KINEMATIC ASPECTS OF BLOCK PHASE TECHNIQUE IN SPRINTING

Neil E. Bezodis[1,2], Aki I.T. Salo[a] and Grant Trewartha[1]

[1]Sport and Exercise Science, University of Bath, Bath, United Kingdom
[2]School of Human Sciences, St Mary's University College, Twickenham, London, United Kingdom

This study investigated kinematic aspects of block phase technique during the sprint start and their relationships with performance amongst a heterogeneous group of 16 sprinters. Lower limb kinematics in the 'set' position were not associated with block phase performance (average horizontal external power). During block exit a greater rear leg push, in particular from the hip, appeared important for performance. The front leg extended in a proximal-to-distal fashion, with more rapid hip extension again facilitating performance. Striving to achieve higher levels of block phase performance did not appear to negatively affect the first flight phase or the configuration of the sprinters at first touchdown. Sprinters should therefore be encouraged to maximise hip extensions in the blocks and use their rear leg drive to achieve a powerful block exit.

KEYWORDS: athletics, performance, sprint start, track and field.

INTRODUCTION: Since starting blocks were introduced to the sprint events in athletics in 1928-29, the block phase has been the subject of numerous descriptive and experimental biomechanical studies. A large volume of this research has focussed on 'set' position technique, reporting considerable inter-subject variation and weak relationships between 'set' position kinematics and performance (Mero, 1988). However, there exists limited research which has quantitatively determined how the lower limb joint angles change during the block phase once a sprinter reacts to the starter's gun and moves from the 'set' position, and it is not clear how these kinematics influence performance.

External kinetics during the block phase have been widely documented (Payne & Blader, 1971; Baumann, 1976; Mero, 1988; van Coppenolle et al., 1989; Lemaire & Robertson, 1990). Where force has been measured separately on each block face, the higher block exit velocities of better starters have been attributed to an increase in force generation with the rear leg (Payne & Blader, 1971; van Coppenolle et al., 1989; Lemaire & Robertson, 1990). However, due to the dearth of descriptive kinematic data from the block phase, the actual techniques which more successful starters use to achieve these higher levels of performance remain unknown.

A further issue that must be considered is that the block phase is not a 'stand-alone' part of a sprint, and that simply striving to maximise block phase performance could affect performance during subsequent phases of a sprint. Therefore it is also important to investigate whether achieving high levels of block phase performance could potentially inhibit technique and performance during the next stance phase. The aim of this study was to identify the lower limb angular kinematics associated with higher levels of block phase performance and to assess any relationships between block phase performance and kinematics at the first touchdown on the track.

METHODS: Sixteen male sprinters (mean ± *s*: age = 21 ± 5 years, height = 1.78 ± 0.05 m, mass = 74.4 ± 8.3 kg) ranging in ability from world-class (fastest 100 m PB = 9.98 s) to university-level (slowest 100 m PB = 11.6 s; Table 1) provided informed consent for high-speed video data to be collected from one of their training sessions. For 13 of the sprinters, data were collected indoors just prior to the competition phase of the indoor season. For the remaining three sprinters, data were collected outdoors during the competition phase of the outdoor season. Each sprinter completed three maximal effort sprints to 30 m, commencing from starting blocks which were adjusted to their preference. At all sessions, a high-speed digital video camera (Motion Pro®, HS-1, Redlake, USA; 200 Hz) was mounted on a tripod, and images were collected at a resolution of 1280 × 1024 pixels. Indoors, an area of 2.00 m

horizontally by 1.60 m vertically was calibrated at the centre of the running lane inside a 2.50 m wide field of view (restricted by only being able to position the camera 8.00 m away from the lane of interest). Outdoors, the camera was positioned 40.00 m from the lane centre, and an area of 3.50 m horizontally by 1.60 m vertically was calibrated inside a 4.00 m wide field of view. Due to limitations with the camera set-up, rear foot data for Sprinter A in the 'set' position were unavailable, and this sprinter was thus removed from the analysis when variables reliant upon rear foot data from the early block phase were required.
The video clips were digitised using a zoom factor of 2 (Peak Motus®, v.8.5, Vicon®, USA). Eighteen points (vertex, C7, shoulder, elbow, wrist, third metacarpal, hip, knee, ankle and second metatarsal-phalangeal joint centres) were manually digitised from one frame prior to movement onset until 10 frames after first stance touchdown. Following backward replication of the first frame 10 times to alleviate any potential for endpoint error, the data were filtered using a fourth-order Butterworth digital filter with cut-off frequencies determined individually for each displacement time-history via residual analysis (16 to 28 Hz). Joint angles at specific events (e.g. 'set' position, block exit) and peak joint angular velocities during specific phases (e.g. rear leg push, total push phase) were identified. Block exit velocities were calculated from the first derivative of a linear polynomial fitted through the raw CM displacement data (calculated using segmental inertia data from de Leva, 1996) from the flight phase immediately following block exit (Salo & Scarborough, 2006). The change in kinetic energy during the block phase was calculated from these velocity data, and was divided by the duration of the total push phase to determine average horizontal external block power (hereafter termed block performance) as a measure of performance (Bezodis et al., 2008). Block performance and all linear displacements were normalised to account for body size (Hof, 1996). Mean values for each sprinter were calculated and where appropriate, Pearson's correlations were run to determine the relationship between specific variables using these mean data from each of the 16 sprinters.

RESULTS AND DISCUSSION: Across all 16 sprinters, a strong negative relationship ($r = -0.71$, $p < 0.01$) existed between 100 m PB time and block performance, highlighting that better overall sprinters were also typically better starters. There were exceptions to this (most noticeably Sprinters D and G; Table 1), which indicated that block phase technique should be compared against block phase performance, not performance measures including subsequent phases of a sprint. Joint extension ranges of motion during block contact varied considerably between sprinters (Table 1). Whilst all sprinters extended their front hip joint over the greatest range of all the front leg joints, the largest rear leg extension typically occurred at the hip, but also at the knee for two sprinters. Rear hip range of motion during rear block contact was moderately correlated with block performance ($r = 0.44$, $p = 0.09$), although the rear hip angle at block exit was more strongly correlated ($r = 0.58$, $p < 0.05$) suggesting greater rear hip extension through the higher end of its range of motion may be important for performance. In addition to this apparent trend for rear hip extension to facilitate performance, a greater push duration with the rear leg (as a % of total push phase duration) was also associated with higher levels of block performance ($r = 0.49$, $p = 0.06$). These results reinforced previous suggestions (Payne & Blader, 1971; van Coppenolle et al., 1989; Lemaire & Robertson, 1990) regarding the importance of the rear leg push against the blocks, and it appeared that extension of the rear hip plays an important role in this.

Table 1. Ability level (100 m personal best (PB) in seconds), block phase performance and lower limb joint angle ranges of motion (°) during respective block contacts (mean values).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
100 m PB*	9.98	10.22	10.35	10.51	10.53	10.70	10.90	11.10	11.19	11.2	11.2	11.3	11.3	11.55	11.6	11.6
Block power†	6.46	6.00	6.28	5.50	6.91	6.64	4.05	5.57	6.04	6.01	5.15	4.99	4.73	4.49	4.20	4.45
Rear hip	44	31	53	26	26	53	25	13	20	50	17	37	16	24	36	27
Rear knee	18	21	28	8	10	21	25	19	14	17	14	23	17	16	27	14
Rear ankle	n/a	19	29	14	19	15	24	35	22	9	14	27	17	15	28	0
Front hip	117	110	124	118	107	125	113	95	103	130	117	103	113	107	112	111
Front knee	76	79	77	66	66	75	74	73	74	69	87	66	74	57	85	74
Front ankle	32	35	49	22	47	30	44	45	25	34	34	37	50	22	41	21

*100 m PB times reported to the nearest 0.1 s are hand timed. †Normalised horizontal block power.

The relationships between peak joint extension angular velocities and block performance were generally weak, with only two correlation coefficients exceeding ± 0.40. The correlation between block phase performance and peak front hip angular velocity was r = 0.56 ($p < 0.05$), and at the rear hip was r = 0.43 ($p = 0.09$), suggesting an importance associated with the rate of extension of the front, and potentially the rear, hip joint. The temporal pattern of peak leg joint angular velocities (Figure 1) revealed that all 16 sprinters showed a rear leg sequencing of knee-hip-ankle. In contrast, all sprinters (except Sprinter C) exhibited a proximal-to-distal hip-knee-ankle extension pattern with the front leg. This proximal-to-distal pattern was unsurprising, since it is commonly associated with power demanding tasks due to the action of the biarticular muscles facilitating a transfer of power down the leg (Jacobs & van Ingen Schenau, 1992). However, such a strategy was not used when extending the rear leg, which could be due to the knee joint starting from a more extended angle in the 'set' position (group range = 95° to 122° compared to 78° to 95° in the front leg). The rear knee therefore could not extend for long, limiting its force producing capability. It appears that in the rear leg, hip joint extension is of major importance, due not only to the aforementioned relationships with performance, but also the increased time over which it is extending during rear block contact. The limited knee extension may be a strategy designed to reduce the rear block contact time after the initial extension of the hip, allowing the leg to swing through in preparation for the first ground contact on the track.

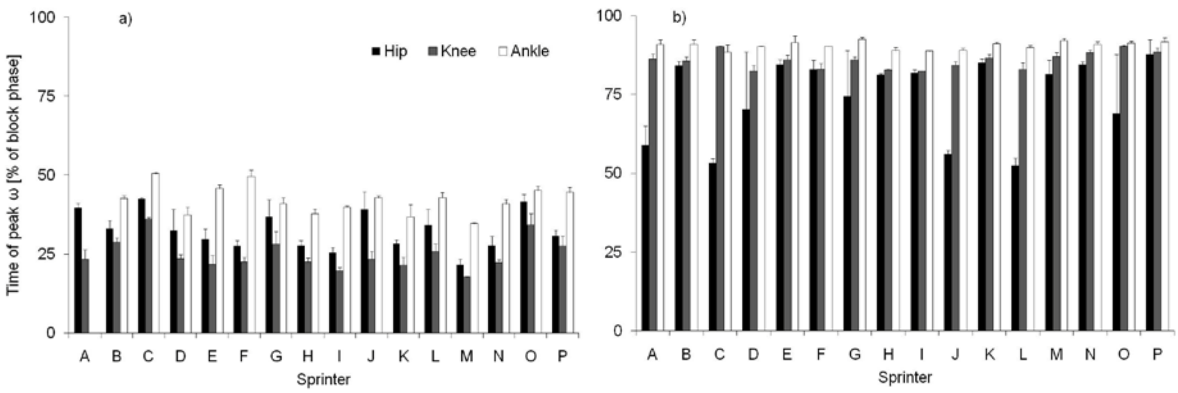

Figure 1. Timing of peak extension angular velocities at a) the rear leg and b) the front leg.

In the 'set' position, no lower limb or trunk angles were correlated with block performance above a strength of ± 0.24 ($p > 0.05$). This confirmed previous suggestions regarding the lack of an 'optimal' block positioning that is applicable for all sprinters. Smaller rear knee and hip angles in the 'set' position were correlated with increases in rear foot push duration (r = -0.59, $p < 0.05$ and r = -0.57, $p < 0.05$, respectively). These increased durations subsequently appeared to allow the rear hip to extend over a greater range during rear block contact and also reach greater extension angular velocities (respective correlations with rear foot push duration were r = 0.83, $p < 0.001$ and r = 0.80, $p < 0.001$). The use of personalised block settings therefore appears paramount, and specific adjustments could be made to address certain deficiencies in technique, such as reducing rear knee and hip angles if an increased push with the rear leg is required.

Beyond block exit, a large inter-subject range of stance leg joint angles existed at first touchdown (Table 2). These stance leg configurations at touchdown affected touchdown distance (the horizontal distance between the CM and the stance toe at touchdown, with negative values representative of the toe behind the CM; Table 2). Touchdown distance can have a considerable effect on a sprinter's ability to generate propulsive force during stance, since the CM must be rotated further in front of the stance foot prior to leg extension for this extension to propel the sprinter in a more favourable horizontal direction (Jacobs & van Ingen Schenau, 1992; Bezodis et al., 2008). However, whilst levels of block performance did not appear to affect the subsequent flight duration (r = 0.19, $p = 0.48$), potentially favourable trends existed between block performance and (normalised) step length (r = 0.41, $p = 0.12$)

and (normalised) touchdown distance ($r = -0.42$, $p = 0.10$). This suggests that striving to increase block performance does not appear to inhibit subsequent performance in a sprint, since sprinters tended to take longer steps and land in a better position at touchdown without major increases in flight duration, although the causality of this cannot be determined.

Table 2. First flight duration (ms), step length, touchdown distance and stance leg angles (°) at touchdown.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Flight time	85	102	90	63	82	68	62	50	78	80	57	70	27	70	122	67
Step length*	1.14	1.18	1.24	1.12	1.11	1.03	1.03	1.04	1.09	1.17	1.10	1.05	1.15	1.03	1.12	1.02
T/d distance*	-0.23	-0.28	-0.16	-0.21	-0.30	-0.29	-0.22	-0.18	-0.23	-0.20	-0.12	-0.18	-0.03	-0.23	-0.23	-0.17
Hip angle	96	95	98	99	103	99	111	73	91	103	91	96	79	97	98	86
Knee angle	102	112	93	100	99	102	94	93	100	99	101	106	89	115	110	103
Ankle angle	112	105	91	98	98	102	100	83	95	94	95	96	83	100	96	93

* Normalised step length and touchdown (T/d) distance using the convention of Hof (1996)

CONCLUSION: The results of this study highlighted the role of extension of the leg joints during the block phase. For all sprinters, all three joints in the front leg extended over at least 20° in a proximal-to-distal extension pattern. Whilst the rear leg joints extended over a smaller range, this rear leg extension, in particular at the hip joint, was associated with higher levels of block phase performance. Due to the differing strategy adopted with each leg in the blocks it is possible that different legs may be more suited to either the front or back block. Coaches should adjust block settings on an individual basis, and make specific changes if deficiencies in block phase technique are identified (e.g. if the rear leg push is short or weak, the blocks should be adjusted to facilitate slightly more flexed rear knee and hip angles in the 'set' position). As higher levels of block performance were not subsequently associated with any potential decrements in technique at the onset of the first stance phase, sprinters should be encouraged to maximise extension with both hips during the block phase in an attempt to achieve maximal horizontal external power production.

REFERENCES:

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. (2008). Understanding elite sprint start performance through an analysis of joint kinematics. In *Proceedings of XXVI International Symposium on Biomechanics in Sports* (edited by Y-H. Kwon, J. Shim, J. K. Shim and I-S. Shin) pp. 498-501. Seoul, Korea: Seoul National University Press.

van Coppenolle, H., Delecluse, C., Goris, M., Bohets, W. & Vanden Eynde, E. (1989). Technology and development of speed: evaluation of the start, sprint and body composition of Pavoni, Cooman and Desruelles. *Athletics Coach*, *23,* 82-90.

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.

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

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

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*, 155-167.