UNDERSTANDING ELITE SPRINT START PERFORMANCE THROUGH AN ANALYSIS OF JOINT KINEMATICS

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This study aimed to investigate how leg kinematics contribute to the performance, in terms of external horizontal power production, of three elite sprinters during the block and first step phases of a sprint. The highest block phase power was produced by sprinter B, who exhibited the greatest hip extension, particularly at the rear leg. Sprinter A achieved a higher horizontal block exit velocity, however, this appeared to be due to a longer push duration rather than greater average force production. The highest horizontal power during the first stance was again produced by sprinter B, who exhibited the greatest total stance leg joint extension. The other two sprinters exhibited similar leg extension to each other. However, sprinter A was able to generate greater horizontal power, which may have been due to his centre of mass being further in front of his foot at touchdown.

KEY WORDS: acceleration phase, angular kinematics, block phase, power, technique.

INTRODUCTION:

The start is an important part of a sprint in athletics, as the sprinter must strive to rapidly accelerate from the stationary set position. Large variations in set positioning have been observed between elite sprinters, and no single optimum position appears to be appropriate for all (Atwater, 1982). Detailed kinetics and the associated centre of mass (CM) kinematics during block exit and the first step have previously been described (Baumann, 1976; Mero, 1988). However, the actual joint kinematics have not been investigated, and analysing these may further the understanding of the techniques used to achieve high levels of performance.
Sprint start performance has typically been quantified using horizontal impulse, or more commonly the variable it directly determines, horizontal velocity (e.g. Baumann, 1976; Mero, 1988). As impulse is the product of force magnitude and push duration, the use of impulse or velocity to quantify sprint performance can be misleading due to the duration component being in conflict with the primary criterion of sprint performance (i.e. time to 100 m). A more suitable measure may therefore be average external horizontal power, as this takes into account changes in both time and velocity (Bezodis *et al.*, 2007). Horizontal power (P) can be calculated based on the rate of change in kinetic energy (E), using the changes in velocity (v) and time (t), and the mass of the sprinter (m):

$$P = \frac{\Delta E}{\Delta t} \qquad \text{in which} \qquad E = \frac{m \cdot v^2}{2} \qquad \text{therefore} \qquad P = \frac{m \cdot \Delta v^2}{2 \cdot \Delta t}$$

The power production of sprinters can therefore be indirectly calculated from accurate video data. This allows data to be collected at elite training sessions, without the need for force plates which are often limited to laboratory settings. The aim of this study was therefore to investigate how the leg joint kinematics exhibited by elite sprinters during the block phase and first stance contributed to their performance, using power as a measure of performance.

METHOD:

Three male sprinters (Table 1), who have subsequently reached the European Indoor 60 m final, provided consent for an outdoor training session to be videotaped for analysis. A high-speed video camera (Redlake, Motion Pro HS-1; 200 Hz) was located perpendicular to the running lane, 40 m from the lane centre, and 0.75 m in front of the start line. Prior to the training session, a 2D area of 3.50 m horizontally x 1.60 m vertically was calibrated. Images were collected at a resolution of 1280 x 1024 pixels. Following a coach-directed warm-up, each sprinter completed three or four maximum effort 30 m sprints, commencing from blocks.

Table 1. Subject information (PB = personal best 100 m performance at time of data collection)

Subject	Age (years)	Mass (kg)	Height (m)	100 m PB (s)	No. of runs
A	19	80.4	1.81	10.22	4
B	30	74.9	1.76	9.98	4
C	19	81.4	1.78	10.51	3

The instants of movement onset, block exit, touchdown and toe-off were identified directly from the video. Eighteen anatomical landmarks were manually digitised and digitally filtered using cut-off frequencies determined by residual analysis. These filtered data were combined with segmental inertia data (de Leva, 1996) in order to create a 14-segment (head, trunk, upper arms, forearms, hands, thighs, shanks, feet) model and obtain the whole-body CM trajectory. Ankle, knee and hip angles and angular velocities were calculated. Block exit velocity and first stance take-off velocity were calculated as the derivative of first order polynomials fitted through raw horizontal CM data during each subsequent flight phase (Salo and Scarborough, 2006). Average external powers were determined using the method described in the introduction, and were normalised to account for body size (Hof, 1996).

RESULTS:

The best performances, based on normalised power, were exhibited by subject B during both phases, although subject A exhibited the highest block exit horizontal velocity (Table 2).

Table 2. Performance descriptors (mean ± *s*) during the block phase and first step of a sprint

		Subject A	Subject B	Subject C
Block phase	Push duration (s)	0.346 ± 0.005	0.330 ± 0.004	0.360 ± 0.005
	Block exit horizontal velocity (m/s)	3.48 ± 0.06	3.43 ± 0.06	3.32 ± 0.08
	Average power (W)	1406 ± 38	1337 ± 47	1245 ± 57
	Normalised average power	5.94 ± 0.16	6.33 ± 0.27	5.29 ± 0.20
First stance	First stance duration (s)	0.170 ± 0.004	0.190 ± 8	0.187 ± 0.003
	Horizontal velocity increase (m/s)	1.17 ± 0.18	1.30 ± 0.17	0.94 ± 0.10
	Average power (W)	332 ± 112	340 ± 93	195 ± 43
	Normalised average power	1.40 ± 0.47	1.61 ± 0.44	0.83 ± 0.18

At first touchdown the CM of subject A was further ahead of the stance foot MTP (0.265 ± 0.011 m) than that of subject B (0.220 ± 0.014 m) or C (0.195 ± 0.019 m). Subject C exhibited a much greater increase in vertical CM position during the the first stance phase compared to subjects A and B (Figure 1), particularly during the latter part of stance.
The ∆ joint angle values presented in Table 3 represent the overall range of extension. The ankle values are split into the initial dorsiflexion magnitude and the subsequent plantarflexion magnitude, e.g. -6 +24 represents 6° of dorsiflexion followed by 24° of plantarflexion.

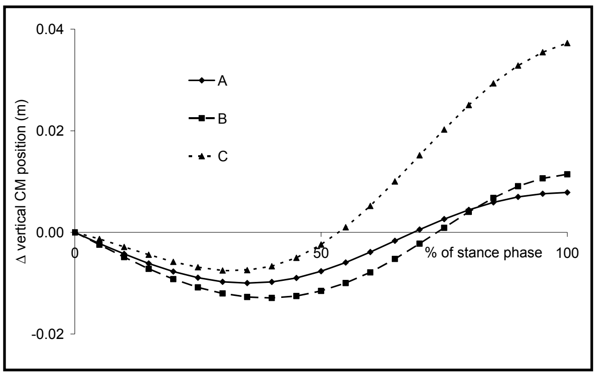

Figure 1. Mean changes in vertical CM displacement (relative to the position at touchdown) during the first stance phase

Table 3. Mean leg joint kinematics during the block phase and first step of a sprint

			Rear hip	Rear knee	Rear ankle	Front hip	Front knee	Front ankle
Block phase	Δ joint angle (°)	A	31	22	-6 +24	109	78	-21 +55
		B	41	19	n/a	116	75	-9 +41
		C	26	8	-5 +19	118	66	-19 +41
	Peak extension ω (°/s)	A	317	268	347	507	582	597
		B	329	216	n/a	537	560	482
		C	252	116	296	520	549	464
	Joint angle at exit (°)	A	-	-	-	163	169	162
		B	-	-	-	166	166	155
		C	-	-	-	158	149	145
First stance	Δ joint angle (°)	A	66	35	-11 +47	-	-	-
		B	70	53	-8 +45	-	-	-
		C	61	42	-11 +52	-	-	-
	Peak extension ω (°/s)	A	474	526	664	-	-	-
		B	516	456	583	-	-	-
		C	525	489	725	-	-	-
	Joint angle at toe-off (°)	A	161	148	140	-	-	-
		B	165	152	148	-	-	-
		C	160	142	139	-	-	-

DISCUSSION:

The higher performance levels of subject B, both in the block phase and first stance (Table 2), were consistent with his ability level (Table 1). The techniques behind this increased average power production can be investigated by considering the leg joint kinematics (Table 3). Subject B exhibited slightly higher mean peak angular velocities at both hips during the block phase, but also a greater mean range of extension at the rear hip (41°) compared to subjects A (31°) and C (26°), and at the front hip (116°) compared to subject A (109°). Combined with his shorter push phase duration (0.330 s), subject B therefore produced higher average hip extension velocities, particularly at the rear hip. The rear hip extensors are the first active leg muscles during the block phase, and remain active throughout rear block contact (Guissard and Duchateau, 1990). Although this contact is shorter than that with the front foot, large peak horizontal forces have previously been found to be generated at the rear block (Lemaire and Robertson, 1990). An increased contribution from the rear hip extensors could therefore be important for a larger velocity increase during the early block phase whilst the rear leg remains in block contact. This could assist the generation of block exit velocity in a shorter period of time (i.e. power), and reinforces previous suggestions (Payne and Blader, 1971) that better starters typically exhibit a stronger rear leg action.

In contrast, subject A exhibited a larger and faster extension of the more distal joints during the block phase, particularly at the front ankle where mean peak angular velocity (597°/s) was considerably higher than subjects B (482°/s) and C (464°/s). The plantarflexors which extend the front ankle have been previously found to be primarily active during the late block phase (Guissard and Duchateau, 1990), and thus this increase in range of motion could be associated with the extra 0.016 s that subject A spent pushing in the blocks compared to subject B. As subject A produced forces in the blocks for a longer period of time, this could explain his higher mean block velocity (3.48 m/s). However, subject A generated less normalised block phase power (5.94) than subject B (6.33), suggesting that his higher block velocity was predominantly due to a longer push phase duration, rather than any concurrent increase in average force production. Subject C also did not extend his front knee or ankle to a great extent, and his block velocity was thus lower (3.32 m/s). However, he actually spent the longest time in contact with the blocks (0.360 s) due to his lower normalised power production (5.29). Additional motion at the distal front leg joints (e.g. subject A) may therefore decrease overall power production by increasing the time spent generating low forces towards the end of contact. However, limited leg joint extension (e.g. subject C) may also be detrimental for power production by reducing the magnitude of the total force generated.

During the first stance, the leg joints of all three sprinters extended continuously, aside from some initial ankle dorsiflexion (Table 3). Subject B exhibited the greatest range of extension at both the hip (70°) and knee (53°), with subject C showing less hip extension (61°) and subject A considerably less knee extension (35°). Subject B was also able to limit the amount of dorsiflexion during early stance (8°) compared to subjects A and C (both 11°). It is likely that the higher total range of extension at the leg joints of subject B (160°) contributed to his greater performance (Table 2) by increasing the force produced by the extensor muscles, whilst subjects A and C exhibited lower total leg joint extension (137 and 144°, respectively). However, despite a slightly lower total range of extension, subject A generated greater normalised power (1.40) than subject C (0.83) during the first stance, resulting in a greater increase in horizontal velocity (1.17 m/s) than subject C (0.94 m/s). Figure 1 shows that rather than augmenting his horizontal motion, the leg extension of subject C contributed to a much greater increase in the vertical position of his CM. Subject C landed with his CM closer to his stance foot MTP at touchdown (CM 0.195 m ahead) than subject A (0.265 m). The leg extension of subject C would therefore have been directed more vertically than that of Subject A, who was in a more favourable initial position for the subsequent generation of horizontal velocity during stance (Jacobs and van Ingen Schenau, 1992).

CONCLUSION:

An increased push with the rear leg in the blocks, particularly at the hip, may assist the generation of power in elite sprint starters. Although greater motion at the more distal joints could augment block velocity, this appears to be largely due to a longer push duration rather than greater average force production. These findings reinforce previous suggestions that biomechanists and coaches should not quantify performance based on velocity alone. Power is a more suitable measure, and can be calculated from accurate kinematic data. During first stance, a large extension of the leg joints appears to benefit performance. The positioning of the CM further in front of the stance foot at touchdown could also improve performance by directing the subsequent leg extension more horizontally.

REFERENCES:

Atwater, A.E. (1982). Kinematic analyses of sprinting. *Track and Field Quarterly Review*, *82*, 12-16.

Baumann, W. (1976). Kinematic and dynamic characteristics of the sprint start. In P.V. Komi (Ed.), *Biomechanics V-B* (pp. 194-199). Baltimore: University Park Press.

Bezodis, N.E., Trewartha, G. & Salo, A.I.T. (2007). Choice of performance measure affects the evaluation of sprint start performance. *Journal of Sports Sciences*, *25*, S72-S73.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics*, *29*, 1223-1230.

Guissard, N. & Duchateau, J. (1990). Electromyography of the sprint start. *Journal of Human Movement Studies*, *18*, 97-106.

Lemaire, E.D. & Robertson, D.G.E. (1990). Force-time data acquisition system for sprint starting. *Canadian Journal of Sports Science*, *15*, 149-152.

Hof, A.L. (1996). Scaling gait data to body size. *Gait & Posture*, *4*, 222-223.

Jacobs, R. & van Ingen Schenau, G. J. (1992). Intermuscular coordination in a sprint push-off. *Journal of Biomechanics*, *25*, 953-965.

Mero, A. (1988). Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. *Research Quarterly for Exercise and Sport*, *59*, 94-98.

Payne, A.H. & Blader, F.P. (1971). The mechanics of the sprint start. In J. Vredenbregt & J. Wartenweiler (Eds.), *Biomechanics II* (pp. 225-231). Baltimore: University Park Press.

Salo, A.I.T. & Scarborough, S. (2006). Changes in technique within a sprint hurdle run. *Sports Biomechanics*, *5*, 155-166.