system for the assessment of spatiotemporal sprint characteristics in boys.

Although the co-efficient of variation (CV) in spatiotemporal measures during the 4-step analysis were below the 10% threshold for most variables, 4-step analysis may be deemed the least reliable measure owing to the fact that speed and step length were substantially more unreliable when compared to 1- and 2-step analyses. Additionally, the intra-class correlations and change in the mean between testing occasions would seem to indicate the potential for greater systematic bias and greater variability in the 4-step analysis when compared to the other step analyses. Cumulatively these data result in wider limits of agreement with large amounts of systematic bias, and on that basis the use of a 4-step analysis to establish spatiotemporal variables associated with maximal sprinting in adolescent boys is discouraged. There was some evidence of systematic bias during trial two during the 2-step analysis. Such systematic bias is difficult to rationalise, although importantly such bias was not evident when a third test was included, and was not evident in the 1-step analysis. Combined with low levels of random variation it is suggested that the use of 1- and 2-step analysis are the best approaches to elicit satisfactory levels of reliability.

The CV for speed during the 1- and 2-step analysis were marginally higher, yet the intra-class correlation values were comparable (ICC $\leq$ 0.82-0.98, CV $\geq$ 0.83-1.91%) to previous studies where speed was assessed (3,7). However, in both studies photo-electric timing gates were used with athletic populations rather than a ground level optical measurement system with a general population as used here, making direct comparisons between studies difficult. Furthermore, the present study sought to establish maximal speed from single or multiple steps at any point during the 15-30 m data collection zone, rather than establish reliability of distance-specific split times during a 0-30 m sprint. Whilst, it is accepted that split-times from photo-electric timing gates are reported as highly reliable (35), the level of information gathered about the spatiotemporal characteristics of the sprint is not comparable with the methods employed in the current study. Finally, and most importantly, the age range in the present study represented a sample that included the period of adolescence (mean age from PHV = -0.31 ± 0.90 years). Variability in explosive jump performance is known to be greater in children and adolescents compared to adults (10). Therefore some of the variability evident in the current study may result from a combination of focusing on maximal speed measures rather than split times, and the selection of an adolescent population where more variable motor control may be evident (29).

With reference to the other spatiotemporal variables, it was noted that in the 1- and 2-step analyses, all variables produced reasonable levels of reliability with coefficients of variation <7.5%, except for flight time (CV = 10.4-12.6%). Whilst the importance of step length and step frequency in relation to sprint performance is well established, the contribution of these variables to acceleration and maximal speed sprint performance in different populations still remains an area of debate (39,15,28).

Furthermore, the good reliability evident in the contact time variable during all analyses is important due to the impact of reduced contact time upon subsequent step frequency (39,28). Interestingly, data from this study reports higher CV values for flight time and contact time than for step frequency, despite step frequency being a product of flight and contact time. Such an observation may support the fact that male youth self-regulate their step frequency by the manipulation of flight and contact time, although such a conclusion warrants further investigation.

Although speed had good reliability in the 1-step analysis, step frequency had higher variability within the same analysis. The impact of step frequency on sprint speed has also been demonstrated in boys who were of a similar maturational status (25), with the suggestion that the stabilization of step frequency with advancing maturation might be a stimulus for improved sprint performance.

The use of the 1-step analysis may also prove useful for the assessment of spatiotemporal asymmetries. Previous authors have suggested average asymmetries assessed over 30 m on a non-motorised treadmill were around 17% in a population of boys around peak height velocity (36). With such a high degree of variability evident in this population, and the reported link between asymmetry and injury (17), the use of 1-step analysis for the exploration of spatiotemporal asymmetry in boys seems worthy of further research.

Finally, the noise and signal ratios shown in Table 3 provide useful insight into the use of the spatiotemporal sprint determinants for monitoring changes in athletic performance (12). Although none of the spatiotemporal variables achieved noise values less than the signal, speed in the 2-step analysis achieved a typical error of measurement less than twice the smallest worthwhile change and all variables elicited noise:signal ratios less than four. A previous study has reported noise:signal ratios for sprint activities of adults during soccer simulations between 1.5-2.5 (41); the slightly higher noise:signal ratios in the current study may be due to the measurement of maximal speed (and not sprint time) and use of an adolescent population in the current study. Importantly, a previous study has reported typical changes in maximal speed of 0.77 m/s with increases in maturation from -1 to +1 years peak height velocity (25), demonstrating observed changes that are greater than the smallest worthwhile change and substantially greater than twice the typical error in boys around the period of adolescence. Consequently, the spatiotemporal data quantified in this study provide sufficient reliability to accurately monitor changes in maximal speed related to changes in growth and maturation in boys. The simple and brief nature of sprinting also allows the option of taking a mean value across more trials to reduce the level of noise, where random variation will be reduced by a factor of 1/√number of trials (32). For example, repeating the procedures three times and taking a mean value would reduce random variability by a factor of 0.57 and reduce the noise:signal ratios to <2 for all 1-step and 2-step variables.

A limitation of this study may be the information gathered regarding participants habitual and sporting activities outside of the physical education curriculum. These data were not collected, and as such it is not possible to determine the variation in training age throughout the sample and to determine the influence of these data upon the reliability of spatiotemporal determinants of sprint performance.

In conclusion, this study has added to the limited data pertaining to the reliability of field-based assessment of the spatiotemporal determinants of maximal sprint performance. Using analyses over 1-, 2- and 4-steps acceptable levels of reliability were found for speed, step length, step frequency and contact times. One- and 2-step analyses are deemed the most suitable approaches for scientists and coaches to make reliable assessments of spatiotemporal sprint characteristics using the proposed methodology. Whilst the 2-step analysis may have the lowest levels of random variation, the 1-step may facilitate the reliable assessment of spatiotemporal asymmetries in sprinting. The levels of random variation and noise:signal ratio during the 2-step analysis were deemed acceptable to monitor changes in maximal sprint speed and the associated spatiotemporal characteristics around the adolescent growth spurt in boys.

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