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Title: Choice of sprint start performance measure affects the performance-based ranking within a group of sprinters: which is the most appropriate measure?

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Abstract

Sprint start performance has previously been quantified using several different measures. This study aimed to identify whether different measures could influence the performance-based ranking within a group of 12 sprinters and if so, to identify the most appropriate measure. None of the ten performance measures ranked all sprinters in the same order; Spearman's rho correlations between different block phase measures ranged from 0.50 to 0.94, and between block phase measures and those obtained beyond block exit from 0.66 to 0.85. Based on consideration of what each measure quantifies, normalised average horizontal external power was identified as the most appropriate, incorporating both block velocity and the time spent producing this velocity. The accuracy with which these data could be obtained in an externally valid field setting was assessed against force platform criterion data. For an athlete producing 678 ± 40 W of block power, a carefully set-up manual high-speed video analysis protocol produced systematic and random errors of +5 W and ± 24 W, respectively. Since the choice of performance measure could affect the conclusions drawn from a technique analysis, for example the success of an intervention, it is proposed that external power is used to quantify start performance.

198 words.

Introduction

Successful performance in any sprint event is evaluated based on an ability to cover a specific distance in the least possible time. However, when analysing a discrete part of a sprint such as the start the exact definition of success is less clear. For example, it is difficult to objectively determine whether reaching a specific distance (e.g. 5 m) earlier or reaching this distance slightly later but with a greater instantaneous velocity represents better performance. This may partly explain why several different performance measures have been used in previous sprint start research.

The most commonly used measure of sprint start performance is block velocity (e.g. Henry, 1952; Baumann, 1976; Vagenas and Hoshizaki, 1986; Mero, 1988; Mero and Komi, 1990; Guissard et al., 1992; Schot and Knutzen, 1992; Mendoza and Schöllhorn, 1993; Mero et al., 2006). This quantifies the horizontal velocity of a sprinter's centre of mass (CM) at the instant of block exit, and accurate values are typically calculated from horizontal force data via calculation of impulses. As shown in Table 1, previous studies using force transducers in or under the blocks have reported considerable variation in block velocities, even within sub-groups of relatively homogenous overall ability levels.

****Table 1 near here****

Other widely adopted measures (often used concurrently with block velocity) include the time taken to reach a specific distance (e.g. Henry, 1952; Mero et al., 1983; Vagenas and Hoshizaki, 1986; Schot and Knutzen, 1992; Mendoza and Schöllhorn, 1993; Mero et al., 2006), the instantaneous velocity at a specific distance (e.g. Schot and Knutzen, 1992; Salo and Bezodis, 2004), or the instantaneous velocity at a specific event such as first-step toe-off (e.g. Mero, 1988; Mero and Komi, 1990; Schot and Knutzen, 1992). Where velocity or time measures have been recorded at specific distances, the distances used have varied widely, from 2.29 m to 45.72 m (2.5 yards to 50 yards). A small number of studies have also reported other measures of performance such as peak block phase acceleration (Baumann, 1976), average block phase acceleration (Payne and Blader, 1971; Gagnon, 1978; van Coppenolle et al., 1989; Guissard et al., 1992) and average block phase power (Cavagna et al., 1965; Mero et al., 1983; Mendoza and Schöllhorn, 1993). Despite using sprinters of relatively similar ability levels, the block phase power values reported in these three studies did not clearly correspond to each other. This may have been due to the use of different methods for calculating power, as there are numerous 'types' of energy that can be incorporated when quantifying power (Winter, 1978; Willems et al., 1995). The aim of a sprint is to translate the body over a specific horizontal distance in the shortest time (i.e. each sprinter must perform a specific amount of horizontal external work in the least possible time). Therefore, an ability to produce horizontal external power (i.e. to translate the CM horizontally relative to the environment in a short period of time) appears to be a potentially useful measure of block phase performance despite having been largely overlooked in recent sprint start literature.

The use of different performance measures may be a reason why some experimental block phase studies have reported seemingly conflicting results. For example, Mendoza and Schöllhorn (1993) implemented an experimental intervention to ‘set’ position kinematics and reported two main measures of performance (block velocity and time to 10 m). Only three of the sprinters increased their block velocity following the intervention, with three experiencing a decrease and one no change. Whilst the logical conclusion would therefore have been that their intervention was beneficial for less than half of the cohort, alternative performance data suggested otherwise since the interventions reduced the time it took for all but one of the sprinters to reach 10 m. The results of Mendoza and Schöllhorn (1993) therefore highlight an important issue – the choice of performance measure can potentially affect the conclusions reached in research focussing on sprint start technique and performance.

Whilst it appears that the use of markedly different performance measures (e.g. block velocity and time taken to reach 10 m) could influence the perceived performance success, it is not clear whether such a conflict exists when using less diverse variables such as those determined solely from the block phase (e.g. block velocity, average block acceleration, average block power). Furthermore, if the choice of performance measure does influence the identification of trials or sprinters associated with higher levels of performance, it is important that a single optimal performance measure is determined so that an objective quantification of performance can be achieved. It is also important that this variable can be obtained to a sufficient level of accuracy in an externally valid applied setting where force data are unavailable so that high performance data can be confidently collected and analysed. The aim of this study was therefore to determine whether the choice of performance measure influences the performance-based ranking of a group of sprinters, and if so, to determine the most appropriate and objective measure of performance, assessing the accuracy with which it can be quantified in the field.

Methods

Participants and Procedures

Following protocol approval from the Local Research Ethics Committee, 12 university-level male sprinters (mean ± *s*: height = 1.78 ± 0.05 m, mass = 72.4 ± 8.5 kg, age = 21 ± 4 years, 100 m personal best = 11.30 ± 0.42 s) provided written informed consent for data to be collected at their normal indoor sprint start training sessions just prior to the competition phase of the indoor season. After coach-directed warm-ups, all 12 sprinters completed a series of three maximal effort sprints to 30 m commencing from starting blocks. Each sprinter adjusted the blocks according to their personal preference, and wore their own spiked shoes. Each sprint was initiated by the sprinters' coach, who provided standard '*on your marks*' and '*set*' commands. The coach then pressed a custom designed trigger button to provide the auditory start signal through a sounder device, and simultaneous signals were sent to initiate data collection with a high-speed camera and a Laser Distance Measurement (LDM) device. After each trial, sprinters were allowed their normal recovery (approximately 8-10 minutes).

Data collection

A high-speed digital video camera (Motion Pro®, HS-1, Redlake, USA) was mounted on a tripod, 8.00 m away from the centre of the running lane, with the lens centre 1.00 m above the ground and directly in line with the start line. An area of 2.00 m horizontally by 1.60 m vertically was calibrated with its mid-point at the start line at the centre of the lane inside a field of view 2.50 m wide. Images were collected at a resolution of 1280 × 1024 pixels using a shutter speed of 1/1000 s and a sampling frequency of 200 Hz. Due to the indoor conditions, an additional 4000 W of lighting was used to provide a sufficiently bright image. The LDM device (LDM-300C, Jenoptik, Germany) operating at 100 Hz was positioned approximately 20 m behind the start line in the centre of the lane to obtain data relating to the displacement of the lumbar region of the sprinter for the entire 30 m sprint. The exact distance between the LDM device and the start line was determined during a static trial prior to data collection so that all LDM device distances could subsequently be expressed relative to the start line (0.00 m).

Data processing

The raw video files were viewed to determine movement onset (the first frame in which movement was visible) and block exit (the first frame in which the front foot lost contact with the front block). The video files were then digitised (Peak Motus®, v. 8.5, Vicon, USA) at full resolution with a zoom factor of 2, thus yielding a resolution of measurement of less than 1 mm. Eighteen specific anatomical points (vertex, seventh cervical vertebra, shoulder, elbow, wrist, third metacarpal, hip, knee, ankle and second metatarsophalangeal joint centres) were manually digitised from the frame prior to movement onset through to ten frames after first stance touchdown. The raw digitised co-ordinates were scaled (using projective scaling with the four corner points of the aforementioned rectangular calibration area). The resulting raw displacement time-histories were exported to Matlab™ (v. 7.4.0, The MathWorks™, USA) for subsequent analysis. The raw displacement data were combined with segmental inertia data (de Leva, 1996) to create a 14-segment model. Inertia data for the feet were taken from Winter (1990) to allow for a linked segment model to be created, and the measured mass of each individual sprinter's spiked shoe (group mean = 0.23 ± 0.05 kg) was added to both feet. The raw whole-body CM displacement time-history (required for the calculation of performance measures) was calculated from the segmental data using the summation of segmental moments approach (Winter, 1990).

Calculation of performance measures

Block velocity was calculated using the raw CM displacement data from each frame of the first flight phase. The first derivative of a linear polynomial fitted through the raw horizontal CM coordinates from the first flight phase was used to calculate horizontal velocity at take-off (i.e. block velocity), as outlined by Salo and Scarborough (2006). Block velocity was also calculated with two other commonly used methods, but as the above polynomial method was found to provide the most accurate estimation (see Appendix for details) it was used throughout this study. Average horizontal block acceleration was calculated as block velocity divided by the duration of the push phase (i.e. from movement onset to block exit). Average horizontal external power during the push phase was calculated based on the rate of change of mechanical energy in a horizontal direction (i.e. change in kinetic energy divided by time):

$$\overline{P} = \frac{m\left(v_f^{\,2} - v_i^{\,2}\right)}{2 \cdot \Delta t}$$

in which v_i and v_f are the horizontal velocities at the start and end of the push phase, respectively (i.e. v_i = 0 m/s), Δt is the duration of this phase, and m is the mass of the sprinter.

The LDM device was used to obtain displacement and velocity-based measures of performance from beyond the block phase for inclusion in the comparison of performance measures. It was important to obtain LDM device velocity time-histories that were relatively smooth functions, independent of any within-step fluctuations, as these could influence instantaneous velocity values taken from a specific point on the curve as shown by Salo and Bezodis (2004). To improve the 'averaging method' used to calculate velocity by Salo and Bezodis (2004), a fifth-order polynomial function was fitted to the raw LDM displacement data to remove both the within-step velocity fluctuations and the random noise. This function was analytically differentiated with respect to time in order to yield a fourth-order representation of the velocity profile. From these functions, the time at which displacement equalled 10, 20 and 30 m was identified, as were the corresponding velocity values at these distances.

From the high-speed camera and LDM device, nine measures of performance were thus obtained, all of which had been used in previous sprint start research. These were:

- Block velocity
- Average horizontal block acceleration
- Average horizontal external block power
- Time to 10 m
- Time to 20 m
- Time to 30 m
- Velocity at 10 m

- Velocity at 20 m
- Velocity at 30 m

Because smaller sprinters require less power to translate their CM to the same extent as a larger sprinter, a tenth performance measure (normalised average horizontal external block power) was calculated. This was based on a modification of the function presented by Hof (1996) in order to obtain a dimensionless normalised power (P_N) value:

$$P_N = \frac{\overline{P}}{m \cdot g^{3/2} \cdot l^{1/2}}$$

where m is the mass of the sprinter, g is the acceleration due to gravity, and l is the leg length of the sprinter. This was corrected from the function presented by Hof (1996) since that was found to produce normalised power with the units s^{-2} rather than as a dimensionless number as intended.

For all of the above variables used to quantify performance, the mean performances of each of the 12 sprinters were ranked from 1 (best) to 12 (worst). Spearman's rank order correlation co-efficients (ρ) were then calculated from these ordinal data to determine whether different performance measures ranked the mean performances of the 12 sprinters in the same order, or whether the choice of performance measure affected the rank order of the sprinters.

Accuracy of high-speed video protocol

The internal validity of the video set-up and data processing methods was evaluated against criterion kinetic data by replicating the previously described camera set-up in a laboratory setting. One trained male sprinter (age = 23 years, mass = 62.3 kg, height = 1.71 m, 100 m personal best = 11.20 s) provided informed consent and completed a series of 20 sprint start trials. The starting blocks were firmly spiked into a 1 cm thick rubber mat which was strongly bonded to a sheet of thin steel, which in turn was securely bolted to a 0.900 x 0.600 m force platform (Kistler, 9287BA, Kistler Instruments Ltd., Switzerland) operating at 1000 Hz. The hands were placed on the front edge of the force platform, and the starting blocks were adjusted to the preference of the sprinter. The blocks were constrained to remaining on the force platform in order to ensure that all points of ground contact were on the platform. In each trial, the sprinter raised in to the 'set' position upon standard starting commands from the investigator. The investigator subsequently pressed a trigger button, sending a signal to the sounder device and high-speed video camera, and additionally to the computer collecting the force platform data. The trigger signal was also transmitted to a series of 20 light-emitting diodes (Wee Beastie Ltd, UK) placed in the camera view, one of which illuminated every 1 ms thus allowing synchronisation of the force and video data to the nearest millisecond.

Horizontal impulse data were obtained through integration (trapezium rule) of the raw horizontal force data, and the associated velocity data were subsequently determined. Criterion movement onset time was defined as the frame in which the horizontal force first increased, and then subsequently remained, two standard deviations above the mean horizontal force recorded during the first 50 ms following the starting signal (during which the athlete remained stationary in the set position before reacting to the signal). Criterion block exit time was determined as the frame in which horizontal force first dropped below a threshold of 10 N (this was different to the threshold used to identify movement onset due to the vibrations of the blocks on the force platform rendering the previously used threshold inaccurate). The corresponding velocity at the instant of block exit was thus identified and recorded as the criterion measure of block velocity. Force platform power values were calculated from the product of the horizontal force and velocity time-histories, and were averaged across the push phase to yield a criterion measure of average horizontal external power.

The video data were reduced and processed exactly as outlined in the previous section in order to directly replicate the protocol used in the field. Difference scores were calculated between the high-speed video estimate of block velocity and the force platform criterion measure for all 20 trials (i.e. video minus criterion score). These difference scores were then plotted against the mean value of the video and criterion measures of block velocity from each corresponding trial (Altman and Bland, 1983). To quantify the validity of the high-speed video data, 95% limits of agreement were calculated from the standard deviation of all the difference scores between the video and criterion values (Bland and Altman, 1986) using the appropriate critical *t*-value (2.093, $p = 0.05$) for the number of trials analysed. Finally, using the block velocities and push phase durations estimated from the video data, average block acceleration and average horizontal external block power data were also calculated, and 95% limits of agreement were calculated for these variables against the associated criterion data.

Results

No two measures ranked the performances of all sprinters in the same order (Figure 1), and thus no two measures were perfectly correlated (in Figure 1 it would be expected that there would be 12 horizontal lines if each measure ranked all subjects in the same order). Whilst the ‘time to’ and ‘velocity at’ measures were closely matched to each other (i.e. the right hand side of Figure 1, where the lines cross over each other considerably less; ρ = 0.91 – 0.99, $p < 0.01$), correlations between these and the block phase measures were weaker (i.e. ρ = 0.66 – 0.85, $p < 0.05$). The high-speed video based measures of block phase performance for each subject are presented in Table 2, and correlations between these measures were typically moderate to strong. The correlation between block velocity and average horizontal block acceleration was ρ = 0.68 ($p < 0.05$), between block velocity and average horizontal external block power was ρ = 0.50 ($p = 0.10$), and between average horizontal block acceleration and average horizontal external block power was ρ = 0.80 ($p < 0.01$). Normalised average horizontal external block power values were correlated with the absolute values with a strength of ρ = 0.72 ($p < 0.01$), and when these normalised power data were correlated with the block velocity and acceleration data, the coefficients were ρ = 0.88 and ρ = 0.94 (both $p < 0.01$), respectively.

****Figure 1 near here****

****Table 2 near here****

The systematic bias associated with the high-speed video estimates of block velocity relative to the force platform criterion values was +0.005 m/s, with 95% limits of agreement of ± 0.048 m/s (Figure 2). The duration of the push phase could be estimated from the high-speed video data to an accuracy of -0.001 ± 0.007 s. When these high-speed video estimates of block velocity and push phase duration were used to calculate average horizontal block acceleration and average horizontal external block power, systematic and random errors of +0.025 ± 0.173 m/s^2 and +5 ± 24 W, respectively, were observed.

****Figure 2 near here****

Discussion and implications

This study determined that the choice of performance measure influenced the identification of successful performance during the block phase of an athletic sprint start. The controlled laboratory replication of the field-based methods confirmed that all of the high-speed video based measures of block phase performance (block velocity, average horizontal block acceleration and average horizontal external block power) could be accurately determined in an externally valid setting. The following section will briefly review the accuracy of the manual high-speed video protocol, before discussing the different performance measures and ultimately identifying which measure provides the most objective assessment of block phase performance.

Relative to the criterion force platform data, the systematic bias associated with the high speed video block velocities (+0.005 m/s) represented less than 0.2% of the mean criterion block velocity measured from the 20 laboratory trials (2.89 m/s). The random error (quantified by the 95% limits of agreement) associated with block velocity measurement was also small (± 0.048 m/s, less than 1.7% of the mean criterion value). If using block velocity as a measure of performance, the current high-speed video protocol could therefore be used to distinguish between trials or sprinters separated by just under 0.1 m/s. Compared to the block velocity data presented in Table 1 from sprinters of a similar ability range to those in the current study, this appears to be a sufficient level of accuracy with which to distinguish levels of performance both within and between individual sprinters. The systematic biases associated with average horizontal acceleration and average horizontal external power were also small (+0.025 m/s^2 and +5 W, respectively) due to the duration of the push phase being accurately determined from the video clips. This systematic error in the measurement of acceleration represented less than 0.4% of the mean value (7.45 m/s^2), whilst the random error (± 0.173 m/s^2) associated with the estimation of acceleration represented a 2.3% error. For the power data, the systematic error (5 W) represented 0.7% of the mean value (678 W), and the 95% limits of agreement (± 24 W) associated with the high-speed video measurement of power were 3.5% of this mean value. Given the lower ability level of the sprinter used for the laboratory analysis, and the fact that a slightly ‘bunched’ start was used (due to the constraint that all points of contact were required to be on the force platform), these velocity, acceleration and power values were lower than those typically observed in the literature (e.g. Table 1; van Coppenolle et al., 1989; Mendoza and Schöllhorn, 1993). The percentage errors presented above would therefore be expected to be lower in externally valid field settings using more well-trained sprinters (with higher velocity, acceleration and power) adopting their normal ‘set’ positioning since the errors relate to the data collection and processing protocol rather than the ability level of the sprinters. The results of this validity analysis therefore revealed that manual high-speed video estimates of block velocity, average horizontal block acceleration and average horizontal external block power all contained appropriately low levels of systematic and random error.

None of the ten measures ranked all of the sprinters in the same order, as indicated by the Spearman's rank order correlations which revealed that no two measures of performance were perfectly correlated (Figure 1). Despite some strong and significant correlations in this study, any rank order correlation coefficient less than 1.00 indicated inconsistency in the performance-based ranking of these 12 sprinters. The correlation coefficients between the measures obtained at block exit and those obtained further down the track ($\rho = 0.66 - 0.85$) confirmed the ideas developed from the results of Mendoza and Schöllhorn (1993) that although measures obtained from beyond block exit have been widely used when investigating the block phase, their direct relevance to technique and performance during just the block phase must be considered with caution. Whilst they clearly provide meaningful sprint performance data, the time taken to reach set distances or the velocity at these distances is a function of the techniques used in every step prior to that distance, and not just technique during the block phase. Whilst it is acknowledged that as the distance at which performance is measured moves further from the start line, the value obtained will get continually closer to the key performance indicator in sprinting (i.e. the time taken to reach the finishing distance), performance should ideally be quantified during just the phase over which technique is analysed, allowing the observed performance levels to be directly attributed to the observed techniques.

Whilst all of the performance data calculated solely from the block phase (i.e. block velocity, average horizontal block acceleration, average horizontal external block power and normalised average horizontal external block power) could be accurately calculated from high-speed video data, the correlation coefficients between each of these measures highlighted that even the use of different block phase measures could affect the outcome of a study. The correlation ($\rho = 0.72$) between the average and normalised block power data confirmed that different subject morphologies influence the absolute magnitudes of power generated, and thus power data should be normalised to account for this when used as a measure of performance between subjects. Even when body size was accounted for in these normalised power data, the sprinters were still ranked in a conflicting order to both the block velocity and acceleration data ($\rho = 0.88$ and $\rho = 0.94$, respectively). The potential influence of the choice of performance measure on the perceived ability of one single sprinter within the cohort is well illustrated by sprinter I – ranked the third best sprinter based on block velocity, the eleventh best based on average horizontal block acceleration, the worst based on average horizontal external block power, and the eighth best based on normalised average horizontal external block power. It is therefore clearly important to consider what each measure actually quantifies, and to determine the most objective and appropriate measure of sprint start performance.

The use of block velocity as the sole measure of performance is potentially misleading. Velocity is directly determined by horizontal impulse production, and because impulse is equal to the product of force and time, an increased block velocity could therefore be due to either an increase in the net propulsive force generated, or to an increased push duration. Spending a longer time in the blocks conflicts with the 'least possible time' nature of a sprint, and therefore if an increased block velocity were associated solely with an increase in push duration, it would not be beneficial for overall sprint performance. Although measures of both velocity and time could be obtained, the relative weighting of each of these variables would be difficult to objectively determine, and so a single measure of performance is a more appropriate and unbiased approach. Average horizontal block acceleration is potentially a more useful measure of performance than block velocity due to the additional incorporation of time, and it has previously been shown that whilst one athlete may exhibit a higher block velocity, another could have a higher acceleration due to a shorter push phase duration (van Coppenolle et al., 1989). Power also incorporates the effects of both time and velocity; however, acceleration and normalised power-based rank orders were not perfectly correlated ($\rho = 0.94$). Being a kinetic variable, power production ultimately determines acceleration (a kinematic variable), and since the overall aim in sprinting is to reach the finish in the least possible time (each sprinter must perform a specific amount of work to translate their CM horizontally over 100 m, and the time it takes to do this depends on horizontal external power production), power production is of critical importance. Average horizontal external power is not the same as total power, since it ignores the necessary vertical motions and the internal power associated with the relative motion of body segments (Winter, 1978). However, reducing metabolic cost is not the main goal in sprinting (Caldwell and Forrester, 1992) and thus neither the total power nor the efficiency of movement are of major importance when using power as a measure of sprint performance. Theoretical studies have suggested that the most preferable strategy in sprint events is one in which maximal horizontal external power is produced from the very beginning. Although more energy is theoretically lost to air resistance and thus velocity is reduced towards the end of the race, this is outweighed by less time being spent running at submaximal velocities at the start (van Ingen Schenau et al., 1991, 1994; de Koning et al., 1992). Maximal external power production during the block phase therefore appears paramount for performance. Furthermore, based on these theoretical data, maximal external power production also appears important during every part of a sprint, and thus normalised average horizontal external power potentially offers an appropriate measure of performance for any stage of a sprint which is being analysed (be it trying to maximise power generation during the early stages of a sprint, or to minimise power loss during the latter stages of a sprint).

Although it was not the main aim of this study, the performance data in Table 2 also provide further information about the block phase to the literature. Sprinters A and B, who had the two best personal bests, also achieved the highest power values, both in absolute and normalised terms. The absolute power values for these two subjects were comparable to values presented by Mendoza and Schöllhorn (1993), suggesting that sprinters able to run close to 10.5 s possess the ability to generate such power in the blocks. Interestingly the sprinter with the third fastest personal best (sprinter C) exhibited the lowest level of block phase performance (normalised block power). This suggests that his start is relatively weak and improvements could potentially be achieved in this area. Similarly, sprinters E and F seem to have better normalised block power values than other sprinters of similar calibre. This might suggest that sprinters E and F could focus more on their actual running than on the block phase to improve their performance. Overall, this type of comparison could give coaches a clear indication of an athlete's relative strengths and weaknesses, and thus help to guide their training.

Conclusion

The results of this study revealed that each of ten previously used measures of block phase performance ranked the performances of a cohort of 12 sprinters in different orders. Therefore, if a coach or researcher intended to associate aspects of block phase technique with changes or improvements in performance, the choice of performance measure could clearly influence the conclusions reached. Normalised average horizontal external power was identified as the most appropriate measure of performance because it objectively reflects, in a single measure, how much a sprinter is able to increase their velocity and the associated length of time taken to achieve this, whilst accounting for variations in morphologies between sprinters. Furthermore, external power is clearly directly relevant to overall sprint performance and can be used to analyse performance from any phase of a sprint. The accuracy with which these power data could be determined from a carefully set-up manual high-speed video analysis protocol was also assessed, and it was shown that accurate high-performance data could be obtained using this non-invasive approach in field settings.

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Appendix

The accuracy of different methods for calculating block velocity

In addition to the method used to calculate block velocity from high-speed video data in this article (i.e. the first derivative of a linear polynomial fitted through raw CM data from the subsequent flight phase), the accuracy of two other available methods for calculating block velocity was assessed to ensure that the most accurate method was used. Firstly, the commonly adopted process of digitally filtering the CM data from the block phase and first flight, and extracting the instantaneous block exit velocity was undertaken. Secondly, the gradient of a straight line fitted between the raw CM displacement data from first and last frames of flight only was calculated (Yu and Hay, 1996). The block velocity values obtained from these two methods were compared to the criterion force platform data using a 95% limits of agreement approach (Bland and Altman, 1986). Relative to the criterion data, the digital filtering method yielded systematic and random errors of +0.084 ± 0.190 m/s, respectively, whilst the method of Yu and Hay (1996) yielded systematic and random errors of +0.018 ± 0.056 m/s, respectively. Despite using the same raw displacement data, these methods were less accurate than the polynomial method ultimately used in the current article (systematic and random errors of +0.005 ± 0.048 m/s).

Table 1. Force transducer-based estimates of block velocity for male sprinters of a similar ability range to those in the current study (mean ± *s*).

Study	n	PB* (s) (range if reported)	Block velocity (m/s)
Baumann (1976)	12	10.35 ± 0.12 (10.20 – 10.60)	3.60 ± 0.20
Baumann (1976)	8	11.11 ± 0.16 (10.90 – 11.40)	3.10 ± 0.15
Baumann (1976)	10	11.85 ± 0.24 (11.60 – 12.40)	2.90 ± 0.20
Mero (1988)	8	10.79 ± 0.21 (10.45 – 11.07)	3.46 ± 0.32
Mero and Komi (1990)	4	10.76 ± 0.19	3.42 ± 0.38
Mero and Komi (1990)	4	10.82 ± 0.23	3.50 ± 0.22

* PB = 100 m personal best time.

Table 2. High-speed video recorded measures of block phase performance for each of the 12 sprinters (mean ± *s*).

Sprinter	100 m PB (s)	Block velocity (m/s)	Horizontal block acceleration (m/s^2)	Average horizontal external block power (W)	Normalised average horizontal external block power
A	10.53	3.52 ± 0.06	10.52 ± 0.58	1449 ± 95	0.63 ± 0.04
B	10.70	3.83 ± 0.09	10.55 ± 0.13	1703 ± 57	0.66 ± 0.02
C	10.90	3.00 ± 0.01	7.94 ± 0.14	912 ± 14	0.40 ± 0.01
D	11.10	3.28 ± 0.12	9.43 ± 0.44	1113 ± 93	0.52 ± 0.04
E	11.19	3.31 ± 0.04	10.56 ± 0.08	1298 ± 24	0.58 ± 0.01
F	11.2*	3.39 ± 0.11	9.69 ± 0.31	1013 ± 63	0.56 ± 0.03
G	11.2*	3.13 ± 0.03	8.75 ± 0.27	953 ± 33	0.47 ± 0.02
H	11.3*	3.24 ± 0.09	8.95 ± 0.18	874 ± 35	0.48 ± 0.02
I	11.3*	3.41 ± 0.06	8.06 ± 0.21	803 ± 32	0.46 ± 0.02
J	11.55	3.11 ± 0.07	8.49 ± 0.15	966 ± 37	0.44 ± 0.02
K	11.6*	2.97 ± 0.07	8.14 ± 0.21	951 ± 42	0.41 ± 0.02
L	11.6*	3.12 ± 0.08	8.58 ± 0.51	1097 ± 93	0.44 ± 0.04
Mean ± *s*	11.30 ± 0.42	3.28 ± 0.24	9.14 ± 0.99	1094 ± 264	0.51 ± 0.09

* 100 m personal best (PB) times reported to the nearest 0.1 s are hand timed. The presented mean value includes a standard 0.24 s adjustment to the hand timed values.

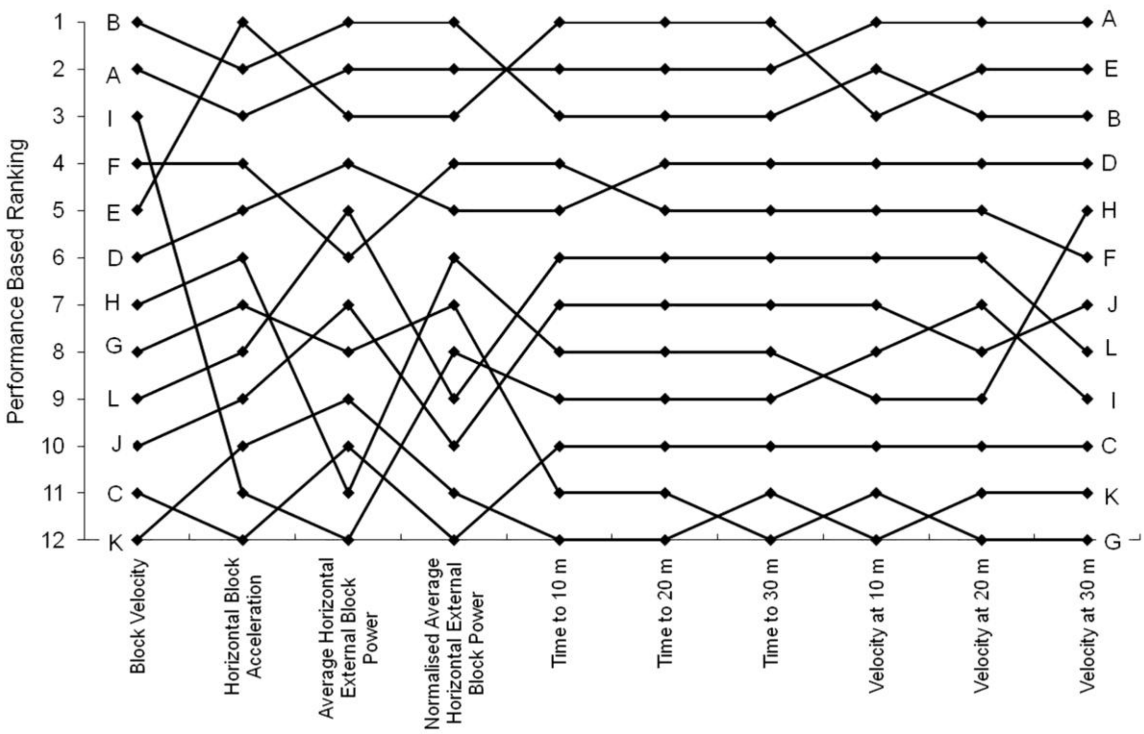

Figure 1. Rank order of all of the 12 sprinters using each of the different performance measures.

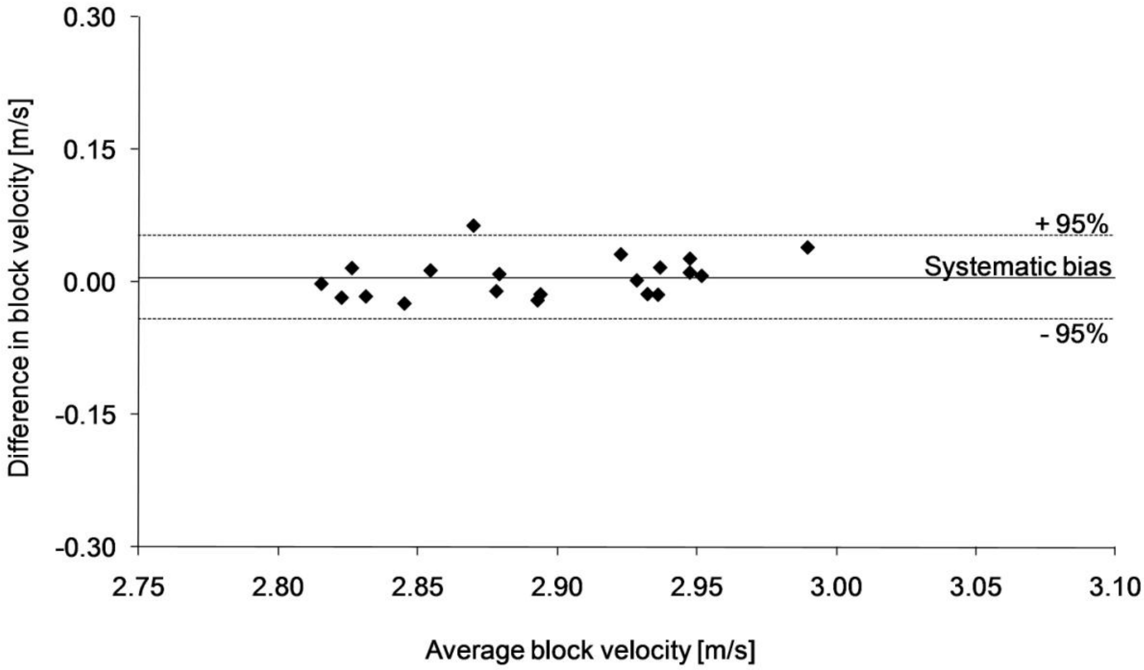

Figure 2. Illustration of the systematic bias and 95% limits of agreement for the high-speed video block velocity data.