

BIOLOGICAL MOVEMENT VARIABILITY DURING THE SPRINT START

Elizabeth J. Bradshaw, Peter S. Maulder*, and Justin Keogh*

Australian Catholic University, Melbourne, Australia

*Auckland University of Technology, Auckland, New Zealand

The current study proposed a method for estimating biological movement variability in order to examine its effect on 10 m sprinting performance. Two 250 Hz cameras recorded the sprinters (male, n=10) action across four trials to enable the kinematics of their block start and initial strides to be obtained using motion analysis software (APAS). Infra-red timing lights were utilised to measure the 10 m sprinting times. The coefficient of variation (CV %) calculation was adjusted in order to separate biological movement variability (BCV %) from variability induced by measurement error (SEE %). This adjustment revealed that measurement error highly inflated traditional measures of movement variability (CV %) by up to 72%. Variability in task outcome kinematics was considerably lower than that observed in joint rotation patterns. Few biological variability measures had a direct relationship with reduced sprinting time.

KEY WORDS: variability, coefficient of variation, standard error, sprint.

INTRODUCTION: The kinematic pattern of skilled athletes performing the short sprints has received considerable attention in the literature (e.g. Atwater, 1982) in an attempt to provide coaches and athletes with a relatively invariant biomechanical model for training. However, the sprint start and early strides is a coordinated muscular effort that must be achieved with movement stability for consistent performance. To accomplish this goal, a flexible control strategy afforded by redundant degrees of freedom during the execution of the skill could be favourable over a traditional approach of absolute invariance in the movement through repetition (Knight, 2004). A flexible (variant) movement control strategy during the execution phase could enable the performer to adjust for various intrinsic (e.g. confidence, fatigue) and extrinsic factors (e.g. wind, temperature) that can influence their performance (Bradshaw and Aisbett, 2006). Thus, these subtle changes between sprints can preclude exact movement coordination patterns from one race to the next (Lee et al, 1982; Bradshaw and Aisbett, 2006). Measuring only the average movement pattern, such as the kinematic descriptors of the accelerative stride (e.g. length, frequency, angles), therefore, ignores the coordinative strategies employed.

The motor control and learning literature has indicated that movement coordination from either the task outcome (e.g. stride length) or the coordination patterns (e.g. joint rotation speed) provides distinctly opposing views of variability (Heiderscheit, 2000). Variability in stride characteristics has been traditionally viewed as a limitation to the successful performance of locomotion tasks; whereas variability in joint coordination can provide the necessary flexibility for superior task execution. High stride-to-stride walking 'outcome' variability (length, duration), for example, may be a predisposing factor for an injurious fall in the elderly (Heiderscheit, 2000). In closed kinetic chain activities such as drop landings, however, increased 'component' variability in, for example, knee flexion in combination with internal tibial rotation (joint coupling) reduces the demands on the rotary stabilisers and may therefore provide the individual with the coordinative flexibility to safely adjust for different landings (Tillman et al, 2005).

High outcome movement variability may be indicative of reduced performance stability either through suboptimal execution, or by unstable tasks such as movement transitions (e.g. walk-to-run transition), and/or acceleration or deceleration (Heiderscheit, 2000). In locomotion tasks where there is no real endpoint goal that spatially constrains the performers movement, stride-to-stride movement variability (footfall position variability) has been demonstrated to increase with each successive foot strike (Bradshaw and Sparrow, 2001). In long jumping, the ability to flexibly control stride variability through visual adjustments enables the performer to better satisfy the dual task constraints of speed and spatial endpoint accuracy,

leading to enhanced performance (Bradshaw and Aisbett, 2004). However, to the authors' knowledge, the effect of this stride-to-stride variability on sprinting performance has not been addressed, particularly in regards to the sprint start and early acceleration phase of the 100 m dash. Whilst there is no spatial endpoint goal that constrains movement in the short sprints, there is arguably a temporal endpoint goal; that being to perform the task within a certain (lowest possible) time.

Outcome and component movement variability has typically been quantified using the coefficient of variation (CV %) (e.g. Hausdorff et al, 1999). However, this same measure has also often been utilised as an estimate of the reliability of specific measurements in science (e.g. Atkinson and Nevill, 1998; Hopkins, 2000). Perplexingly, therefore, the coefficient of variation measures may include variable percentages of both measurement error (e.g. due to the filming set-up, environmental changes during field testing, digitisation) and biological movement variability (Rodano and Squadrone, 2002). The purpose of the current study was, therefore, to propose a method for estimating biological movement variability, and to examine the effects of biological movement variability on the start and early acceleration phase of sprinting performance.

METHOD: Ten 17-23 year old male regional and national-level track sprinters (100 m personal best: 10.87 ± 0.36 s) performed four 10 m sprints from a block start on a Mondo track surface. Swift timing lights (80 Hz) recorded the athlete's performance from the starting signal to the 10 m line. The block start and the first two strides were filmed two-dimensionally using two high-speed cameras (Fastcam PCI1000) operating at 250 Hz with a shutter of 1/500 s placed perpendicular to the action (left hand side of the athlete). The first camera captured the starting action and the initial stride; whilst the second camera captured the next stride. Both cameras were positioned 13 m from the athlete and elevated to the athlete's approximate hip height of 1.1 m. A 1.7 m high calibration rod, fitted with a spirit level, was filmed pre and post each testing session at three known locations along the centre of the lanes long axis, to provide a two-dimensional scale reference for the subsequent video analysis. The calibration positions included one overlapping view for the cameras.

The high-speed video footage from both cameras was analysed frame-by-frame to identify the x,y coordinates of eighteen points on the athletes body using a manual motion analysis system (APAS), consistent with the methods of Johnson and Buckley (2001). Digitizing commenced from the starter's signal until five frames after the take-off for the third stride. In this study, a stride was defined as the time and distance between two consecutive foot touchdowns consistent with the terminology utilized in the literature specific to athletics (e.g. Hay and Nohara, 1990). The data was smoothed using a digital filter with a cut-off frequency of 8 Hz. From the data of the eighteen body landmarks, position, time, and velocity of the joints and segments were derived. All absolute angles were measured from the distal end of the segment in a counter clockwise direction (i.e. trunk angle – hip to shoulder angle with reference to the horizontal axis at the hip, averaged across both sides of the body, push-off angle – toe to centre of gravity angle with reference to the horizontal axis about the toe of the planted foot).

Means (\bar{X}), standard deviations (SD), standard error ($SEE \% = \left[\frac{SD/\sqrt{n}}{\bar{X}} \right] \times 100$), coefficient of variations ($CV \% = SD/\bar{X} \times 100$), and biological coefficient of variations ($BCV \% = CV \% - SEE \%$) were calculated for the kinematic measures for each individual athlete at the instant of block push-off, and at the average for the instant of toe-off across the initial two strides. The biological coefficient of variation was calculated to estimate the effect of measurement error on the true biological movement variability. Pearson's product-moment correlation coefficients and linear regression analysis was employed to establish relationships between measures of biological movement variability (BCV %) and 10 m sprint start performance (best 10 m time) or 10 m sprint start performance consistency (10 m time BCV %) using SPSS version 12.0. Statistical significance was set at $p \leq 0.05$ for all analyses.

RESULTS AND DISCUSSION: Four of the athletes performed the block start and 10 m sprint in 2.0 s or less (Table 1). Interestingly, all of the athletes performed their best time during the first trial with performances ranging from 1.93 to 2.14 s ($\bar{X} = 2.03 \pm 0.06$ s). The individual variability (BCV %) in the athletes performances across the four trials ranged from 0.12 to 0.97 % ($\bar{X} = 0.56 \pm 0.27$ %), after accounting for the estimated measurement error (SEE %) of approximately 0.60 % (0.16 to 1.33 %).

Table 1. The 10 m performance and consistency for the ten male athletes.

Rank	Best Performance			Coefficient of Variation			Biological Coefficient of Variation		
	10m Time (s)	Total Block Time (s)	Run Time (s)	10m Time (%)	Total Block Time (%)	Run Time (%)	10m Time (%)	Total Block Time (%)	Run Time (%)
1	1.93	0.368	1.56	0.94	4.55	0.18	0.47	2.27	0.09
2	1.98	0.352	1.57	2.30	9.15	2.44	0.97	4.57	1.03
3	1.99	0.440	1.54	1.42	4.29	1.53	0.71	2.15	0.77
4	2.00	0.384	1.60	1.35	8.67	0.65	0.68	4.34	0.33
5	2.04	0.432	1.59	1.83	1.48	2.48	0.91	0.74	1.24
6	2.04	0.400	1.62	1.01	5.34	0.55	0.50	2.67	0.28
7	2.05	0.440	1.60	0.69	3.79	0.27	0.34	1.89	0.13
8	2.06	0.480	1.57	1.14	2.47	1.93	0.57	1.23	0.96
9	2.11	0.456	1.65	0.27	2.44	0.55	0.12	1.22	0.23
10	2.14	0.440	1.69	0.66	1.46	0.81	0.33	0.73	0.40
Average	2.03	0.419	1.60	1.16	4.36	1.14	0.56	2.18	0.55
SD	0.06	0.04	0.05	0.60	2.72	0.88	0.27	1.36	0.42

Tables 2 and 3 summarize the movement variability observed during the starting block and early stride phases, respectively. Reduced variability in the generation of horizontal speed when leaving the starting blocks ($r=0.683$, $p=0.030$) was associated with improved performance (best 10 m time). However, linear regression modelling revealed that the combined effect of reduced variability in horizontal block leaving velocity and increased variability in the angular velocity of the lead ankle were the best coordinative measures associated with reduced 10 m sprinting time ($r=0.882$, $p=0.005$). The ability to achieve more consistent speed out of the starting blocks led to more stable speed production during the first two strides (Stride 1 - $r=0.933$, $p=0.000$; Stride 2 - $r=0.687$, $p=0.027$), especially with regards to controlling the length of the successive (second) stride ($r=0.642$, $p=0.045$).

Table 2. The traditional coefficient of variation (CV %) and biological coefficient of variation (BCV %) measurements for the starting block action at push-off.

Block Take-Off Phase	Angle (deg)			Angular Velocity (deg/s)		
	SD	CV (%)	BCV (%)	SD	CV (%)	BCV (%)
Trunk	6.03	10.37	5.19	-	-	-
Push Off	1.37	2.52	1.26	-	-	-
Lead Hip	6.82	4.65	2.39	65.87	37.47	17.38
Lead Knee	5.34	4.62	2.66	100.47	21.34	10.67
Lead Ankle	4.72	3.21	1.60	50.17	54.46	26.29
Trail Hip	8.02	2.33	1.29	92.81	60.55	29.72
Trail Knee	5.19	1.93	0.53	77.14	53.09	25.76
Trail Ankle	6.41	3.52	1.76	100.81	22.28	11.14

Overall, it was revealed that variability induced by measurement error accounted for 42% (Block take-off lead knee angle) to 72% (Block take-off trail knee angle) of movement variability when utilising the traditional coefficient of variation measure. Further, outcome movement variability (linear kinematics) was generally lower than component variability (angular kinematics). Outcome movement variability (BCV %) ranged from 0.55% for run time to 2.47 % for the velocity of the secondary stride. Whereas; component variability ranged from 0.53% for the trail knee angle to 29.72% for trail hip angular velocity during the block take-off.

Table 3. The traditional coefficient of variation (CV %) and biological coefficient of variation (BCV %) associated with measurements of the strides; (a) linear kinematics and (b) angular kinematics.

(a) Strides	SD	CV (%)	BCV (%)	(b) Angle (deg)			Angular Velocity (deg/s)		
				SD	CV (%)	BCV (%)	SD	CV (%)	BCV (%)
Contact Time (s)	0.02	4.60	2.30						
Stride 1:									
Length (m)	0.03	2.59	1.32						
Frequency (Hz)	0.17	2.75	1.54						
Velocity (m/s)	0.27	4.69	2.37						
Stride 2:									
Length (m)	0.12	4.35	2.20						
Frequency (Hz)	0.30	3.29	1.59						
Velocity (m/s)	0.32	4.94	2.47						
Trunk	5.46	8.31	4.16	-	-	-			
Push Off	1.95	3.29	1.64	-	-	-			
Lead Hip	6.48	4.65	2.33	76.96	32.70	16.35			
Lead Knee	5.76	3.14	1.57	77.45	19.61	9.81			
Lead Ankle	4.05	3.07	1.54	61.60	53.59	26.80			
Trail Hip	7.88	2.02	1.01	79.19	55.65	27.82			
Trail Knee	6.23	2.30	1.15	138.72	25.80	12.90			
Trail Ankle	5.73	2.49	1.24	134.89	27.84	13.92			

CONCLUSION: Traditional observations of movement variability are corrupted by variable proportions of measurement error and, thus, provide limited insight on true biological variability. Biological movement variability associated with the sprint starting action is generally low, however joint coordination measures (joint rotation speed) alludes to a flexible movement coordination strategy. Consistent generation of high horizontal speed out of the blocks leads to more stable and faster starting strides for the short sprint events in athletics. A flexible control strategy may be encouraged during training by, for example, small changes to the athlete's preferred block set-up, utilising different running surfaces, and training with and against the prevailing wind conditions. Future research could investigate the role of joint coupling in the generation of horizontal speed during the sprinting action.

REFERENCES:

- Atkinson, G. & Nevill, A.M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, **26**, 217-238.
- Atwater, A.E. (1982). Kinematic analyses of sprinting. *Track and Field Quarterly Review*, **82**, 12-16.
- Bradshaw, E.J. & Sparrow, W.A. (2001). Effects of approach velocity and foot-target characteristics on the visual regulation of step length. *Human Movement Science*, **20**, 401-426.
- Bradshaw, E.J. & Aisbett, B. (2006). Visual guidance during competition performance and run-through training in long jumping. *Sports Biomechanics*, **5**, 1-14.
- Hausdorff, J.M., Zeman, L., Peng, C.-K., Goldberger, A.L. (1999). Maturation of gait dynamics: stride-to-stride variability and its temporal organization in children. *Journal of Applied Physiology*, **86**, 1040-1047.
- Hay, J.G. & Nohara, H. (1990). Techniques used by elite long jumpers in preparation for take-off. *Journal of Biomechanics*, **23**, 229-392.
- Heiderscheit, B.C. (2000). Movement variability as a clinical measure for locomotion. *Journal of Applied Biomechanics*, **16**, 419-427.
- Hopkins, W.G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, **30**, 1-15.

- Johnson, M.D. & Buckley, J.G. (2001). Muscle power patterns in the mid acceleration phase of sprinting. *Journal of Sports Sciences*, **19**, 263-272.
- Knight, C.A. (2004). Neuromotor issues in the learning and control of golf skill. *Research Quarterly for Exercise and Sport*, **75**, 9-15.
- Lee, D.N., Lishman, J.R., & Thomson, J.A. (1982). Regulation of gait in long jumping. *Journal of Experimental Psychology: Human Perception and Performance*, **8**, 448-459.
- Rodano, R. & Squadrone, R. (2002). Stability of selected lower limb joint kinetic parameters during vertical jump. *Journal of Applied Biomechanics*, **18**, 83-89.
- Tillman, M.D., Hass, C.J., Chow, J.W., Brunt, D. (2005). Lower extremity coupling parameters during locomotion and landings. *Journal of Applied Biomechanics*, **21**, 359-370.