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Research article

The Biomechanics of Standing Start and Initial Acceleration: Reliability of the Key Determining Kinematics

Regan J. Standing and Peter S. Maulder ✉
Centre for Sport Science and Human Performance, Waikato Institute of Technology, Hamilton, New Zealand

Abstract

The reliability of the key determining kinematic variables associated with short sprint performance provide insight into how and why movement may vary between individual trials. Currently, literature surrounding these determinants is scarce when investigating the first three strides of a sprint. The purpose of this study was to investigate the reliability of sprint acceleration and the key kinematic determinants involved during the first three steps of the movement. The aim was to use a practical method of kinematic analysis to help explain why changes may occur in sprint performance via the use of correlative statistics and to provide reference values for intervention research to make conclusions about their change scores. Ten male volunteers from various team sports attended two separate testing sessions, a minimum of 48 hours apart. They performed three maximal sprint trials over a 10m distance from a standing start, where researchers captured 5m and 10m sprint times alongside high speed camera footage, from which the key kinematic variables were measured. Results demonstrated that although 5m and 10m sprint times depicted moderate to large levels of similarity between sessions, neither of these variables met the criteria to be classified as adequately, or highly reliable. Kinematic measures typically produced ICC values > 0.70 and CV% < 10%, demonstrating all relevant statistical traits to be categorised as reliable measures. Step frequency and flight time during the third step showed the largest correlation with performance, exhibiting ‘r’ values of -0.386 and 0.396, respectively. These findings demonstrate that kinematic variables may not have an influential role with sprint times; therefore suggesting kinetic concepts may in fact be the key determinants of speed. Future research is required investigating the interaction of kinetic and kinematic variables associated with sprinting and how the variability in these concepts effects the reliability of performance.

Key words: Flight, stance, step, length, knee, take-off.

Introduction

Sprinting is an athletic event that requires individuals to cover a set distance as fast as possible, predominantly comprising of an acceleration, transitional and maximal velocity phases (Cronin and Hansen, 2006; Delecluse, 1997). In numerous team sports such as football, rugby league, netball and hockey, short sprint speed is crucial to achieve gameplay tasks, especially when trying to do so against opponents (Leblanc and Gervais, 2004). The ability to improve initial acceleration will provide the individuals the opportunity to be more successful during these movements and therefore improve their overall gameplay (Leblanc and Gervais, 2004). Sprint distances at Olympic events include 100m, 200m and also the 400m, with competitors constantly seeking individual improvement. It is common to see winning margins of less than 0.01s in many of these sprint events; therefore small alterations in performance can be the defining factor between gold and silver medal placings (Docherty and Hodgson, 2007; Young, 2006). Research has investigated the effects of acute interventions and longitudinal training programmes, in an attempt to identify if these can aid in improving an individual’s sprint times, with numerous concepts proving beneficial (Cronin and Hansen, 2006; Kotzamanidis, 2006; Matthews et al., 2004; Needham et al., 2009; Yetter and Moir, 2008). However, for these interventions to be used with confidence throughout the sprinting community, research must prove that the corresponding effect on performance is actually due to the intervention or training protocol and not caused by random variation. To do this, the reliability of sprint performance (sprint times) must be investigated, allowing concise conclusions to be made about the intervention strategies being implemented (Hopkins et al., 2001).

Reliability is a term used to describe the consistency of research to produce the same, or similar results on different occasions (Bannigan and Watson, 2009; Levinger et al., 2009). A measurement that is less reliable produces data which has a larger degree of variation; therefore making systematic changes caused by interventions much harder to recognise (Hopkins et al., 2001). Moreover, reliability provides a quantitative description of the spread of the error involved with a particular movement or performance, allowing accurate conclusions to be drawn based on these values (Hopkins et al., 2001).

The reliability of sprint performance is a concept that provides a numerical reference to the variability in sprint times, indicating how much these values differ between trials, protocols and testing procedures (Hopkins, 2000). As previously stated, the reliability of this performance is important in determining the degree of influence that interventions or training strategies may have. Acute interventions such as post-activation potentiation (Matthews et al., 2004; Smith, 2012), ergogenic aids (Forbes et al., 2007; Paton et al., 2010) and variations in equipment (Squadrone and Gallozzi, 2009), have been shown to improve performance; with longitudinal training strategies also contributing to improvements in this area (Cronin and Hansen, 2006; Kotzamanidis, 2006). The influence of these interventions is determined by the change they induce in the measurements. For a worthwhile change in performance to be attributed to an intervention, the change incurred must be greater than the typical variance in the measured performance (Pearson et

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al., 2007). If the reliability of sprint performance is low (high variability), then it is less likely that any changes seen can be attributed to the inclusion of an intervention. The problem with sprint performance is that it is a product of many other contributing factors such as acceleration, top speed and deceleration characteristics (Cronin and Hansen, 2006; Delecluse, 1997), which are themselves influenced by each individuals physical sprinting mechanics (Hunter et al., 2004a). These mechanics play a large role in raw sprint performance and therefore need to be recognised in order to understand why changes may occur with the inclusion of intervention strategies or training programmes.

Sprint mechanics refers to the kinetic and kinematic variables associated with human running movements (Morin et al., 2012). The interaction of these variables ultimately determines sprint velocity and therefore sprint performance, making them very important when identifying variations in sprint times (Hunter et al., 2004a). The kinetics of sprinting are typically measured via force platforms which are expensive and burdensome as they are often fixed in place. This makes them unpractical for your typical track coach, or team sport strength and conditioner, who don't have access to a research facility. Kinetic determinants are very important to sprint performance, as measures such as maximal power, average power and horizontal and vertical ground reaction forces have been shown to have correlations of 0.59 – 0.87 with maximal speed (Hunter et al., 2004a). Due to this correlation with maximal speed, it is important to acknowledge the relationships between kinetic determinants and kinematic variables associated with sprinting, because many of these kinematic variables have an influential relationship with sprint kinetics, and therefore may play an important role in maximal speed also (Hunter et al., 2004a). There are numerous studies investigating the kinematic determinants of sprint performance, with common trends witnessed throughout. Murphy et al., (2003), compared kinematic variables between a 'fast' group and a 'slow' group of individuals, differentiated by horizontal velocity measures. The 'fast' group displayed significantly shorter (11-13%) ground contact times ($p < 0.05$), increased stride frequency (~9%) and significantly higher horizontal hip velocity. These findings are consistent with further research by Hunter et al., (2005), who concluded that a higher hip velocity was present during foot contacts with higher propulsive magnitudes, which identified as key kinetic determinants of sprint performance. To further support the findings of Murphy et al., (2003), studies by Lockie et al., (2013), and Willwacher et al., (2016), established that shorter contact times were displayed by subjects with faster sprint performance measures; and Mackala et al., (2015), reiterated the fact that stride length had a moderate - high correlation with 10m, 30m and 100m sprint times. Many other kinematic variables such as knee angles at take-off (Petrakos et al., 2016), hip angle at take-off (Hunter et al., 2005), flight times (Hunter et al., 2004b), and step frequency (Weyand et al., 2000), have been discussed and / or measured as possible determinants of sprint performance, with less convincing findings amongst literature. Kinematic variables are typically measured via high speed cameras and analysis software, both of which are becoming increasingly cheaper and more accessible to coaches. If it can be proven that kinematic variables are changing as a result of an intervention or training programme, it will firstly help to explain 'why' and 'how' an individual's overall sprint performance is altered, but will also do so in a manner which is practical for coaches and conditioners to use on a daily basis with their athletes. Similarly to sprint performance, in order to understand any changes in these kinematic variables, their reliability between trials and sessions must be understood so alterations can be measured and reported with confidence.

To this author's knowledge, information on the reliability of sprint kinematics is scarce. Two articles by Hunter et al., (2004b), and Salo et al., (1996), report reliability for several of the key sprint variables, as outlined by Hunter et al., (2004a). These measurements were taken during late acceleration (16m), and nearing max speed, whereas many interventions aim to improve short sprint performance due to its importance in a larger range of sports (Cronin and Hansen, 2006; Randell et al., 2010).

The primary aim of this study was to investigate the reliability of sprint acceleration performance and the reliability of the key kinematic determinants involved during the first three steps of the sprint. The secondary aim was to utilise a practical method of kinematic analysis to help explain why changes may occur in sprint performance via the use of correlative statistics and to provide reference values for intervention research to make conclusions about their change scores.

It is hypothesised that short sprint performance will provide reliability scores which indicate a low level of variability, with the kinematic variables having a lower level of reliability in comparison to performance. Third step frequency and step length will show small levels of association with sprint performance, with variables such as stance time and flight time having a lesser level of association.

Methods

Study design

This study utilised a test-retest design to determine inter-session reliability of both short sprint performance and the kinematic variables, where each change score was measured in respect to each individual over two sessions (Hopkins, 2008). These two sessions were separated by a minimum of 48 hours, with the participants not partaking in any other form of moderate to high intensity exercise between sessions. A cross-sectional design was performed utilising Pearson correlation analyses to identify the associations between 5m sprint times and third step sprint kinematics. Cronin et al., (2007), and Frost et al., (2008), were studies that established significant reliability over a 5m distance; therefore this distance was also chosen for this study so comparisons can be made. The third step was chosen to allow comparable data with other kinematic based research (Maulder et al., 2008; Moir et al., 2007; Salo, 2005).

Participants

A total of 10 physically active individuals (mean ± SD: age 22.4 ± 3.4 yrs; height 1.80 ± 0.06 m; weight 87.3 ± 11.8 kg; training years 3.4 ± 2.7 yrs) volunteered for this study, all recruited through various sporting communities. Each individual was required to be involved in a current training regime (minimum of three trainings per week for at least six weeks prior to testing) in a sport that contained a running component of maximal or near maximal intensity. Participants were within the age of 17 and 27 and had a minimum of one year resistance training experience with no injuries within the two months prior to testing (Chiu et al., 2003). Before being included in the study, protocol information and participant requirements were provided and explained to the volunteers, before medical questionnaires and consent forms were issued and signed. Ethical approval was granted for all procedures from the institutes' ethics committee.

Experimental procedures

Subjects were required to attend two separate testing sessions, each involving familiarisation and data collection. Participants were requested to wear their preferred style of training shoe and short sleeved/legged training attire. The initial testing session began with individual height and weight taken (shoes off). Testing sessions commenced with a 15min self-selected warm-up, typically consisting of cycling, jogging, dynamic stretching and acceleration based run-outs. Familiarisation followed with a verbal and visual demonstration of the required sprint start position. This consisted of a standing split stance with their preferred foot placed on the starting line. They were to begin each trial with a forward movement of the torso, as opposed to a rocking motion where momentum can be generated prior to first foot movement (Murphy et al., 2003). Each individual then performed two practise trials over the full 10m distance, with a minimum of two minutes rest between each trial (Cronin et al., 2007). Once sprint familiarisation had occurred, the individuals were allocated a randomly assigned running order which they maintained throughout the entire data collection process.

Sprint data collection began with the researcher asking the participant to step up to the starting line, before providing the commands "three, two, one, when you're ready". Once this command was given, the participant was free to commence their maximal sprint trial. This was to remove any variability in reaction times between sessions (White and Gunter, 2002). They were then given four minutes passive rest (De Salles et al., 2009), before being called back to the start line to complete their second and third maximal sprint trials.

The second testing session was performed a minimum of 48 hours after the initial session and was repeated in the exact same manner as stated above. Individuals were asked to perform a similar warm-up procedure before entering familiarisation and data collection, which occurred with the same rest periods and testing order as performed in the initial session.

Data collection

Sprint trials were performed on a rubberized tile surface in an indoor gym facility. Participants began each trial with their front foot 0.5m behind the first timing light (Crewther et al., 2011). A duel-beam-modulated SWIFT timing light system (Wacol, Australia), was used to capture performance times. Three sets of lights were placed at the zero, 5m and 10m marks, at a height of 0.85m (to lowest reflector), with the lane width approximately 4m. Two high speed cameras (Casio exilim, ex-zr200) capturing at 120fps on fixed tripods were setup to capture the first three steps of the sprint trials. These we placed perpendicular to the movement on both sides of the lane, 1.02m in front of the initial starting line and 4.27m from the lanes centre (see Figure 1). Joint markers were placed on both sides of the body at the lateral malleolus of the ankle, lateral epicondyle of the knee and greater trochanter of the hip.

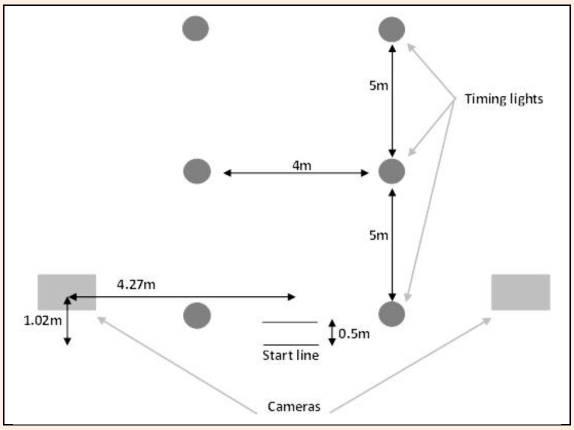

Figure 1. Schematic of testing equipment setup.

Data analysis

Silicon-coach pro 7 (Dunedin, New Zealand), was used to analyse the variables of interest over the first three steps of the sprint trials. Specifics of how these were measured are as follows:

Step length (m) - Horizontal distance between the point of touchdown of one foot (furthest point) and the touchdown of the following foot (Bezodis et al., 2008).

Step rate (Hz) – The amount of steps per second, calculated via the following equation, 1/(Stance + flight time) (Weyand et al., 2000).

Stance time (s) - Duration of the time taken from first point of contact to the last video frame of contact with the ground (Murphy et al., 2003).

Flight time (s) - Duration of the time taken from first video frame without ground contact, to last frame before touchdown (Hunter et al., 2004b).

Knee angle at touchdown (°) - Angle between lateral malleolus of the ankle, lateral epicondyle of knee and greater trochanter of the hip at first point of ground contact (Mann and Herman, 1985).

Knee angle at take-off (°) - Angle between lateral malleolus of the ankle, lateral epicondyle of knee and greater trochanter of the hip at first frame without ground contact (Mann and Herman, 1985).

Trunk angle at take-off (°) - At first video frame without ground contact, the angle (in relation to the horizontal) from the greater trochanter of the hip to the central point of the shoulder nearest to acromion process.

Statistical analysis

Test-retest reliability of the measured performance objectives (5m and 10m times) and the kinematic variables associated with the sprint trials, were measured via the change in mean ± 90% confidence levels for each of the first three steps. This was performed using a pre-configured spreadsheet (Hopkins, 2015), where outliers were removed and data was LOG transformed in order to alleviate any skewed distribution and improve the interpretability of results. Reliability was measured via the typical error of measurement expressed as the coefficient of variation (CV%) and intra-class correlation coefficients (ICC), with a variable deemed to have an adequate level of reliability if the CV% was < 10% and an ICC between 0.70 and 0.80, with a high level of reliability given to statistics with a CV% < 10% and an ICC > 0.80 (Hopkins and Manly, 1989; Paungmali and Sitilertpisan, 2012; Shrout and Fleiss, 1979). Qualitative descriptors were utilised to make inferences about the effect magnitudes based on the work of Hopkins (2002), (see Table1).

Table 1. Qualitative Descriptors of the Correlation Coefficient (CC).

CC (r)	Qualitative descriptor
0.0 – 0.1	Very small, Trivial, Insubstantial
0.1 – 0.3	Small, Low, Minor
0.3 – 0.5	Moderate, Medium
0.5 – 0.7	Large, High, Major
0.7 – 0.9	Very large, Very high
0.9 – 1.0	Substantial, Almost perfect, Distinct

Pearson correlations were made between 5m sprint times and step length, step frequency, stance time and flight time of the third step using SPSS software (Version 22, IBM, Armonk, NY), to determine the level of relative influence. The descriptors of Hopkins (2002), were again used to draw qualitative conclusions from the data, with 90% confidence intervals established for each variable via a second pre-configured spreadsheet by Hopkins (2007).

Results

Group means and standard deviations evaluating test-retest reliability between session one and session two are displayed in Table 2. Both of the performance variables (5m and 10m sprint times) displayed 0.02s and 0.01s variations in group means between sessions, which were coupled with ICC values of 0.37 and 0.62, respectively. Although this depicts moderate to large levels of similarity between sessions, neither of these variables met the criteria to be classified as adequately (ICC between 0.70 – 0.80 and CV% <10%) or highly (ICC > 0.80 and CV < 10%) reliable.

Kinematic measures which include 2nd and 3rd step step frequency, 2nd and 3rd step stance time, 3rd step knee angle on touchdown and 2nd step trunk angle at take-off all exhibited the necessary statistical traits to be categorised as adequately reliable, with CV% values ranging between 3.0 and 7.5 and ICC levels identifying a 'very large' level of relatedness for all aforementioned variables. High levels of reliability (ICC > 0.80 and CV < 10%) were recognised between 1st step step frequency, 2nd step step length, 1st step stance time, 1st and 2nd step knee angles at touchdown, 1st step knee angle at touchdown and 1st and 3rd step trunk angle at take-off. These variables exhibited 'very large' to 'substantial' levels of similarity between sessions and all exhibited CV% values of < 5%.

Flight time was the only variable identified that did not met the requirements of at least 'adequate'

Table 2. **Coefficient of variation and re-test correlation of Day 1 and Day 2 performance measures and kinematic variables.**

		Day 1	Day 2				
Variable	**Step**	**Mean (±SD)**	**Mean (±SD)**	**Change in mean (units)**	**CV%**	**ICC**	**Reliability factor**
5m time (s)	-	1.10 (.07)	1.08 (.05)	-.02	4.5	.37	Nil
10m time (s)	-	1.83 (.08)	1.82 (.06)	-.01	2.6	.62	Nil
Step frequency (Hz)	1	4.53 (.33)	4.54 (.41)	.01	3.6	.85	High
	2	4.74 (.24)	4.65 (.31)	-.10	3.2	.75	Adequate
	3	4.67 (.28)	4.73 (.36)	.06	3.5	.79	Adequate
Step length (m)	1	.98 (.15)	.99 (.12)	.01	9.0	.65	Nil
	2	1.12 (.08)	1.12 (.09)	.00	3.9	.80	High
	3	1.27 (.12)	1.24 (.11)	-.03	7.2	.44	Nil
Stance time (s)	1	.180 (.020)	.190 (.020)	.010	4.1	.93	High
	2	.160 (.020)	.170 (.020)	.010	6.0	.73	Adequate
	3	.150 (.010)	.150 (.020)	.000	7.5	.73	Adequate
Flight time (s)	1	.042 (.016)	.035 (.020)	-.006	34.9	.74	Nil
	2	.049 (.001)	.045 (.009)	-.004	18.8	.40	Nil
	3	.063 (.014)	.058 (.014)	-.004	19.0	.42	Nil
Knee angle at touchdown (°)	1	115 (8)	117 (9)	1.5	3.2	.85	High
	2	122 (7)	125 (7)	3.0	3.0	.80	High
	3	124 (6)	127 (7)	2.6	3.0	.70	Adequate
Knee angle at take-off (°)	1	152 (4)	152 (4)	-.2	1.3	.83	High
	2	156 (7)	154 (6)	-1.6	2.8	.60	Nil
	3	156 (5)	157 (5)	1.0	1.9	.69	Nil
Trunk angle at take-off (°)	1	41 (6)	40 (4)	-2.1	5.0	.90	High
	2	46 (4)	45 (3)	-1.4	4.6	.70	Adequate
	3	49 (5)	49 (5)	.5	2.6	.96	High

reliability within any of the first three steps. Changes in means ranged from -0.004 to -0.006, which provided ICC values 0.40 - 0.74 and CV% values of 18.8 – 34.9.

Kinematic determinants of 5m sprint times are displayed in Table 3. Step frequency and flight time during the third step show the largest correlation with performance, exhibiting ‘r’ values of -0.386 and 0.396, respectively. Third step length and stance time demonstrate a ‘very small’ correlation with 5m sprint times as per Hopkins (2002), each with ‘r’ values less than 0.03 for both variables. The majority of associations calculated via Pearson correlations were insignificant however the 90% confidence intervals of some outputs indicate that the true value of the statistic may still be substantially meaningful.

Table 3. Correlations between third step kinematic variables and 5m sprint performance.

	Correlation coefficient ‘r’	90% Confidence Interval	Qualitative inference
Step Frequency (Hz)	-.386	-.77 to .21	Small
Step Length (m)	-.227	-.69 to .37	Very small
Stance Time (s)	-.088	-.61 to .49	Very small
Flight Time (s)	.396	-.20 to .78	Small

Discussion

The purpose of this study was to investigate the reliability of short sprint performance and the reliability of the key kinematic determinants involved during the first three steps of the sprint. The aim was to use a practical method of kinematic analysis to help explain why changes may occur in sprint performance via the use of correlative statistics and also to provide reference values for intervention based research. It was hypothesised that short sprint performance would produce high reliability scores, with the kinematic variables demonstrating a lower level of reliability in comparison to performance. It was also hypothesised that step frequency and step length would show high levels of association with sprint performance, with variables such as stance time and flight time having a lesser level of association. The results of this study prove this hypothesis to be incorrect, with sprint performance not meeting the criteria to be considered a reliable measure. Despite this, many of the kinematic variables did prove to be adequately reliable and in some instances demonstrating high levels of reliability. Third step sprint determinants including step frequency and flight time returned small levels of association with sprint performance, with step length and stance time producing very small correlational relationships; therefore proving the secondary hypothesis to be partially correct.

The reliability of sprint performance is a term used to describe the variance in sprint times over a number of trials or testing occasions (Hopkins, 2000). A review of the literature revealed it is common to see short sprint protocols (< 20m) fitting within the criteria required to be considered as either adequately reliable (ICC between 0.70 and 0.80, CV% < 10%), or in most cases highly reliable (ICC > 0.80, CV% < 10%) (Hopkins and Manly, 1989; Paungmali and Sitilertpisan, 2012; Shrout and Fleiss, 1979). Results from the current study were contrasting in comparison to past literature, as neither sprint distance (5m or 10m) met the criteria for either of these two categories. Despite having CV% < 10% (4.5% and 2.6%, respectively), the ICC values for the 5m (0.37) and 10m (0.62) distances did not reach the minimum reliability benchmark; therefore could not be considered as reliable measures**.**

There are multiple reasons for why this discrepancy in results may have occurred between the current study and past literature. Firstly, the effort and intensity utilised by the subjects during each of their trials on the two separate testing days may not have been consistent. As previously stated, small changes (0.01s) in sprint times can be the difference between first and second place. When testing on different days, or over a number of trials, there will be a level of variation in times, even if the athletes sprint maximally every time (Hopkins, 2000). If a participant does not produce maximal efforts consistently throughout each trial / session, there is amplification of the variation and therefore a decrease in the level of reliability the data holds (Hopkins, 2000). The second possible cause of the discrepancies between this study and past literature is the methods and protocols used during testing. Factors such as timing light height, start protocol and start distance can all affect the overall reliability of sprint performance, although typically only by a small percentage (Cronin et al., 2007; Cronin and Templeton, 2008; Frost et al., 2008). Start distance (0.5m) and start protocol (preferred foot split stance) were kept consistent between sessions and the methods were derived from past literature, suggesting they should not have produced any discrepancies, assuming they remained constant throughout testing. It is possible that a combination of these factors united with the suggested lack of individual effort, may have contributed to the overall reliability scores.

One trend that the data of this study did follow, was the lesser degree of variation over longer distances. The variation of the 5m distance (4.5%) was higher than at the 10m distance (2.6%), which imitates trends witnessed in several other studies reporting the reliability of sprint performance (Cronin et al., 2007; Moir et al., 2004). Cronin and Templeton (2008), suggest that the lower CV% at the longer distance is likely due to a larger amount of body variation at the shorter distances, with running becoming more consistent as the distance increases. Due to the fact the population assessed during the current study were team based athletes and not track sprinters, it is assumed that this theory can be applied in this instance also, as their starts are hypothesised to vary more between trials. As previously mentioned, sprint performance is largely dependent on a variety of kinetic and kinematic mechanical variables that ultimately produce movement (Bezodis et al., 2008; Morin et al., 2012). These mechanical variables can have a contributing effect on an individual’s sprint performance; therefore if they vary considerably between trials, it can be assumed that performance will display variance also.

A review of the literature determined that there is very little data surrounding the reliability of the kinematic variables associated with sprinting. Hunter et al., (2004b), and Salo et al., (1996), investigated the reliability of many kinetic and kinematic variables associated with sprinting and sprint hurdles for individuals in late acceleration and running near top speed. These studies obtained reliability statistics for step length, step frequency, stance time, flight time and several body angles associated with touchdown and take-off, which revealed ICC values > 0.70, with many > 0.90 and all CV% values < 10%. Results of the current study somewhat mimic these findings; however not in every case. Step frequency, stance time, knee angle at touchdown and trunk angle at take-off revealed data which corresponded to either an adequate or high level of reliability during each of the first three steps. These values are similar to those witnessed in the studies by Hunter et al., (2004b), and Salo et al., (1996), which suggests in some instances, sprint mechanics are equally as constant nearing top speed as they are in the initial acceleration portion of a sprint. Contrasting to this statement, step length and knee angle at take-off revealed only one step out of the three to be reliable, with flight time not producing any. This could partially be explained by the findings of Salo et al., (1996), who found that step length was a measure that often varied between trials and required at least 11 trials to obtain a reliability score >0.70; therefore the three trials used in the current study may not have been enough to establish a constant average value. Another reason for the irregularities in these particular variables is simply due to the variance that occurs during the initial acceleration phase of individuals who do not train for consistency or strict form (such as our population sample), in comparison to someone such as a track sprinter (Cronin and Templeton, 2008). The advantage of these variables producing reliable data, is that this information can be used to help explain why any changes in performance may have occurred. If an intervention is implemented and an improvement in performance is seen, changes in the measured variables may help describe where and how this intervention has improved. For example, a post-activation potentiation intervention may improve sprint times by 0.2s, but due to the kinetics of performance being impractical to measure, an increase in step length (without a decrease in step frequency) would suggest a larger impulse on take-off. It must be noted that in order for this change to be considered as worthwhile, the change in step length must exceed the CV% achieved, which in the current study was 3.9% – 9%, depending on the step in question (Pearson et al., 2007). It can be stated that although these variables ranged in terms of consistency between trials, human movement over the first three steps does compare somewhat to movement later in a sprint when variability is concerned. The amount of influence these variables have on overall sprint performance can be identified via the investigation of the correlation between particular determinants of interest and sprint performance.

Sprint performance is ultimately determined by a number of kinetic and kinematic variables, which interact with one another causing movement (Bezodis et al., 2008; Morin et al., 2012). Research has identified step length and step frequency as two of the key kinematic sprint determinants, as both have been reported to exhibit strong correlations with performance, although these values do fluctuate within literature (Hunter et al., 2004a; Salo et al., 2011). Stance time and flight time have also been identified as important characteristics in regards to short sprint performance, typically because of their influential relationship with step length and step frequency (Hunter et al., 2004b). The results of this study show dissimilar trends to these statements, as step frequency and stance time had the greatest level of association with 10m sprint performance. Although this was the case, these values (r = -0.386 and 0.396, respectively) only demonstrate a ‘small’ level of interaction between the variables and performance (Hopkins, 2002). These findings were accompanied by ‘very small’ levels of association for both step length and stance time, which again do not mimic typical sprinting theories. When comparing the scarce pool of literature surrounding this topic, it is evident that many of the results also vary from these generally accepted beliefs. For example, Hunter et al., (2004b), investigated the importance of step length and step frequency in relation to sprint velocity. The correlations found between sprint velocity and step length (r = 0.73) and step frequency (r = 0.14) were far different than those found by Morin et al., (2012), who reported data demonstrating step length (r = 0.363) had a much smaller influence than step frequency (0.897), when correlated with max treadmill speed. It is difficult to directly compare these results at face value with the current study, as it would have to be assumed that kinematic correlations with sprint performance will mimic the relationships witnessed for sprint velocity. The small pool of literature surrounding this topic leaves little opportunity for precise comparisons to be made, especially due to the varying nature of the testing procedures. Some research states track speed and treadmill speed are biomechanically different and cannot be generalised due to mechanical and kinetic irregularities between the two (Sinclair et al., 2013); however this conclusion is not consistent throughout literature and is currently still under investigation (Riley et al., 2008). This means conclusions about why these two previous studies may be different, or if values can be compared still remains unclear. The contradicting data-sets between the current study, Hunter et al., (2004b), and Morin et al., (2012), does however fit with the conflicting literature surrounding step length and step frequency, which suggests that although they are key sprint determinants, it is ultimately up to the physical characteristics of the subject to which variable plays a more defining role (Armstrong et al., 1984; Maulder et al., 2008; Mero et al., 1992; Murphy et al., 2003; Salo et al., 2011). It could therefore be possible that variations of this magnitude between three different studies could be explained by the preferences of the individual subjects taking part. The confidence intervals reported in this study suggest this assumption may have some feasibility, as ranges between r = -0.77 and r = 0.21 were identified, which demonstrate high levels of correlations for some subjects, with minimal associations with others. Another key factor that needs to be considered in the current study is the method of measuring kinematic variables. A study by Maćkała et al., (2015), reported a correlation of r = 0.83 between 30m step frequency and 30m sprint times. This method utilised a measurement style which encompassed all the steps over a 30m distance, whereas studies such as Hunter et al., (2004b), used only a single step 16m from the starting point and in this current study measures were taken on the third ground contact. These irregularities in measuring strategies may help explain some of the differences between the studies; however due to the small amount of literature surrounding this topic, it is difficult to state which method is preferred.

Stance times and flight times were investigated by Morin et al., (2012), who found correlations of -0.852 (p < 0.01) and -0.018 (p = 0.95) with maximal treadmill running speed and -0.751 (p< 0.01) and 0.773 (p = 0.88), respectively for 100m performance. This again proves much different to the values obtained for stance time (-0.088) and flight time (0.396) in the present study, which suggests that the treadmill stride patterns may differ than those witnessed during a linear sprint method; therefore backing the conclusions of Sinclair et al., (2013). The findings of Morin et al., (2012), do however compare well with the results of Murphy et al., (2003), who did not perform a correlative study with performance, but identified that there was a significant (p = 0.01) difference between the stance times of ‘slow’ and ‘fast’ athletes. This interaction of results suggests that stance times may in-fact have a greater influence on sprint times than witnessed in the values derived from the current study. Confidence intervals of this study suggest that in some individuals, there was higher correlations of flight and stance times than the final value suggests; therefore it is concluded that kinematic determinants do vary between runners and this concept needs to be recognised when working in group environments. Measurements of stance times and flight times over a number of steps is recommended in order to find which step, or combination of step values (if any), holds the strongest correlation with sprint performance, as currently data pool is scare and still unclear.

One limitation of this study is the number of participants recruited to assist with this investigation. It was concluded by Salo et al., (1996), that the larger the pool of participants utilised during a reliability study, the stronger the results become, as outliers and irregular trials have a lesser influence on the overall outcome. Although ten participants returned a substantial amount of data in the current study, it can be assumed a larger pool of participants would have retuned more reliable results. A second limitation within this study is the number of trials used to establish reliability. Hunter et al., (2004b), found that reliability figures improved when averages of numerous trials were used, with the variance decreasing as trial numbers increased. This trend is consistent with the findings of Salo et al., (1996), who identified that kinematic variables required anywhere from 1-35 trials in order to reach a reliability rating of >0.70. This means that in the current study, a larger number of trials per participant may have provided a more accurate mean value and therefore more reliable results than those achieved by averaging just three trials. The two sessions involved the setup of high speed cameras, timing lights and also body markers on the participating individuals. In order to maintain as little variability as possible, all timing light and camera markers were left marked between sessions, with precautionary re-measurements occurring prior to the second session beginning. Joint markers were kept as consistent as possible by using the same experienced researcher for all the subjects in both sessions; however, there is a possibility that small variations in these markings could have influenced the data analysis process.

Conclusion

The results of this study suggest that short sprint performance (5-10m) does not produce reliable results between trials / sessions, despite these findings being contradictory to past research. It is hypothesised that participant numbers, total trials performed and subject exertion may have played a role in the contrasting results; however due to the population being team sport based, the results cannot be discounted, as these individuals may be more prone to inconsistency in their running. The kinematic variables associated with short sprint performance did produce reliable values in most cases over the first three steps; therefore suggesting they were not as influential on performance as research would suggest. The typically reliable sprint kinematics coupled with the unreliable short sprint times elude to the fact that there must have been other factors influencing the overall performance. This is backed by the correlational findings of this study, which show only ‘small’ and ‘very small’ levels of association found with third step kinematic variables and 5m sprint times. It is recommended that future research investigates kinetic variables associated with performance and identifies if the reliability of these measures corresponds with the reliability of performance. Future research is also required investigating kinematic variables such as step length, step frequency, stance time and flight time and their correlational relationship with different kinetic variables, in order to identify how much (if any) influence they have with these velocity determining components. The practical implications of this study include providing reference values for intervention studies attempting to produce beneficial alterations in performance, as well as adding to a scarce pool of literature surrounding the reliability of sprint kinematics. By having a more in-depth understanding of the components of sprinting and how the underlying concepts interact, it will ultimately provide researchers with the information required to continually develop the movement and draw the best out of athletes in competition.

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Key points

- Key kinematic variables associated with sprint performance produced reliable results between trials/sessions, although sprint performances were identified as unreliable.
- Determinants of sprint performance may vary between individuals from team sports and track sprinters, suggesting intervention studies may benefit from testing both groups.
- Key kinetic variables associated with sprint performance may have a greater influence on outright sprint performance than the key kinematic variables.

AUTHOR BIOGRAPHY

Regan J. STANDING

Employment

Academic Staff Member, Centre for Sport Science and Human Performance, Waikato Institute of Technology

Degree

BSpExSc(Hons)

Research interests

Biomechanics and Physiology of athletic performance

E-mail: regan.standing@wintec.ac.nz

Peter S. MAULDER

Employment

Principal Academic Staff Member, Centre for Sport Science and Human Performance, Waikato Institute of Technology (Wintec)

Degree

PhD

Research interests

Biomechanics of athletic performance

E-mail: Peter.maulder@wintec.ac.nz

✉ **Peter S. Maulder**

Centre for Sport Science and Human Performance, Waikato Institute of Technology, Hamilton, New Zealand