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Published version

JUDSON, Laura, CHURCHILL, Sarah, BARNES, Andrew, STONE, Joseph, BROOKES, Ian and WHEAT, Jonathan (2019). Kinematic modifications of the lower limb during the acceleration phase of bend sprinting. *Journal of Sports Sciences*.

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**Kinematic modifications of the lower limb during the acceleration phase of bend
sprinting**

Running title: Joint kinematics in the acceleration phase of bend sprinting

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Key words: athletics, curve, motion capture, adduction

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1 **Abstract**

2 A decrease in speed when sprinting on the bend compared with the straight has been
3 attributed to kinetic, kinematic and spatiotemporal modifications. Although maximal
4 speed is dependent on an athlete's ability to accelerate, there is limited research
5 investigating the acceleration phase of bend sprinting. This study used a lower limb
6 and trunk marker set with 15 optoelectronic cameras to examine kinematic and
7 spatiotemporal variables of the lower limb during sprinting on the bend and straight.
8 Nine sprinters completed up to six 30 m maximal effort trials in bend (radius 36.5 m,
9 lane one) and straight conditions. An increase in body lateral lean at touchdown
10 resulted in a number of asymmetric kinematic modifications. Whilst the left limb
11 demonstrated a greater peak hip adduction, peak hip internal rotation and peak ankle
12 eversion on the bend compared with the straight, the right limb was characterised by
13 an increase in peak hip abduction. These results demonstrate that kinematic
14 modifications start early in the race and likely accumulate, resulting in greater
15 modifications at maximal speed. It is recommended that strength and conditioning
16 programmes target the hip, ankle and foot in the non-sagittal planes. In addition,
17 sprint training should prioritise specificity by occurring on the bend.

18 **Key words:** athletics, curve, motion capture, adduction

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22 In track and field sprint events longer than 100 m, more than half the total
23 distance is ran on a curved portion of track (Meinel, 2008). Compared with the
24 straight, anti-clockwise bend sprinting elicits a decrease in maximum speed at
25 approximately 40 m (Churchill, Salo, & Trewartha, 2015). This reduction in speed
26 has been attributed to kinetic, kinematic and spatiotemporal alterations (Churchill, et
27 al., 2015; Churchill, Trewartha, Bezodis, & Salo, 2016). However, the current
28 understanding of biomechanical modifications during anti-clockwise bend sprinting
29 in the acceleration phase (0 - 30 m) is limited. Identification of these affected
30 parameters could aid overall race performance through the development of targeted
31 training programmes and increased specificity of athlete preparation.

32 During bend sprinting, mean body lateral lean angles of 14° and 11° at
33 touchdown have been reported in the left and right step, respectively (Churchill et
34 al., 2015). It is thought this lean is responsible for inducing a number of kinematic
35 changes of the lower limb (Churchill et al., 2015) which occur predominantly in the
36 frontal and transverse planes (Alt, Heinrich, Funken, & Potthast, 2015; Churchill et
37 al., 2015). More specifically, the left limb is characterised by a mean increase in left
38 peak hip adduction of approximately 6° during bend sprinting at 40 m compared
39 with the straight (Alt et al., 2015; Churchill et al., 2015). Furthermore, a high peak
40 left ankle eversion angle (e.g. 13° Alt et al., 2015; > 35° Luo & Stefanyshyn, 2012)
41 has been reported, but in protocols that are not representative of a competitive elite
42 environment, for example, at submaximal effort (Alt et al., 2015) and with a smaller
43 radius (2.5 m, Luo & Stefanyshyn, 2012). It has been suggested that excessive and
44 repetitive eversion may result in injury (Clarke, Frederick, and Hamill, 1984) thus

45 highlighting the importance of further investigation with a protocol more closely
46 replicating race conditions.

47 In the right limb, a mean 4° increase in internal knee rotation on the bend
48 compared with the straight is thought to contribute to a rotational strategy which
49 serves to control horizontal plane motion (Alt et al., 2015). This finding did not
50 reach the alpha level $p < 0.05$, but due to the small sample size ($n = 6$) was reported
51 as a tendency ($p < 0.1$, Alt et al., 2015), suggesting this should be interpreted
52 cautiously until further evidence is available. However, bend sprinting did result in a
53 3° increase in peak right ankle external rotation compared with the straight
54 ($p < 0.05$, (Alt et al., 2015). Despite Alt et al. (2015) providing some initial findings
55 using a controlled submaximal velocity, gaining further evidence during
56 representative performance conditions (such as during acceleration) would enhance
57 the current evidence base.

58 Spatiotemporal parameters such as contact time, step frequency and step
59 length are fundamental components of sprint performance with these parameters
60 being affected during bend sprinting. For example, Alt et al. (2015) found an
61 increase in left contact time on the bend compared with the straight at submaximal
62 speed. This increase in contact time is consistent with others during the maximal
63 speed phase (approximately 40 m, Churchill et al., 2015; Churchill et al., 2016;
64 Ishimura & Sakurai, 2010; Ishimura, Tsukada, & Sakurai, 2013). However, the
65 evidence base regarding spatiotemporal variables is sometimes contradictory. For
66 example, a reduction in right step length on the bend compared with the straight at
67 maximal speed has been reported by several authors (Churchill et al., 2015;

68 Churchill et al., 2016; Ishimura, et al., 2013). This reduction was considered
69 responsible for a loss of speed on the bend compared with the straight (Churchill et
70 al., 2015), highlighting the importance of spatio-temporal variables and their
71 relationship with performance. However, step length was unaffected during sub-
72 maximal effort bend sprinting (Alt et al., 2015). Moreover, the majority of available
73 research has focussed on the maximal speed phase of bend sprinting (Alt et al., 2015;
74 Churchill et al., 2015; Churchill et al., 2016; Ishimura et al., 2013). The limited
75 research available in the acceleration phase showed both left and right step lengths
76 were reduced on the bend compared with the straight (Stoner & Ben-Sira, 1979).
77 Therefore, further research is required regarding the effect of the bend during the
78 acceleration phase on spatiotemporal aspects of technique and performance.

79 Alt et al. (2015) suggested some modifications may be velocity dependent.
80 Thus, during the acceleration phase, where athletes have not yet reached maximum
81 speed, the kinematic demands of bend sprinting may be different. Whilst there is
82 always an element of acceleration during bend sprinting due to constant change of
83 direction, for the purpose of comparisons with straight-line sprinting, the
84 acceleration phase during this paper is considered to occur at 0-30 m. It is possible
85 that modifications such as increased hip adduction and ankle eversion are less
86 prominent during acceleration. Moreover, the maximum speed a sprinter is able to
87 attain is dependent on the sprinters' ability to accelerate. However, the acceleration
88 phase has received little attention within the bend sprinting literature. Therefore, the
89 aim of the present study was to investigate the effect of bend sprinting on the
90 kinematic and spatiotemporal parameters of the lower limb during the acceleration

91 phase. It was hypothesised bend sprinting would result in greater adaptations in the
92 frontal and transverse planes than on the straight.

93 **Method**

94 **Participants**

95 Ethical approval was provided by the Sheffield Hallam Research Ethics
96 Committee. Nine male sprinters (mean age 22 ± 4 years; body mass 71.48 ± 9.47 kg;
97 stature 1.81 ± 0.06 m) with experience of bend sprinting (200 and /or 400 m)
98 volunteered to participate in this study. The sample size was guided by previous
99 bend sprinting literature (Alt et al., 2015; Churchill et al., 2015; Churchill et al.,
100 2016; Judson et al., 2019) and the number of available skilled athletes meeting the
101 inclusion criteria of the study. To standardise ability with previous research (Alt et
102 al., 2015, 22.60 ± 0.33 s; Churchill et al., 2015, 22.15 ± 0.93 s), the inclusion criteria
103 required a 200 m personal best of 23.5 s or faster (mean 22.70 ± 0.49 s, range
104 21.8 - 23.43 s). All athletes were active in training and injury free at the time of data
105 collection. The study procedures were fully explained to participants who
106 subsequently provided written informed consent.

107 **Experimental set-up**

108 Kinematic data were collected at 200 Hz, using a 15-camera (13 x Raptor
109 model and 2 x Eagle model, Motion Analysis Corporation (MAC), Santa Rosa, CA,
110 USA) optoelectronic motion capture system (calibration volume: 7 m long, 3 m
111 wide and 1.5 m high). Data were recorded at approximately 10 - 17 m of the 30 m
112 sprints. For the identification of gait events, a force plate (Kistler, Model 9287BA,

113 900 x 600 mm) was embedded into the track surface at approximately 12 m. For full
114 details of the experimental set-up, please refer to Judson et al. (2019).

115 A modified Vicon Plug in Gait (PiG) marker set (lower limb and trunk;
116 Judson, Churchill, Barnes, Stone, & Wheat (2017)) was used to model the torso,
117 pelvis, thighs, shanks and foot segments (toebox, forefoot, rearfoot). For full details
118 of marker locations please see (Judson et al., 2018). The marker set was applied by
119 the same researcher for all participants.

120 **Protocol**

121 Data collection took place on a standard flat indoor track surface. A bend
122 replicating lane 1 (radius 36.5 m) of a standard 400 m running track (IAAF, 2008)
123 was reconstructed and a 30 m section of straight track was used for straight-line
124 trials. The order of bend and straight trials were randomised between participants to
125 minimise order effects. Participants completed a typical warm-up followed by up to
126 six maximal effort trials for 30 m from starting blocks in both bend and straight
127 conditions. Athletes were instructed to sprint at maximal effort for the full 30 m, and
128 '*on your marks, set, go*' signal was used. To avoid the onset of fatigue, approximately
129 eight minutes were allowed between trials (Churchill et al., 2015). Participants wore
130 their own sprint spikes for the testing session.

131 **Data processing**

132 3D marker coordinate data were tracked using Cortex software (version 5.3,
133 Motion Analysis Corporation, Santa Rosa, CA, USA) and automatic gap filling
134 (cubic spline) performed on any gaps <10 frames. Raw marker positions were

135 filtered at 18 Hz using a low-pass, fourth order recursive Butterworth filter. The cut-
136 off frequency was determined with the use of residual analysis. Segments, local
137 coordinate systems and joint centres were defined using Visual 3D software (version
138 6, C-Motion, Rockville, MD, USA) in accordance with ISB guidelines ((Wu et al.,
139 2002; Wu et al., 2005). de Leva (1996) was used to estimate body segment inertial
140 parameters. At the foot, segment inertia values were then adjusted by 150 to 189 g
141 representing the mass of individual participants' spiked shoe according to
142 manufacturer guidelines.

143 Vertical force data was used to identify touchdown and take-off events,
144 where the mean plus two standard deviations of the vertical ground reaction force
145 (with zero load on the force plate) was used as a threshold (Bezodis, Thomson,
146 Gittoes, & Kerwin, 2007). All variables were measured individually for the left and
147 right step. The foot that initiated the step defined whether the step was left or right.
148 For touchdown of the second foot contact, or trials where the athlete did not make
149 contact with the force plate and so force data was not available, methods described
150 by Bezodis et al. (2007) were used where the mean plus two standard deviations of
151 the fifth metatarsal head vertical coordinates in the static trial were used as a
152 threshold to detect touchdown and take-off. Spatio-temporal variables were
153 calculated following the methods of Churchill et al. (2015). The first central
154 difference technique was calculated using the horizontal distance travelled in the
155 anterior direction by the CoM to give *absolute speed*. *Race velocity*, which provides
156 a measure of performance in terms of official race distance, was calculated by first
157 using a four-quadrant inverse tangent to calculate the angle between the x and z CoM
158 position at each time point. The difference between angles at two consecutive time

159 points was used to calculate race displacement. Finally, first central difference
160 technique was then used to calculate instantaneous velocity of the CoM relative to
161 the race line. Similarly, *race step length* is a measure of the length of official race
162 distance travelled with each step and was calculated using a the angle between the
163 MTP at two consecutive ground contacts was calculated (θ), then multiplied by the
164 radius of the race line (36.7 m). *Directional step length* was calculated relative to the
165 direction of travel. A vector between the horizontal positions of the 2nd metatarsal
166 head at consecutive ground contacts was created. A step progression vector was then
167 created between the horizontal positions of the CoM at consecutive ground contacts
168 and divided by its norm to create a unit vector. The dot product of the two vectors
169 gave directional step length. *Step frequency* was calculated as absolute speed divided
170 by directional step length. *Touchdown distance* was calculated as the horizontal
171 displacement between the CoM and second MTP joint at touchdown. *Contact time*
172 was the time from touchdown to take-off of the same leg and *flight time* the total step
173 time (touchdown of one foot to touchdown of the contralateral foot) minus contact
174 time. *Turn of centre of mass* (CoM; a measure of how much 'turning' occurred) was
175 calculated using the angle between CoM progression vectors during the flight phase
176 before and after the ground contact of interest.

177 *Joint angles* were defined as the distal segment relative to the proximal
178 segment. Joint angles were calculated using the cardan sequence *zxy* (multi-segment
179 foot angles: *zyx*) and cropped to the stance phase. To enable standardisation with
180 previous bend sprinting research (e.g. Alt, et al., 2015), peak angle during stance was
181 then calculated and averaged across three trials for each participant. For ease of
182 interpretation, values of the left limb were multiplied by minus one. Body lateral

183 lean at touchdown was calculated following methods of Yeadon (1990) in Matlab
184 (v2017a, Mathworks, Natick, USA) and used as a measure of how much the athletes
185 were 'leaning' into the bend (Churchill et al., 2015).

186 **Statistical analysis**

187 Shapiro-Wilk normality test ($p > 0.05$) was used to confirm normal
188 distribution of data. Differences between the bend and straight conditions for the left
189 and right limb were assessed using a two way repeated measures Analysis of
190 Variance (ANOVAS), (condition: bend vs. straight, limb: left vs. right) for each
191 dependent variable. Owing to the small sample size, effect size was also
192 implemented for the interpretation of results. Cohen's d provides an estimate of
193 effect with a population, and so can be biased for small samples (Lakens, 2013).
194 Therefore, Hedges's g was used, which includes a correction for small sample size.
195 Effect size (g) was interpreted based on Cohen (1988) guidelines where $g < 0.20$
196 represents a trivial difference, $0.20 \geq 0.50$ indicating a small difference, $0.50 \geq 0.80$ a
197 moderate difference and ≥ 0.80 a large difference between means.

198 **Results**

199 **Joint kinematics**

200 For joint kinematics, there was a condition x limb interaction for peak hip
201 abduction joint angle ($F_{(1, 8)} = 6.075, p = 0.039$), with the right limb being more
202 abducted on the bend compared with the straight (Table 1). There was a condition x
203 limb interaction for peak hip adduction angle, $F_{(1, 8)} = 12.093, p = 0.008$. Peak left
204 step hip adduction was greater on the bend (8°) compared with the left step on the
205 straight (4°) and the right step on the bend (6° , Table 1). In addition, a large effect

206 size suggesting higher peak left hip external rotation ($g = 0.89$) on the bend
207 compared with the straight, $F_{(1, 8)} = 3.859$, $p = 0.085$. There was a condition x limb
208 interaction for body lateral lean at touchdown, $F_{(1, 8)} = 26.697$, $p = 0.001$ which was
209 greater in both the left and right step on the bend (left step -5° ; right step -12°)
210 compared with the straight (left step 6° ; right step -5°). Left step peak ankle internal
211 rotation was greater on the bend compared with the straight and the right step on the
212 bend resulting in a condition x limb interaction ($F_{(1, 8)} = 17.091$, $p = 0.003$).
213 Although no main effect was reported for peak ankle eversion ($F_{(1, 8)} = 1.247$, $p =$
214 0.297), left step peak ankle eversion was 55% greater on the bend compared with the
215 straight ($g = 0.88$). No significant interactions were reported for any variables at the
216 knee.

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

218 **Spatiotemporal variables**

219 There was no main effect for condition on absolute speed, $F_{(1, 8)} = 0.574$,
220 $p = 0.47$. For race velocity, which takes into consideration the progression of the
221 athlete with respect to the actual race distance, there was no main effect for condition
222 ($F_{(1, 8)} = 2.673$, $p = 0.141$, Table 2). However, there was a significant condition x
223 limb interactions ($F_{(1, 8)} = 19.467$, $p = 0.002$) due to shorter race step lengths on the
224 bend compared with the straight (Table 2).

225 For step frequency, there was a significant condition x limb interaction,
226 $F_{(1, 8)} = 12.144$, $p = 0.008$, due to the left step on the bend being lower compared
227 with the left step on the straight ($g = 0.66$) and the right step on the bend ($g = 0.61$).
228 There was a condition x limb interaction for touchdown distance, $F_{(1, 8)} = 5.477$,

229 $p = 0.04$, where left step touchdown distance was longer on the bend (0.30 ± 0.05 m)
230 compared with the straight (0.25 ± 0.05 m).

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

232 **Discussion**

233 The aim of this study was to investigate the effect of bend versus straight-line
234 sprinting during the acceleration phase of a race on the kinematic and spatiotemporal
235 parameters of the lower limb. During bend sprinting, a non-significant increase in
236 peak left hip adduction (8° , $g = 1.09$), combined with a non-significant increase in
237 peak left hip external rotation (-14° , $g = 0.89$) was reported compared with straight-
238 line sprinting. This supports research during sub-maximal effort bend sprinting at
239 approximately 9.26 m/s (Alt et al., 2015) which also reported peak left hip adduction
240 (14°) and external rotation (22°). The excessive hip adduction observed might have
241 implications for injuries, particularly at the knee (Li et al., 2015). For example, it is
242 expected that iliotibial band tension would increase with hip adduction, potentially
243 resulting in iliotibial band syndrome (Chuter & Janse de Jonge, 2012; Powers, 2010).
244 Therefore, the high peak hip adduction observed during bend sprinting may be a
245 precursor for injury. Strength and conditioning programmes should aim to ensure the
246 hip joint is capable of withstanding high loads and prevent long-term implications
247 for athletes.

248 The present study observed a large, but non-significant, increase in peak left
249 step ankle eversion on the bend compared with the straight ($g = 0.88$). These
250 findings support the theory from Alt et al. (2015) that the left limb is associated with
251 a stabilising role achieved through the combination of greater hip adduction and

252 ankle eversion. Whilst increased eversion enables the attenuation of impact forces
253 (Hreljac, 2004), it is also linked with medial tibial stress syndrome and
254 patellofemoral pain syndrome (Chuter & Janse de Jonge, 2012) both of which were
255 amongst the most frequently reported injuries in indoor bend sprinters over a season
256 (Beukeboom, Birmingham, Forwell, & Ohrling, 2000). Therefore, strengthening
257 evertor muscles at the foot and ankle should be prioritised to reduce the risk of injury
258 in bend sprinters. It is apparent that the left limb is in a complex segmental
259 arrangement which might compromise force production and therefore be responsible
260 for the loss of speed observed on the bend. As Chang and Kram (2007) suggested, it
261 is possible that modifications in the transverse and frontal planes restrict the capacity
262 of muscles to operate and produce force in the sagittal plane. Therefore, future
263 analysis of joint moments during bend sprinting is warranted.

264 The modifications reported in the present study during the acceleration phase
265 on the bend compared with the straight are not as great as those reported during the
266 maximal speed phase. For example, Churchill et al. (2015) and Alt et al. (2015)
267 reported peak left hip adduction values during bend sprinting of 11° and 14°
268 respectively, compared with the 8° in the present study. This suggests kinematic
269 modifications between the bend and straight become more prominent as velocity
270 increases. However, greater modifications have also been found at smaller radii
271 when running at slower speeds (Chang & Kram, 2007; Luo & Stefanyshyn, 2012).
272 Therefore, it is likely that a combination of radius and velocity are responsible for
273 inducing kinematic modifications. However, the effect of lane allocation has not yet
274 been investigated during the acceleration phase despite performance differences

275 being observed across lanes during the maximal speed phase of bend sprinting
276 (Churchill, Trewartha, & Salo, 2018).

277 Based on the results of the present study, modifications of the right limb
278 during the acceleration phase of bend sprinting can be characterised by an increase in
279 hip abduction. In addition, the present study did not observe a change in peak right
280 ankle external rotation or internal knee rotation. These two factors were suggested by
281 Alt et al. (2015) to contribute towards a rotational strategy of the right limb.
282 However, findings of this study cannot support this during the acceleration phase.
283 This further highlights the left and right limb have differing functions on the bend,
284 whilst also advancing the notion that the key to understanding the limits of bend
285 sprinting performance lie within the left limb. Hence, limb specific training, with an
286 appreciation of these between-limb differences, should be considered when
287 developing training programmes.

288 There was a large increase in body lateral lean at touchdown on the bend
289 compared with the straight. These findings, combined with the aforementioned
290 kinematic modifications support the suggestion from Churchill et al. (2015) that the
291 increase in lateral lean angle found on the bend might be responsible for inducing
292 kinematic modifications in the lower limb. However, this was lower than the -10°
293 (left step) and -15° (right step) lean angles reported during maximum speed
294 (Churchill et al., 2015), suggesting these smaller changes accumulate during the
295 acceleration phase, resulting in greater changes at faster speeds. To ensure the
296 transfer of strength training to sports performance, the principle of training
297 specificity is of paramount importance (Young, 2006). Coaches tend to prefer the

298 specificity of training is addressed by adding resistance to sporting movements rather
299 than attempting to make gym exercises more sports specific (Burnie et al., 2017).
300 Therefore, as suggested by Churchill, Trewartha, Bezodis, and Salo (2016) the use of
301 ropes or harnesses in training to provide resistance in a leaning position might be
302 beneficial to performance. In addition, undertaking representative sprint training on
303 the bend to further promote specificity is essential.

304 Small effect sizes were observed when comparing absolute speed on the
305 bend and the straight for the left ($g = 0.52$, 2%) step. Whilst the reported effect sizes
306 suggest these reductions are small, a 2% reduction may be meaningful in terms of
307 competitive race performance. For the left step, the 2% reduction found in the
308 present study is the same as reported in previous research into the acceleration phase
309 of bend sprinting (Stoner and Ben-Sira, 1979). Similarly to Churchill et al. (2015) at
310 maximal speed, the reduction in left step velocity on the bend can be attributed to a
311 reduction in left step frequency. Moreover, an increase in left step touchdown
312 distance was apparent on the bend compared with the straight. An increase in
313 touchdown distance has previously been shown to be related to a decrease in ratio of
314 force (Bezodis, Trewartha, & Salo, 2015). A decrease in ratio of force during bend
315 sprinting was also demonstrated by Judson et al. (2019); suggesting reducing
316 touchdown distance may be a key consideration for improving performance on the
317 bend.

318 Churchill et al. (2015) suggest the reduction in right step absolute speed is
319 due to a shorter right directional step length on the bend compared with the straight.
320 However, no reduction in right step absolute speed was observed in the present

321 study. A small ($g = 0.35$) decrease in right directional step length on the bend
322 compared with the straight was reported, although the difference (0.03 m) does not
323 meet the minimum detectable difference (MDD) of 0.08 m identified by Judson, et
324 al. (2018). Therefore, from the results suggest maintaining a similar right directional
325 step length on the bend and straight aided in avoiding a reduction in right step
326 absolute speed.

327 A main effect for condition was reported with a reduction in race step length
328 on the bend compared with the straight in both the left ($g = 2.89$) and right steps
329 ($g = 6.16$). The reductions reported here are up to twice as great as those found by
330 Churchill et al. (2015) and Churchill et al. (2016) during the maximal speed phase.
331 The radius in the present study was 36.5 m (lane one), whilst Churchill et al. (2015)
332 and Churchill et al. (2016) examined a 37.72 m radius (lane two), which might have
333 some impact on the results. Furthermore, athletes tend to try and maintain a straight
334 path for as long as possible during the acceleration phase. Qualitative analysis of
335 video data shows athletes were not running straight at the point of data collection.
336 However, doing so in the earlier phases of the race may result in athletes not closely
337 following the race line and consequently, a 3% and 2% decrease in race velocity for
338 the left and right steps, respectively. Therefore, sprinting with the aim of maintaining
339 a straight path during the acceleration phase may not be an effective strategy.

340 It is acknowledged that the sample size is small, however, the number of
341 participants ($n = 9$) is within the range of those previously reported in bend sprinting
342 research (Alt et al., 2015; Churchill et al., 2015; Churchill et al., 2016; Churchill et
343 al., 2018). In addition, the statistical analysis was appropriate to account for the

344 small sample size, with the use of Hedge's g , which includes a correction for smaller
345 samples (Lakens, 2013). In some instances, although not statistically significant,
346 small effect sizes were observed when comparing the left and right limb on the
347 straight. For example, small effect sizes of $g = 0.26, 0.34$ and 0.41 were reported for
348 directional step length, ankle inversion and hip internal rotation, respectively.
349 However, existing sprint literature offers some plausible explanations for these
350 differences. For example, Exell, Irwin, Gittoes, and Kerwin (2017) reported
351 asymmetry in all kinetic and kinematic variables analysed during maximal velocity
352 straight-line sprinting. Furthermore, asymmetrical differences in the strength of
353 invertor and evertor muscle groups of indoor bend sprinters have also been observed
354 (Beukeboom et al., 2000). It is possible the differences observed between the left and
355 right limbs on the straight may be a result of muscular changes due to expertise in
356 the discipline of bend sprinting. Importantly, Excell et al., (2017) concluded that
357 asymmetry was athlete-specific and not necessarily detrimental to performance.
358 Finally, the evaluation of one lane is a limitation, since Churchill et al. (2018)
359 demonstrated differences in kinematic modifications across lanes. However, Judson
360 et al. (2018) demonstrated that the reliability of kinematic variables decreases when
361 sessions take place across two days. Therefore, the collection of data in one session
362 was prioritised, although this consequently constrained the number of trials available
363 due to the risk of fatigue induced injury.

364 **Conclusion**

365 The results of the present study demonstrate that the bend impacts upon
366 kinematic and spatiotemporal parameters of technique and performance during the

367 acceleration phase. These results show that altered kinematics start early in the race
368 and likely accumulate, resulting in greater modifications during the maximal speed
369 phase and thus a greater reduction in speed. Furthermore, the reported kinematic
370 modifications are more prominent in the left limb. A recent study by Ohnuma, Tachi,
371 Kumano, and Hirano (2018) compared technique on the bend and straight in 'good'
372 and 'poor' bend sprinters - where athletes were categorised by their ability to
373 maintain their maximum straight-line speed on the bend (i.e. those with a higher
374 percentage difference in running speed were categorised as poor, and vice versa). It
375 was concluded that better bend sprinters are those who are able to more closely
376 maintain the same sagittal plane kinematics and kinetics as on the straight path.
377 Therefore, coaches should prioritise strategies to address the reported modifications
378 of the left limb, such as reducing touchdown distance and increasing step frequency
379 on the bend. Moreover, an investigation of joint moments may be warranted to
380 understand the mechanisms responsible for these modifications and identify their
381 role in restricting or aiding performance.

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Table 1 Joint kinematics. Group mean \pm standard deviation. Significant main effects are marked with *. Significant interactions are marked with #.

Peak angle (°)	Straight		Bend		Effect size (g) (% difference)			
	Left	Right	Left	Right	Left vs right straight	Left vs right bend	Straight vs bend left	Straight vs bend right
Hip abduction	-6 \pm 4	-6 \pm 3	-6 \pm 3	-8 \pm 3	0.08 (27%) [#]	0.66 (21%) [#]	0.22 (20%) [#]	0.50 (28%) [#]
Hip adduction	4 \pm 4	7 \pm 3	8 \pm 4	6 \pm 4	0.49 (72%) [#]	0.63 (30%) [#]	1.09 (106%) [#]	0.24 (31%) [#]
Hip internal rotation	2 \pm 8	5 \pm 4	1 \pm 9	7 \pm 5	0.41 (104%)	0.75 (126%)	0.15(86%)	0.41 (38%)
Hip external rotation	-9 \pm 8	-10 \pm 9	-16 \pm 7	-8 \pm 4	0.13 (11%)	1.22 (89%)	0.89(51%)	0.28 (14%)
Knee abduction	-2 \pm 4	-1 \pm 7	-2 \pm 4	0 \pm 4	0.03(75%)	0.39 (23%)	0.03 (0%)	0.21(93%)
Knee adduction	5 \pm 5	5 \pm 4	5 \pm 4	6 \pm 6	0.10(26%)	0.15(17%)	0.05(5%)	0.05 (21%)
Knee internal rotation	-1 \pm 8	-5 \pm 8	-1 \pm 6	-5 \pm 9	0.37 (70%)	0.52 (80%)	0.02 (18%)	0.07 (11%)
Knee external rotation	-15 \pm 7	-13 \pm 7	-14 \pm 6	-15 \pm 8	0.18 (6%)	0.18 (4%)	0.14(5%)	0.22 (6%)
Ankle inversion	14 \pm 9	10 \pm 9	11 \pm 9	12 \pm 9	0.34 (48%) [#]	0.06 (6%) [#]	0.22 (33%) [#]	0.19 (16%) [#]
Ankle eversion	-2 \pm 9	-4 \pm 10	-5 \pm 9	-3 \pm 10	0.15 (36%)	0.12 (23%)	0.88 (55%)	0.02 (8%)
Ankle internal rotation	2 \pm 4	3 \pm 5	12 \pm 7	1 \pm 7	0.25 (44%) ^{*#}	1.95 (562%) ^{*#}	1.70 (346%) ^{*#}	0.46(108%) ^{*#}
Ankle external rotation	-10 \pm 5	-10 \pm 3	-5 \pm 5	-9 \pm 5	0.13 (9%)	0.85 (42%)	0.95(50%) [*]	0.20 (6%)
Body lateral lean at touchdown	6 \pm 3	-5 \pm 1	-5 \pm 2	-12 \pm 2	3.24 (221%) ^{*#}	2.98 (62%) ^{*#}	4.01 (168%) ^{*#}	3.39(78%) ^{*#}

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511 **Table 2:** Spatiotemporal variables. Group mean \pm standard deviation . Significant main effects are marked with *. Significant interactions are marked with #.

	Straight		Bend		Effect size (g) (% difference)			
	Left	Right	Left	Right	Left vs right straight	Left vs right bend	Straight vs bend left	Straight vs bend right
Absolute speed (m/s)	7.98 \pm 0.34	8.00 \pm 0.20	7.81 \pm 0.30	7.98 \pm 0.34	0.12(0%)	0.48(2%)	0.52 (2%)	0.05 (0%)
Race velocity (m/s)	7.98 \pm 0.34	8.00 \pm 0.20	7.76 \pm 0.32	7.86 \pm 0.27	0.12 (0%)	0.32 (1%)	0.64(3%)	0.56 (2%)
Contact time (s)	0.107 \pm 0.007	0.111 \pm .012	0.119 \pm 0.007	0.114 \pm 0.008	0.34 (4%) [#]	0.57 (4%) [#]	1.50 (11%) ^{*#}	0.27 (24%) ^{*#}
Flight time (s)	0.135 \pm 0.019	0.133 \pm 0.016	0.135 \pm 0.021	0.124 \pm 0.016	0.10(2%)	0.53 (9%)	0.01 (0%)	0.51 (7%)
Step Frequency (Hz)	4.33 \pm 0.25	4.29 \pm 0.22	4.11 \pm 0.37	4.30 \pm 0.22	0.18 (1%) [#]	0.61 (5%) [#]	0.66 (5%) [#]	0.09 (1%) [#]
Directional step length (m)	1.84 \pm 0.11	1.87 \pm 0.08	1.90 \pm 0.12	1.84 \pm 0.07	0.26 (2%) [#]	0.55 (3%) [#]	0.48 (3%) [#]	0.35 (2%) [#]
Race step length (m)	1.84 \pm 0.11	1.87 \pm 0.08	1.53 \pm 0.10	1.37 \pm 0.08	0.26 (2%) [#]	1.70 (12%) ^{*#}	2.89 (17%) ^{* #}	6.16 (37%) ^{* #}
Touchdown distance (m)	0.25 \pm 0.06	0.26 \pm 0.07	0.30 \pm 0.05	0.27 \pm 0.08	0.12 (4%) [#]	0.49 (10%) [#]	0.95 (29%) [#]	0.11 (4%) [#]
Turn of CoM (°)			2.48 \pm 0.91	2.61 \pm 0.86		0.13 (5%)		

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