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The Reliability of Force-Velocity-Power Profiling During Over-Ground Sprinting in Children and Adolescents

Abstract

Anaerobic performance in youth has received little attention partly due to the lack of a 'gold-standard' measurement. However, force-velocity-power (F-v-P) profiling recently showed high reliability and validity in trained adults. Therefore, the aim was to determine the reliability of F-v-P profiling in children. Seventy-five children (60 boys, 15 girls; age: 14.1 ± 2.6 years) completed three 30 m sprints. Velocity was measured at 46.875 Hz using a radar device. The F-v-P profile was fitted to a velocity-time curve allowing instantaneous power variables to be calculated. Reliability was assessed using the intra-class correlation coefficient (ICC), coefficient of variation (CV), standard error of measurement (SEM) and smallest worthwhile change (SWC). High reliability was evident for absolute peak (P_{peak}) and mean power (P_{mean}), P_{peak} and P_{mean} expressed relative to body mass, peak and mean velocity, 30 m sprint time, peak horizontal force (F_0), relative F_0, mechanical efficiency index and fatigue rate (ICC: 0.75 – 0.88; CV: 1.9 – 9.4%) with time to peak power demonstrating moderate reliability (ICC: 0.50; CV: 9.5%). The F-v-P model demonstrated at least moderate reliability for all variables. This therefore provides a potential alternative for paediatric researchers assessing sprint performance and the underlying kinetics.

Key Words: Reliability, Maturity, Sprinting, Training

Introduction

Anaerobic parameters, such as peak power and maximal velocity, have received relatively little attention within the paediatric literature, especially when compared to aerobic parameters (peak oxygen uptake ($\dot{V}O_2$ peak) and gas exchange threshold). This is, at least in part, due to a lack of a ‘gold standard’ measure (Matos & Winsley, 2007; Ratel, Duche, & Williams, 2006; Van Praagh, 2000) and researchers predominantly considering anaerobic ability as a performance measure as opposed to a health-related outcome (Gormley et al., 2008; Knowles, Herbert, Easton, Sculthorpe, & Grace, 2015). Indeed, the lack of consensus surrounding the optimal test to quantify anaerobic performance has resulted in a plethora of tests being developed, including: the 30 s cycling Wingate (WnT) (Beneke, Hutler, & Leithauser, 2007; Hebestreit, Dunstheimer, Staschen, & Strassburg, 1999; Naughton, Carlson, & Fairweather, 1992), sprint running (Maliszewski & Freedson, 1996; Rumpf, Cronin, Oliver, & Hughes, 2015; Rumpf, Cronin, Pinder, Oliver, & Hughes, 2012; Zagatto, Beck, & Goratto, 2009), counter-movement jumps (Ingle & Tolfrey, 2013), standing long jump (Baquet, Berthonin, Gerbeaux, & Van Praagh, 2001) and other types of vertical jump (Doré, Bedu, & Van Praagh, 2008; Baquet et al., 2001; Ingle & Tolfrey, 2013; Rumpf, Cronin, Oliver, & Hughes, 2011). Such diverse methodologies have limited inter-study comparisons due to the different outcome measures they provide, and the difficulties surrounding the transferability of performance across athletic events. Subsequently, the ability to draw firm conclusions regarding anaerobic development in youth, and the concomitant influences of growth, maturation, and training interventions remain unclear.

The cycling WnT test has been extensively used in paediatric populations and remains a popular method of anaerobic performance assessment given its ability to account for body size, by removing the weight bearing nature of performance. The ability to account for body size differences is seen as critical to the interpretation of results during the pubescent growth spurt where body mass is accumulated rapidly and differentially between sexes (Fellmann & Coudert, 1994; Roemmich, Richmond, & Rogol, 2001). However, methodological concerns have been raised surrounding optimal flywheel resistance (Doré et al., 2003; Watt, Hopkins, & Snow, 2002), the reliance on only two tests to assess reliability (Hopkins, 2000; Watt et al., 2002) and the use of inappropriate statistical models (Hopkins, Marshall, Batterham, & Hanin, 2009; Hopkins, Schabort, & Hawley, 2001). Thus, an anaerobic measure is needed which not only retains high specificity to athletic events (Rumpf et al., 2011), but can be conducted easily in field settings (Hopkins et al., 2001) and shares a close affinity with children's typical play structure (Pawlowski, Andersen, Troelsen, & Schipperijn, 2016), all three of which the WnT fails to provide.

Due to the methodological concerns regarding the cycling WnT test, over recent years over-ground sprinting has become an increasingly popular measurement of short-term anaerobic performance assessment in paediatric populations (Bongers et al., 2015; Rumpf, Cronin, Oliver, et al., 2015). Sprint running analysis can provide estimates of power output alongside velocity, giving more complete measures of anaerobic performance. Indeed, simple data collection methods coupled with macroscopic biomechanical models enable the quantification of the underlying kinetics. Specifically, Samozino et al. (2016) recently developed a macroscopic force-velocity-power (F-v-P) model, based on the fundamental laws of motion, to derive a continuous measure of power output during a single maximal sprint utilising a mono-exponential representation of the velocity-time curve and basic anthropometric data. The extracted variables of peak power (P_{peak}), time to peak power (t_P_{peak}), peak power relative to body mass (R_P_{peak}), mean power (P_{mean}), relative mean power (R_P_{mean}), peak horizontal force (F_0), relative peak horizontal force (R_F_0), mechanical efficiency index (D_{RF}), peak velocity (v_0), mean velocity (v_{mean}) and 30 m sprint time (t30) demonstrated high test-retest reliability in a cohort of trained adult sprinters (Samozino et al., 2016).

Despite Samozino et al. (2016) reporting high reliability for all parameters, a second study examining the reliability of F-v-P profiling, conducted in young adult male rugby union players (n = 27; age: 18.6 ± 0.6 years), reported only moderate reliability for all power variables (P_{peak}, R_P_{peak}, P_{mean}, R_P_{mean}; Simperingham, Cronin, Pearson, & Ross, 2017). The different populations with which the studies were conducted may explain the reliability differences, as highly trained adult sprinters would be expected to be able to replicate maximal bouts more consistently than moderately trained athletes (Simperingham et al., 2017). However, the reliability of these measures is also likely to be influenced by additional factors, such as the specific sprinting protocol utilised and environmental factors (e.g. wind speed and direction, temperature), limiting inter-study comparisons necessitating further work to elucidate the reliability in populations of interest. Indeed, studies to date are unlikely to be generalisable to paediatric populations who are not-mini adults and are still developing running as a fundamental movement skill with the movement consequently being more variable (Armstrong, 2007). Therefore, the aim of this study was to determine the reliability of F-v-P profiling in sub-elite, paediatric populations using velocity data obtained from a radar device.

Methods

Participants

Following parental/guardian consent and child assent, 75 children and adolescents (60 boys; 15 girls) participated in the study. Specifically, the study consisted of thirteen trained long-distance runners (age = 13.4 ± 2.9 years), 14 trained footballers (age = 14.3 ± 3.2 years), 37 trained hockey players (age = 15.1 ± 1.2 years, girls = 15) and 11 untrained controls (age = 13.7 ± 3.2 years). Ethical approval was obtained from Swansea University and conformed to the Declaration of Helsinki.

Anthropometric Measurements

All participants were required to visit the laboratory where standing, sitting height (both m) and body mass (kg) were measured using a Holtain stadiometer (Holtain, Crymych, Dyfed, UK) and electronic scales (Seca 803, Seca, Chino, CA, USA), respectively. Maturation was assessed using Tanner pubic hair stages (Marshall & Tanner, 1970), with individual maturity offset calculated according to the equation of (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002).

Sprinting Protocol

All participants undertook a standardised 5-minute, low-intensity, running warm up prior to the sprint protocol. Subsequently, all participants completed one maximal 30 m sprint, acting as a familiarisation trial before the three sprint trials. The three trials were all conducted over 35 m to minimise premature deceleration before the end of the sprint, allowing the mono-exponential function to accurately represent the sprint. All sprints were conducted from a two-point start so that vertical displacement during the early part of the sprint was minimised (Mero, Komi, & Gregor, 1992), and participants were instructed to start sprinting with auditory cues (“3….2….1…GO”). All trials were conducted outdoors on a surface that the athletes were used to competing on (Hockey: AstroTurf, Controls and Footballers: Grass, Runners: Track) with the average air temperature and wind speed of 10.2 ± 1.4ºC and 3.1 ± 1.8 $m \cdot s^{-1}$ respectively. During all sessions, the participants ran with the prevailing wind coming from behind to control the effects on sprint performance and the resulting reliability analysis. A radar gun (STALKER RADAR II, Plano, Texas, USA) was mounted on a tripod and positioned 10 m behind the start line to record the raw velocity of the participants over the 30 m distance at a sampling rate of 46.875 Hz. All participants completed three maximal sprints to determine intra-day reliability, in line with previous recommendations (Hopkins, 2000), with at least 3 minutes rest between each sprint.

Biomechanical Modelling

An overview of the biomechanical data processing will be described in this paper; a full description is available in the original research (Samozino et al., 2016). Prior to any processing, the first 0.3 seconds of the trial was deleted in alignment with previous recommendations (Samozino, 2018). The raw velocity-time data from the radar gun was then modelled with a mono-exponential curve to produce a horizontal velocity (v_H) - time (t) profile, as over-ground running acceleration has been shown to follow this mono-exponential profile in recreational through to elite athletes (Morin, Edouard, & Samozino, 2011; Morin, Jeannin, Chevallier, & Belli, 2006). Following integration displacement, $x_H(t)$, was obtained and further derivation of $v_H(t)$, gave the acceleration, $a_H(t)$, of the body's centre of mass (COM), assuming the velocity data is representative of COM motion and the human body can be modelled as a complete system represented by its COM. If the fundamental laws of dynamics are then applied, the net horizontal antero-posterior force, $F_H(t)$, applied to the COM over time can be calculated accounting for aerodynamic drag, based on stature (cm), body mass (kg) and fixed drag coefficients (Morin et al., 2011; Samozino et al., 2016). The external power output applied in the antero-posterior direction (P_H) can subsequently be modelled, assuming the step averaged force applied in the vertical direction, $F_V(t)$, is equal to body weight (Samozino et al., 2016). The mechanical efficiency index (D_{RF}, $\% \cdot s \cdot m^{-1}$) can then be calculated by using the ratio of forces, $F_H(t)$ as a percentage of the resultant force and determining the gradient of the linear fit of these ratio of forces data with respect to running velocity.

The antero-posterior power function was sampled at 0.1 second intervals, with peak power (P_{peak}) determined as the highest power output over the duration of the 30 m sprint, and time to peak power (t_P_{peak}) as the time, during the sprint, at which P_{peak} was achieved. To determine mean antero-posterior power, all power recordings were averaged from the start of the $v_H(t)$ curve to the end of the sprint (determined as the point at which $x_H(t)$ first exceeded 30 m, also providing t30). Power values were divided by the participant's body mass to obtain relative values. Peak horizontal force (F_0) was also sampled at 0.1 s intervals, with peak force determined as the highest force production over the 30 m sprint. Relative peak horizontal force (R_F_0; $N \cdot kg^{-1}$) was calculated by dividing F_0 by each participant's body mass. D_{RF} was subsequently expressed by determining the gradient of the linear velocity – ratio of forces relationship ($\% \cdot s \cdot m^{-1}$). Fatigue rate (FR; $W \cdot s^{-1}$) was quantified as the average rate of power decline every second, from peak power until t30 was reached (Williams et al. 1988). Peak velocity (v_0; $m \cdot s^{-1}$) was derived from the mono-exponential $v_H(t)$ curve with modelled velocities averaged over the same time interval used to determine P_{mean} to determine mean velocity (v_{mean}; $m \cdot s^{-1}$) across the 30 m sprint.

Statistical Analysis

All descriptive statistics are presented as mean ± standard deviation (SD) unless otherwise stated and all statistical tests were conducted using IBM SPSS Statistics Software Package (IBM SPSS Software version 22, IBM, Armonk, NY, USA), with significance accepted at $p < 0.05$. All variables were tested for normality using the Shapiro-Wilks test and then visually assessed for heteroscedasticity using Bland-Altman plots, plotted as the difference between consecutive sprints against their mean (Bland & Altman, 1986). Any variable found to be non-parametric was log-transformed to standardise the data and remove bias.

Absolute reliability was reported using the coefficient of variation (CV), with relative reliability calculated using repeated measures intraclass correlation coefficients (ICCs), aligning with previous recommendations for studies of this type (Eliasziw, Young, Woodbury, & Fryday-Field, 1994). The ICCs were determined from the mean square values derived from the ANOVA, with 95% confidence intervals (CI) calculated and indices back-transformed where data was initially log-transformed. Given the lack of universal consensus regarding reliability thresholds for three or more trials, thresholds for two trials were utilised (Simperimgham et al., 2017). Specifically, the thresholds for determining relative reliability based on the ICC values were 0.20-0.49, 0.50-0.74 and 0.75-0.99 for low, moderate and high reliability, respectively, with a CV of ≤10% considered acceptable (Bennell, Crossley, Wrigley, & Nitschke, 1999). Therefore, measures were deemed highly reliable when the ICC ≥ 0.75 *and* CV ≤10%, moderately reliable when ICC < 0.75 *or* CV > 10%, and unacceptable/poor when the ICC < 0.75 *and* CV > 10% (Simperimgham et al., 2017).

The standard error of measurement (SEM) was calculated using the formula: between participant SD * (1 – Variable ICC) (Atkinson & Nevill, 1988). The smallest worthwhile change (SWC) was subsequently calculated using the formula (0.2 * between participant SD) to quantify the degree of improvement needed to be sure of a worthwhile change in performance. The ability of the model to detect change was deemed good when SEM ≤ SWC, satisfactory when SEM = SWC and marginal when SEM ≥ SWC (Hopkins et al., 2009).

Results

High reliability was reported for P_{peak} (ICC: 0.76; CV: 9.5%), R_P_{peak} (ICC: 0.75; CV: 7.8%) P_{mean} (ICC: 0.88; CV: 5.5%), R_P_{mean} (ICC: 0.85; CV: 4.8%), v_0 (ICC: 0.86; 4.8%), v_{mean} (ICC: 0.83; CV: 1.6%), 30 m sprint time (ICC: 0.82; CV: 1.6%), F_0 (ICC: 0.83; CV: 8.8%), R_F_0 (ICC: 0.81; CV: 7.5%), D_{RF} (ICC: 0.88; CV: 4.2%) and FR (ICC: 0.76; CV: 8.7%). However, t_P_{peak} demonstrated moderate reliability (ICC: 0.50; CV: 9.5%). All variables also demonstrated a good ability to detect changes in performance with all SEM values less than SWC values [Table 3].

The runners were significantly lighter than the hockey players ($F_{(3,72)} = 5.60$, $p < 0.01$), and had a significantly lower BMI than both footballers and hockey players ($F_{(3,72)} = 6.85$, $p < 0.01$). There was no significant difference between training groups for any other anthropometric variable ($p < 0.05$). All anthropometric variables did, however, increase with maturation ($F_{(1,74)} = 6.89$, $p < 0.01$). No significant difference was found within participant between the three sprint trials for any variable ($F = 1.31$ $p = 0.26$ [Table 2]). Furthermore, there was no effect of training ($F = 0.65$, $p > 0.84$) or maturation ($F = 1.35$, $p > 0.21$) on the reliability of any measure, thus all variables were combined for reliability analysis [Table 3].

****INSERT TABLE 1 HERE****

****INSERT TABLE 2 HERE****

****INSERT TABLE 3 HERE****

Discussion

Overall, radar-derived velocity data fitted with the F-v-P model provided reliable measures of P_{peak}, R_P_{peak}, P_{mean}, R_P_{mean}, F_0, R_F_0, D_{RF}, v_0, v_{mean}, t30 and FR in children and adolescents. The F-v-P model also demonstrated moderate reliability for t_P_{peak}. Given the need for more relevant, sport-specific, and reliable testing methods to assess anaerobic performance, the present findings demonstrate the potential for the F-v-P model to be used in future field-based paediatric research to provide a detailed measure of sprint performance.

The PP values reported within this study align closely with Rumpf et al. (2015) which is one of the only studies to examine sprint performance and kinetics in youth. Despite the differences in methodologies, the P_{peak} outputs were comparable, demonstrating children's affinity with sprint running and potentially facilitating inter-study comparisons. However, it is pertinent to note the study of Rumpf et al. (2015) lacks ecological validity as non-motorised treadmills are not widely accessible to coaches and sports practitioners who typically require simple methods to assess athlete progression. The current values of R_F_0 were higher (7.7 $N{\cdot}Kg^{-1}$ vs 6.8 $N{\cdot}Kg^{-1}$) than the adolescent group studied by Rossi, Slotala, Morin & Edouard (2017), which could be due to the age difference between the studied groups (14.1 ± 1.0 years vs 13.6 ± 0.8 years respectively). When also compared against the findings of Rossi et al. (2017), D_{RF} the current cohort produced a slightly less steep decline of the F-v slope (-7.3 $\%{\cdot}s{\cdot}m^{-1}$ vs -8.0 $\%{\cdot}s{\cdot}m^{-1}$).

The current CVs for P_{peak} and P_{mean} (8.5% and 5.5%, respectively), were higher than reported elsewhere for other running kinetics reliability studies (Berthonin, Dupont, & Mary, 2001; Ingle & Tolfrey, 2013; Simperingham, Cronin, & Ross, 2016). The higher P_{peak} variation in the present study may be because the current study population was not formed of trained sprinters, as utilised in previous reliability studies, who would be expected to be able to reproduce maximally bouts more consistently (Malcata & Hopkins, 2014). Additionally, as Simperingham et al. (2016) highlighted, the lack of consistency in reporting the number of repeated trials and the recovery between trials limits direct comparison between studies. In accord with previous recommendations, three trials were used for the reliability analysis as protocols within this population rarely encompass just two trials and the reliability of a measure cannot be assumed to remain constant after the second trial (Hopkins et al., 2009). Furthermore, Hopkins et al. (2001) highlighted studies examining the reliability of a measure from less than three trials cannot account for a learning effect. Indeed, the mean difference between the first two trials in reliability studies is ~1%, which in most cases is indicative of a real change in performance (≥ SWC; Hopkins et al., 2001). Furthermore, when only the first two trials were analysed within this study the CV decreased to 5.6% and 3.6% for PP and MP respectively, aligning them with values reported elsewhere. Thus, studies only relying on two trials to determine reliability not only fail to account for a learning effect but also potentially over-estimate the reliability of measurement devices. Despite the utilisation of three trials, the CV still fell within acceptable limits (CV ≤ 10%) highlighting its potential to be used within paediatric populations.

Fatigue rate was reported, over the more traditional fatigue index, due to the assumptions associated with F-v-P profiling. Specifically, the exponential power function assumes that horizontal power declines from peak power to almost zero by the end of the 30 m sprint. Hence, if fatigue index was calculated using the calculation commonly used for Wingate Tests [((PP – Minimum Power) / PP) * 100] (Sadehgi & Husseini, 2017), the fatigue index would be ~100% for all trials. In contrast, FR offers a more appropriate measure to assess differences between participants whilst retaining high intra-trial reliability. Currently, unlike in adults, there are no objective criteria in children for determining a maximal effort (Van Praagh & Dore, 2002), thus strategies must be employed to ensure motivation is maximised. Indeed, research has suggested the absence of such motivational techniques may contribute to the child-adult differences observed in anaerobic performances (Fargeas, Van Praagh, & Léger, 1993). One such technique trialled within the literature is marking the finish line at 35 m, to minimise slowing down before 30 m, to improve FR reliability (Meyers, Oliver, Hughes, Cronin, & Lloyd, 2015). However, no comparative reliability study has been conducted in relation to finish line distance and FR, so inferences about whether this method further improves reliability remain speculative.

Time to peak power was deemed only moderately reliable (ICC: 0.50; CV: 9.5%) in the current paediatric population using the F-v-P method. The level of participant familiarity to the task could have influenced this parameter. Specifically, whilst over-ground running is familiar to most children and adolescents, a more robust and sprinting specific familiarisation may have been appropriate to improve the inter-trial reliability of this parameter (Rumpf et al., 2011). Additionally, t_P_{peak} may be more reliable during the cycling WnT test due to the fewer degrees of freedom required, whereas during over-ground running the co-ordination of more degrees of freedom is required in order to produce successful, reproducible performances (Dotan et al., 2012). t_P_{peak} may therefore have been found to be moderately reliable in this paediatric population due to the development of co-ordination and therefore the motor skill of running is still being learnt (Dotan et al., 2012). Thus, the movement is likely inherently more variable than in adult sprinters within whom these motor skills and movement patterns have been better established. Further interpretation of the reliability of t_P_{peak} is limited, however, by the need to resolve methodological questions regarding the determination of the appropriate initial time offset to be used for two-point starts. Specifically, whilst an offset of 0.3 seconds was used (Samozino, 2018), the applicability of this offset which has been derived from block starts is currently unclear in two-point starts and therefore may have also influenced the t_P_{peak} (Simperingham et al., 2016).

Radar-derived velocity data enables a more detailed analysis across the distinct phases of the sprint. Over-ground sprinting, compared to jump test batteries and the cycling WnT, eases participant burden and speeds up the data collection process, facilitating longitudinal and larger cohort studies. Indeed, the SEM (all ≤ 2.7%) associated with the current F-v-P profiling was lower than reported for both the cycling WnT (4.8% - 9.0%; (Doré et al., 2003)) and jumping test batteries (3.3% - 5.3%; (Ingle & Tolfrey, 2013)) within paediatric populations. Furthermore, F-v-P profiling could enable greater insights into repeated sprint performance, a test commonly used within the paediatric literature and strongly correlated to performance in team sports (Mendez-Villanueva et al., 2010). Traditionally, six repetitions of 2 × 15 m shuttle sprints (with a 180º turn) with 20 s recovery between sprints has been utilised. Fatigue is subsequently quantified using the equation (100 - (mean time / best time) * 100) but using F-v-P kinetic parameters could also be analysed over multiple sprints potentially facilitating the identification of more subtle differences in sprinting performance. Examples of these subtle differences include inter-trial P_{peak} and t_P_{peak} (acceleration) profiles. Identification of these subtle differences would allow coaches to prescribe individualised training plans to their athletes. Thus, the utilisation of radar-based velocity data during an over-ground sprint potentially allows the small changes that may be evident between the different stages of maturity to be identified to determine whether a maturational threshold is manifest within the results.

The small SEM (all < SWC) values associated with F-v-P profiling potentially allow greater insight into the small changes evident between training groups. Specifically, Sperlich et al. (2011) assessed the effectiveness of high volume training (HVT) versus high intensity interval training (HIIT) in a cohort of 14 year old football players. Thirty metre sprint performance was assessed using photocells with both groups improving t30 pre-post (HVT: -0.17 s; HIIT: -0.22 s) with no significant difference reported between groups. However, if radar derived F-v-P was employed, given that the SWC for t30 is 0.03 s, and the difference between the training groups was 0.05 s, a significant difference may have been reported. Additionally, Rumpf,et al. (2015) examined the effect of resisted sled exercise on sprint performance in a group of pre-pubertal children and pubertal adolescents on a non-motorised treadmill. The magnitude of change was -62W in the pre-pubertal children and +72W pubertal adolescents pre-post intervention respectively, which was deemed insignificant (Rumpf et al., 2015). However, if F-v-P profiling was utilised using radar derived velocity data it may have demonstrated significant differences (PP SWC: 59.5 W) highlighting a meaningful effect of training on this parameter, even before adherence to training was accounted for. These two examples highlight this methods potential to determine the subtle differences that may be evident between training methodologies and the maturational stages and therefore should be used in future training studies examining the trainability of high intensity running performance in children and adolescents.

Force-velocity-Power profiling during over-ground sprinting does have some limitations which need to be acknowledged by researchers before implementing this method into their research. Firstly, inferences are only able to be made regarding intraday reliability of F-v-P profiling in this population as no repeated inter-day measurements were conducted. Secondly, whilst all participants completed the 30 m sprints on surfaces, they were familiar with training or playing on, these were not all on the same surface, thereby potentially influencing the sprint characteristics and outcome variables from the resultant F-v-P profiling. Also, whilst the participants' usual sport-specific warm-ups were prescribed by their respective coaches to enhance ecological validity, a more specific warm-up and familiarisation protocol may have been more effective in preparing the athletes for optimal sprinting performance. Lastly, the initial mono-exponential function fitted to the velocity-time curve does not account for slowing down towards the end of the sprint, potentially raising questions over the validity of the results for all measures if this occurred. Therefore, in accord with the present study, future research should seek to integrate a longer sprint distance (35 m) to minimise deceleration and maintain validity of measurements.

Conclusions

The simple model of Samozino et al. (2016) applied to overground sprinting is quick and easy to administer in children and adolescents, thereby facilitating large cohort, longitudinal studies whilst retaining moderate-to-high reliability. This method therefore provides a potential alternative for paediatric researchers, providing a detailed measure of sprint performance from a single trial. Thus, this could enhance our understanding of the trainability of sprint performance in youth and allow researchers to identify any maturational threshold that may be manifest.

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References

Armstrong, N. (2007). *Paediatric Exercise Physiology*: Churchill Livingstone Elsevier.

Atkinson, G., & Nevill, A. M. (1988). Statistical Methods For Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine. *Sports Medicine, 26*(4), 217-238.

Baquet, G., Berthonin, S., Gerbeaux, M., & Van Praagh, E. (2001). High-intensity aerobic training during a 10 week one-hour physical education cycle: effects on physical fitness of adolescents aged 11 to 16. *International Journal of Sports Medicine, 22*(4), 295-300.

Beneke, R., Hutler, M., & Leithauser, R. M. (2007). Anaerobic performance and metabolism in boys and male adolescents. *European Journal of Applied Physiology, 101*(6), 671-677. doi:10.1007/s00421-007-0546-0

Bennell, K., Crossley, K., Wrigley, T., & Nitschke, J. (1999). Test-retest reliability of selected ground reaction force parameters and their symmetry during running. *Journal of Applied Biomechanics, 15*, 330-336.

Berthonin, S., Dupont, G., & Mary, P. (2001). Predicting sprint kinematic parameters from anaerobic field tests in physical education students. *Journal of Strength and Conditioning, 15*(1), 75-80.

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, 307-310.

Bongers, B. C., Werkman, M. S., Blokland, D., Eijsermans, J. C., van der Torre, P., Bartels, B., . . . Takken, T. (2015). Validity of the Pediatric running-based anaerobic sprint test to determine anaerobic performance in healthy children. *Pediatric Exercise Science, 27*, 268-276.

Doré, E., Bedu, M., & Van Praagh, E. (2008). Squat Jump performance during growth in both sexes: comparison with cycling power. *Research Quarterly for Exercise and Sport, 79*(4), 517-524.

Doré, E., Duché, P., Rouffet, D., Ratel, S., Bedu, M., & Van-Praagh, E. (2003). Measurement error in short-term power testing in young people. *Journal of Sports Sciences, 21*(2), 135-142.

Dotan, R., Mitchell, C., Cohen, R., Klentrou, P., Gabriel, D., & Falk, B. (2012). Child-Adult Differences in Muscle Activation - A Review. *Pediatric Exercise Science, 24*(1), 2-21.

Eliasziw, M., Young, S. L., Woodbury, M. G., & Fryday-Field, K. (1994). Statistical Methodology for the Concurrent Assessment of Interrater and Intrarater Reliability: Using Goniometric Measurements as an Example. *Physical Therapy, 74*(8), 777-789.

Fargeas, M. A., Van Praagh, E., & Léger, I. (1993). Comparison of cycling and running power outputs in trained children. *Pediatric Exercise Science, 5*, 415.

Fellmann, N., & Coudert, J. (1994). PHYSIOLOGICAL-RESPONSES TO EXERCISE IN CHILDREN. *Archives De Pediatrie, 1*(9), 827-840.

Gormley, S. E., Swain, D. P., High, R., Spina, R. J., Dowling, E. A., Kotipalli, U. S., & Gandrakota, R. (2008). Effect of intensity of aerobic training on VO2max. *Medicine and Science in Sports and Exercise, 40*(7), 1336-1343. doi:10.1249/MSS.0b013e316c4839

Hebestreit, H., Dunstheimer, D., Staschen, B., & Strassburg, H. M. (1999). Single-leg Wingate test in children. *Medicine and Science in Sports and Exercise, 31*, 1218-1225.

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine + Science in Sport + Exercise, 41*(1), 3-12.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*, 1-15.

Hopkins, W. G., Schabort, E. J., & Hawley, J. A. (2001). Reliability of power in physical performance tests. *Sports Medicine, 31*, 211-234.

Ingle, L., & Tolfrey, K. (2013). The variability of High Intensity Exercise tests in Pre-Pubertal Boys. *International Journal of Sports Medicine, 34*, 1063-1069.

Knowles, A. M., Herbert, P., Easton, C., Sculthorpe, N., & Grace, F. M. (2015). Impact of low-volume, high-intensity interval training on maximal aerobic capacity, health-related quality of life and motivation to exercise in ageing men. *Age, 37*(2). doi:10.1007/s11357-015-9763-3

Malcata, R. M., & Hopkins, W. G. (2014). Variability of competitive performance of elite athletes: a systematic review. *Sports Medicine, 44*(12), 1763-1774.

Maliszewski, A. F., & Freedson, P. S. (1996). Is running economy different between adults and children? *Pediatric Exercise Science, 8*(4), 351-360.

Marshall, W. A., & Tanner, J. M. (1970). Variations in the pattern of pubertal changes in boys. *Archives of disease in childhood, 45*(239), 13-23.

Matos, N., & Winsley, R. J. (2007). Trainability of young athletes and overtraining. *Journal of Sports Science and Medicine, 6*(3), 353-367.

Mendez-Villanueva, A., Buchheit, M., Kuitunen, S., Douglas, A., Peltola, E., & Bourdon, P. (2010). Age-related differences in acceleration, maximal running speed, and repeated sprint-performance in young soccer players. *Journal of sports science, 29*(5), 477-484.

Mero, A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of Sprint Running: A Review. *Sports Medicine, 13*(6), 376-392.

Meyers, R. W., Oliver, J. L., Hughes, M. G., Cronin, J. B., & Lloyd, R. S. (2015). Maximal Sprint Speed in Boys of Increasing Maturity. *Pediatric Exercise Science, 27*(1), 85-94. doi:10.1123/pes.2013-0096

Mirwald, R. L., Baxter-Jones, A. D. G., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sport & Exercise Science, 34*(4), 689-694.

Morin, J. B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine and Science in Sport & Exercise, 43*(9), 1680-1688.

Morin, J. B., Jeannin, T., Chevallier, B., & Belli, A. (2006). Spring-mass model characteristics during sprint running: correlation with performance and fatigue-induced changes. *International Journal of Sports Medicine, 27*(1), 158-165.

Naughton, G., Carlson, J., & Fairweather, I. (1992). Determining the variability of performance on Wingate anaerobic tests in children aged 6 - 12 years old. *International Journal of Sports Medicine, 13*(512-517).

Pawlowski, C. S., Andersen, H. B., Troelsen, J., & Schipperijn, J. (2016). Children's Physical Activity Behavior during School Recess: A Pilot Study Using GPS, Accelerometer, Participant Observation, and Go-Along Interview. *Plos One, 11*(2). doi:10.1371/journal.pone.0148786

Ratel, S., Duche, P., & Williams, C. (2006). Muscle fatigue during high-intensity exercise in children. *Sports Medicine, 36*(12), 1031-1065. doi:10.2165/00007256-200636120-00004

Roemmich, J. N., Richmond, E. J., & Rogol, A. D. (2001). Consequences of sport training during puberty. *Journal of Endocrinological Investigation, 24*(9), 708-715.

Rossi, J., Slotala, R., Samozino, P., Morin, J. B., & Edouard, P. (2017). Sprint acceleration mechanics changes from children to adolescent. *Computer Methods in Biomechanics and Biomedical Engineering, 20*, 181-182.

Rumpf, M. C., Cronin, J. B., Mohamad, I. N., Mohamad, S., Oliver, J. L., & Hughes, M. G. (2015). The effect of resisted sprint training on maximum sprint kinetics and kinematics in youth. *European Journal of Sport Science, 15*(5), 374-381.

Rumpf, M. C., Cronin, J. B., Oliver, J., & Hughes, M. (2015). Kinematics and kinetics of maximum running speed in youth across maturity. *Pediatric Exercise Science, 27*, 277-284.

Rumpf, M. C., Cronin, J. B., Oliver, J. L., & Hughes, M. (2011). Assessing Youth Sprint Ability-Methodological Issues, Reliability and Performance Data. *Pediatric Exercise Science, 23*(4), 442-467.

Rumpf, M. C., Cronin, J. B., Pinder, S. D., Oliver, J., & Hughes, M. (2012). Effect of Different Training Methods on Running Sprint Times in Male Youth. *Pediatric Exercise Science, 24*, 170-186.

Samozino, P. (2018). A Simple Method for Measuring Force Velocity and Power Capabilities and Mechanical Effectiveness During Sprint Running. In J. B. Morin (Ed.), *Biomechanics of Training and Testing: Innovative Concepts and Simple Field Methods* (pp. 237-269): Springer.

Samozino, P., Rabita, G., Dorel, S., Slawinski, J., Peyrot, N., Saez de Villarreal, E., & Morin, J. B. (2016). A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scandinavian journal of medicine & science in sports, 26*(6), 648-658.

Simperingham, K. D., Cronin, J. B., Pearson, S. N., & Ross, A. (2017). Reliability of horizontal force-velocity-power profiling during short sprint-running accelerations using radar technology. *Sports Biomechanics*, 1-12.

Simperingham, K. D., Cronin, J. B., & Ross, A. (2016). Advances in Sprint Acceleration Profiling for Field-Based Team-Sport Athletes: Utility, Reliability, Validity and Limitations. *Sports Medicine, 46*, 1619-1645.

Sperlich, B., De Marees, M., Koehler, K., Linville, J., Holmberg, H. C., & Mester, J. (2011). EFFECTS OF 5 WEEKS OF HIGH-INTENSITY INTERVAL TRAINING VS. VOLUME TRAINING IN 14-YEAR-OLD SOCCER PLAYERS. *Journal of Strength and Conditioning Research, 25*(5), 1271-1278. doi:10.1519/JSC.0b013e3181d67c38

Van Praagh, E. (2000). Development of anaerobic function during childhood and adolescence. *Pediatric Exercise Science, 12*(2), 150-173.

Van Praagh, E., & Dore, E. (2002). Short-term muscle power during growth and maturation. *Sports Medicine, 32*(11), 701-728.

Watt, K. K. O., Hopkins, W. G., & Snow, R. J. (2002). Reliability of performance in repeated sprint cycling tests. *Journal of Science and Medicine in Sport, 5*(4), 354-361.

Zagatto, A. M., Beck, W. R., & Goratto, C. A. (2009). Validity of the running anaerobic sprint test for assessing anaerobic power and predicting short-distance performances. *Journal of Strength and Conditioning Research, 23*(6), 1820-1827.

Table 1 – Mean ± SD participant characteristics for each of the four groups

	Control	Footballers	Hockey Pla
Age (years)	13.7 ± 3.2	14.3 ± 3.1	15.1 ± 1.
Height (m)	1.65 ± 0.15	1.61 ± 0.12	1.69 ± 0.0
Mass (kg)	51.7 ± 12.9	56.0 ± 12.4	60.4 ± 7.4
BMI (kg·m^2)	20.3 ± 3.5	21.2 ± 2.4*	21.2 ± 1.9
Maturity Offset (years)	- 1.18 ± 3.10	- 1.62 ± 2.71	+ 0.10 ± 1.

All values reported as mean ± SD. BMI, Body Mass Index, *Significant difference compared to the running group (p < 0

Table 2 –Outcome variables for the three sprint trials

	Trial 1	Trial 2
Time to Peak Power (s)	0.65 ± 0.20	0.62 ± 0.16
Peak Power (W)	793 ± 276	814 ± 287
Relative Peak Power (W·kg^{-1})	14.3 ± 4.4	14.5 ± 3.9
Mean Power (W)	298 ± 104	300 ± 102
Relative Mean Power (W·kg^{-1})	5.3 ± 1.6	5.4 ± 1.3
Maximum Velocity (m·s^{-1})	6.87 ± 0.81	6.89 ± 0.70
Mean Velocity (m·s^{-1})	5.67 ± 0.52	5.72 ± 0.49
30 m Sprint Time (s)	5.34 ± 0.49	5.28 ± 0.46
Peak Force (N)	436.5 ± 150.9	439.2 ± 138.6
Relative Peak Force (N·Kg^{-1})	7.8 ± 2.2	7.7 ± 2.1
Mechanical Efficiency Index (%·s·m^{-1})	- 7.1 ± 1.8	- 7.3 ± 1.4
Fatigue Rate (W·s^{-1})	186.4 ± 92.3	180.8 ± 80.4

All variables reported as mean ± SD

Table 3 – Reliability statistics for all three sprint trials

	Overall Mean	95% Confidence Interval		Change in Mean			SEM (%
		Lower Bound	Upper Bound	T1 – T2	T2 – T3	T1 – T3	
Time to peak power (s)	0.63	0.59	0.67	- 0.03	- 0.03	- 0.06	0.01 (1.6
Peak Power (W)	788	724	852	+ 21	- 79	- 58	20 (2.6%
Relative Peak Power (W·kg^{-1})	14.2	13.3	15.1	+ 0.2	- 0.5	- 0.2	0.3 (2.1%
Mean Power (W)	289	267	311	+ 2	- 46	- 44	7 (2.5%
Relative Mean Power (W·kg^{-1})	5.2	4.9	5.9	+ 0.1	- 0.6	- 0.5	0.1 (2.7%
Maximum Velocity (m·s^{-1})	6.78	6.61	6.95	+ 0.01	- 0.45	- 0.44	0.05 (0.7
Mean Velocity (m·s^{-1})	5.64	5.53	5.75	+ 0.05	- 0.27	- 0.22	0.04 (0.7
30 m Sprint Time (s)	5.36	5.25	5.47	- 0.05	+ 0.25	+ 0.20	0.03 (0.6
Peak Force (N)	436.8	403.0	470.5	- 2.7	+ 6.2	+ 3.5	21.8 (5.0
Relative Peak Force (N·Kg^{-1})	7.7	7.2	8.3	- 0.1	- 0.4	- 0.5	0.4 (5.2%
Mechanical Efficiency Index (%·s·m^{-1})	- 7.32	- 7.67	- 6.93	+ 0.1	+ 0.2	+ 0.5	0.37 (5.1
Fatigue Rate (W·s^{-1})	182.4	161.3	203.4	+ 5.8	+ 2.6	+ 3.0	14.2 (8.8

T1 = Trial 1, T2 = Trial 2, T3 = Trial 3, SEM = Standard Error of Measurement, SWC = Smallest Worthwhile Change, IC
CV = Coefficient of Variation (expressed as mean ± standard deviation)