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THE EFFECT OF THE BEND ON TECHNIQUE AND PERFORMANCE DURING MAXIMAL SPEED SPRINTING

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For 200 and 400 m races half of the race is run around the bend. This study aimed to understand the changes in kinematics that occur during maximal effort bend sprinting. Velocity reduction (5%) on the bend compared to the straight was, for the left step, mainly due to increased (20%) touchdown distance and some angular kinematics changes which led to increased contact time and reduced step frequency. During the right step, performance dropped mainly due to a reduction in step length. It is likely that changes caused by inward lean, to counteract moments caused by centripetal forces, on the bend contributed to detrimental changes in sagittal plane kinematics (e.g. knee flexion at touchdown) normally associated with superior performance in sprinting. Similar to straight sprinting, reduced touchdown distance could hold the key to improve bend performance.

KEY WORDS: Three-dimensional kinematics, athletics, frontal plane, 200 m.

INTRODUCTION: During sprint events longer than 100 m half of the race is run around the bend. It is generally accepted that the requirement to generate centripetal acceleration, in order to follow the curved path, has a detrimental effect on bend sprinting performance. However, the techniques employed by athletes in this component of the race have largely been overlooked in the biomechanics literature. The few studies that have been undertaken have taken either a mathematical modelling approach (e.g. Usherwood & Wilson, 2006), have used bend radii not relevant to athletic sprint events (e.g. Chang & Kram, 2007) or have not been concerned with the maximal speed phase of a sprint (e.g. Stoner & Ben-Sira, 1979). The aim of the present study was, therefore, to understand the changes in performance that occur during maximal effort bend sprinting compared to straight line sprinting and how technique changes contribute to such changes in performance.

METHODS: After ethical approval and informed consent, seven male athletes (23.6 ± 1.9 yrs, 80.5 ± 9.2 kg, 1.81 ± 0.07 m, 200 m personal best times ranging from 21.18 to 23.90 s) participated in the study. Bend and straight data were collected on separate occasions on a standard outdoor track during the competition season. On both sessions athletes were asked to perform three maximal effort 60 m sprints in lane 2, with approximately eight minutes recovery. Two video cameras (200 Hz, 1/1000 s shutter speed; MotionPro HS1, Redlake, USA) recorded the athletes at the 40.0-47.5 m section of the 60 m sprints. Camera A was positioned 32.72 m from the inside edge of lane 2 (which was the centre of bend for bend trials) and provided a 'side view'. Camera B was set 30.00 m away at the front with an offset of 1.50 m. (a 'front view'). An 18 point calibration volume of 6.50 m long by 1.61 m wide by 2.07 m high was utilised. Video clips were synchronised using 1 ms interval LED lights in the fields of view and were manually digitised using Vicon Peak Motus software (Version 8.5, Vicon Motion Systems, Inc., USA). Due to technological issues and some athletes not completing all runs, for two athletes video was only available for two bend trials and one athlete had only one bend trial. All athletes had three straight trials available. Touchdown (TD) and take off (TO) were determined visually from the 'front view' video. A 20 point human model was digitised from both views. A 3D-DLT reconstruction allowed exportation of 3D coordinates, which were subsequently filtered with a low-pass, 4th order, zero lag Butterworth filter (20 Hz). Inertia data based on de Leva (1996) was used for all segments except the foot which included forefoot and rearfoot segments based on Bezodis (2009), including the addition of 0.2 kg to each foot as the mass of a typical spiked shoe.

Variables were calculated for left and right steps. A step was determined according to the leg that initiated the step and defined as TD of one foot to TD of the contralateral foot. Variables were calculated as follows: *Absolute Speed:* the horizontal speed of the CoM on the path travelled by the athlete; *Race Velocity:* the horizontal velocity of the CoM relative to the official race line (0.20 m from the inside edge of the lane); *Directional Step Length (SL):* the anteroposterior (AP) displacement between the metatarsophalangeal joint centre (MTP) during contact and the contralateral limb MTP during next contact, relative to the direction of travel of the CoM during the step; *Race SL:* race distance covered by each step; *Step Frequency (SF):* race velocity divided by race SL; *Ground Contact Time:* the time from TD to TO; *Step Contact Factor:* the proportion of total step time (TD to next TD) spent in ground contact; *Touchdown Distance:* the AP displacement between the CoM and the MTP of the contact limb; *Foot Horizontal Velocity at Touchdown:* the AP velocity of the rearfoot segment CoM at TD; *Relative Foot Horizontal Velocity at Touchdown:* AP velocity of the rearfoot segment CoM relative to the AP velocity of the whole body CoM at TD; *Foot Vertical Velocity at Touchdown:* the vertical velocity of the rearfoot segment CoM at TD.

A number of angles, ranges of motion (ROM) and angular velocities were also calculated (Figure 1) for the left and right steps, at events deemed to be important to sprint success based on literature. Where possible, angles were calculated using 3D orientation angles (Yeadon, 1990). Knee, ankle, MTP, elbow, and rearfoot angles were calculated as 3D vector angles. Whole body lateral lean and ROM in the sagittal plane were also measured as 3D orientation angles from the MTP to body CoM during contact.

All subject data were handled as mean values and to measure the effect of the bend on performance and technique, a number of comparisons were made using paired-samples t-tests (SPSS, v 14.0, SPSS Inc., USA), including left bend vs. left straight, right bend vs. right straight, left bend vs. right bend, and left straight vs. right straight.

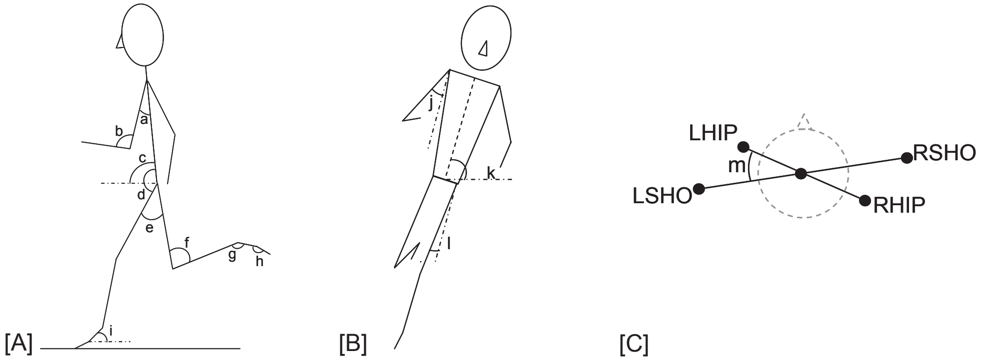

Figure 1: [A] Sagittal plane angles: a) Shoulder flexion/extension ROM; b) Elbow ROM; c) Trunk forward lean at touchdown (TD); d) Hip flexion/extension angle at take off (TO), at full flexion and full extension; e) thigh separation at TD; f) Knee angle at TO, full flexion, TD and minimum and maximum angles during ground contact; g) Ankle angle at TD, minimum during contact, and at TO; h) MTP angle at TD, maximum during absorption phase, minimum during absorption phase, and at TO; i) Rearfoot angle at TD, minimum during ground contact, and at TO. [B] Frontal plane angles: j) shoulder abduction/adduction ROM; k) Trunk lateral lean at TD; l) Hip abduction/adduction at peak abduction, at peak adduction, and at TO. [C] Transverse plane angles: m) maximum thorax rotation.

RESULTS AND DISCUSSION: Variables for which there were significant differences between bend and straight, or between left and right on the bend are shown below (with any differences in these same variables between left and right on the straight also included). Race velocity and absolute speed were significantly reduced on the bend (vs. the straight; Table 1). There were no significant group differences between race velocity and absolute speed. However, individual results showed that whilst three athletes had race velocities slower than their absolute speeds, four exhibited race velocities greater than their absolute speeds indicating that the CoM of these athletes followed a path shorter than that of the race line. Whether this is a factor that identifies some athletes as better bend runners than others warrants further investigation.

Table 1
Left and right mean (± SD) performance descriptors on the straight and bend

	Straight		Bend	
	Left	Right	Left	Right
Race velocity (m/s)	9.86 ± 0.55	9.80 ± 0.59	9.39 ± 0.45*	9.33 ± 0.44$^{\&}$
Absolute speed (m/s)	9.86 ± 0.55	9.80 ± 0.59§	9.40 ± 0.42*	9.34 ± 0.41$^{\&}$
Race SL (m)	2.20 ± 0.10	2.20 ± 0.12	2.14 ± 0.11	2.10 ± 0.14$^{\&}$
Directional SL (m)	2.20 ± 0.10	2.20 ± 0.12	2.16 ± 0.11	2.12 ± 0.14$^{\&}$
SF (Hz)	4.50 ± 0.19	4.46 ± 0.29	4.39 ± 0.26*	4.46 ± 0.31
Ground contact time (s)	0.105 ± 0.003	0.105 ± 0.008	0.116 ± 0.004*	0.109 ± 0.005$^{\#}$
Step contact factor	0.48 ± 0.01	0.47 ± 0.02	0.50 ± 0.02*	0.49 ± 0.02$^{\&}$

Symbols: * significantly different to left on straight, & significantly different to right on straight, # significantly different to left on bend, § significantly different to left on straight at $p<0.05$.

Reductions in velocity during the left step on the bend, compared to the straight, were due to a combination of a reduced SL and SF (Table 1). Left SF decreased due to increased ground contact time during the left step on the bend (vs. the straight), which in turn increased step contact factor. For the left step, this partially supports theoretical models that have attributed reductions in performance on the bend to increased ground contact time, to allow for centripetal force generation (Usherwood & Wilson, 2006). However, the changes in SL seen in the present study suggest that the effect of the bend is more complicated than simply the requirement for centripetal force generation leading to increased ground contact time and thus reduced SF. Indeed, technique changes on the bend, seen in the present study, may also have contributed to increased ground contact time. There was a significantly larger touchdown distance, thigh separation and body sagittal lean ROM for the left step on the bend compared to the straight and to the right on the bend (Table 2). These three variables have all been shown to be related to increased ground contact time (Kunz & Kaufmann, 1981; Hunter et al., 2004). During the right step the main reason for decreased velocity was a reduction in SL of 0.10 m and 0.08 m for race and directional SL, respectively (Table 1). For both steps reduced SL was due to a smaller proportion of the total step spent in flight. Despite increased ground contact time, left flight time increased only slightly (by 0.001 s) and right flight time actually decreased (by 0.009 s) on the bend. The latter suggests the athletes were not able to generate the same vertical and propulsive forces as they had done on the straight, likely due to the additional requirement of centripetal force generation on the bend.

On the bend there was increased inward (more negative) lean of both the trunk and the whole body (Table 2). This caused a significantly increased (more positive) adduction of the left hip at touchdown and at peak adduction on the bend (vs. straight). During the right step the right hip demonstrated significantly less adduction at peak adduction (bend vs. straight). The increased need to stabilise the joints in the frontal plane during bend running may affect the ability of athletes to exert extensor forces, detrimentally affecting performance (Chang & Kram, 2007). This tendency for the left hip to be more adducted and the right hip to be less adducted during the respective stance phases may have important implications for kinetics and kinematics observed in the sagittal plane. For example, several of the muscles involved in flexion/extension of the hip are also involved in ab/adduction (Palastanga et al., 2006). Asymmetries between left and right sagittal plane hip, knee, and ankle kinematics on the bend (Table 2) are likely to also be due to differences seen in frontal plane kinematics.

Mean left hip peak extension angular velocity during contact was reduced by 98°/s (10%) on the bend compared to the straight. This may also have been due to the increased adduction of the left hip meaning the muscles were in a less advantageous position to extend quickly. This combination of increased extension at take off (compared to the right) and reduced extension angular velocity may also have contributed to the increased left ground contact time. At touchdown mean left knee angle was 3.5° less extended on the bend than on the straight, and 3.4° less extended than the right knee at right touchdown on the bend. The right knee was also less extended on the bend compared to the straight by 3.1° (Table 2). Mero and Komi (1985) found similar knee angle differences (4°) between maximal and supramaximal sprinting and suggested that a more extended knee at touchdown may benefit performance by positioning the extensor muscles more favourably to exert force.

Table 2
Left and right mean (± SD) significant kinematics on the straight and bend

	Straight		Bend	
	Left	Right	Left	Right
Touchdown distance (m)	0.30 ± 0.04	0.31 ± 0.04	0.36 ± 0.04*	0.30 ± 0.04$^{\#}$
Thigh separation at TD (°)	17.2 ± 11.4	19.6 ± 5.6	25.5 ± 8.8*	18.5 ± 5.8$^{\#}$
Body sagittal lean ROM (°)	51.1 ± 2.4	51.2 ± 2.7	57.2 ± 1.7*	52.9 ± 2.7$^{\#}$
Trunk forward lean at TD (°)	-10.4 ± 2.2	-7.4 ± 0.8§	-6.7 ± 1.7*	-6.1 ± 0.9$^{\&}$
Trunk lateral lean at TD (°)	-4.5 ± 2.1	2.8 ± 1.6	-12.8 ± 5.6*	-9.9 ± 3.0$^{\&}$
Body lateral lean at TD (°)	3.5 ± 1.2	-4.1 ± 0.8	-10.3 ± 2.3*	-15.2 ± 1.6$^{\&\#}$
Body lateral lean at TO (°)	3.4 ± 1.2	-4.4 ± 0.5§	-8.2 ± 2.2*	-14.1 ± 1.6$^{\&\#}$
Hip flexion/extension at TO (°)	207.6 ± 3.8	203.7 ± 6.8	209.7 ± 5.6	204.4 ± 3.1$^{\#}$
Hip peak flexion (°)	103.9 ± 8.6	104.3 ± 7.7	101.7 ± 6.5	106.6 ± 6.7$^{\#}$
Hip abduction/adduction at TD (°)	-3.4 ± 2.9	-5.5 ±1.9	0.6 ± 3.8*	-7.1 ± 3.3$^{\#}$
Hip peak adduction (°)	4.1 ± 2.6	3.3 ± 3.7	10.6 ± 4.1*	1.0 ± 3.5$^{\&\#}$
Hip peak extension angular velocity during contact (°/s)	951 ± 119	885 ± 152	853 ± 119*	874 ± 132
Knee angle at TD (°)	157.6 ± 4.4	160.6 ± 4.0	154.1 ± 3.5*	157.5 ± 5.6$^{\&\#}$
Ankle angle at TD (°)	130.1 ± 5.9	132.9 ± 4.7	127.3 ± 5.1*	130.4 ± 4.9
Minimum ankle angle (°)	96.6 ± 3.6	97.9 ± 3.9	91.5 ± 2.8*	97.2 ± 3.0$^{\#}$

Symbols: * significantly different to left on straight, & significantly different to right on straight, # significantly different to left on bend, § significantly different to left on straight at $p<0.05$.

CONCLUSION: The present study shows that asymmetrical changes to technique and reduced performance during bend sprinting are due to technique changes that are more complex than simply reduced SF. It appears that one of the major issues hindering the bend sprinting is the increased left touchdown distance. Thus, coaching may aim to reduce this to improve performance on the bend. Furthermore, the present study provides a firm foundation upon which further research can identify techniques associated with better bend sprinting, in order to inform coaching with the aim of improving bend sprinting performance.

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