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BEND SPRINTING PERFORMANCE: NEW INSIGHTS INTO THE EFFECT OF RUNNING LANE

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1   **Bend sprinting performance: new insights into the effect of running lane**

2

3   **Abstract**

4   Athletes in inner lanes may be disadvantaged during athletic sprint races containing a bend

5   portion because of the tightness of the bend. We empirically investigated the veracity of

6   modelled estimates of this disadvantage and the effect of running lane on selected kinematic

7   variables. Three-dimensional video analysis was conducted on nine male athletes in lanes 8, 5

8   and 2 of the bend of an outdoor track (radii: 45.10, 41.41 and 37.72 m, respectively). There

9   was over 2% ($p < 0.05$) reduction in mean race velocity from lane 8 (left step 9.56 ± 0.43

10   m/s, right step: 9.49 ± 0.41 m/s) to lane 5 (left step: 9.36 ± 0.51 m/s, right step: 9.30 ± 0.51

11   m/s), with only slight further reductions from lane 5 to lane 2 (left step: 9.34 ± 0.61 m/s, right

12   step: 9.30 ± 0.63 m/s). Race velocity decreased mainly because of reductions in step

13   frequency as radius decreased. These unique data demonstrate the extent of the disadvantage

14   of inner lane allocation during competition may be greater than previously suspected.

15   Variations in race velocity changes might indicate some athletes are better able to

16   accommodate running at tighter radii than others, which should have implications for athletes'

17   training.

18   (Word count: 198)

19

20   Keywords: Athletics, curve, track and field, three-dimensional kinematics, 200 m

21

22

Introduction

Lane allocation may disadvantage runners in the inner lanes in sprint races that include a bend portion because of the requirement to run on a tighter bend radius (Jain, 1980; Greene, 1985). Mathematical models have estimated the effect that running the inner lanes compared with the outer lanes might have on competition times. Jain (1980) reported the disadvantage is approximately 0.069 s in lane one as opposed to lane seven for a 200 m race. However, Greene (1985) estimated a substantially greater disadvantage of 0.123 s. Empirical evidence at very small radii (1-6 m) has shown running velocity to decrease as bend radius decreases (Chang & Kram, 2007). However, to our knowledge, there have been no robust experimental studies which have aimed to quantify the effect that running lane has on bend running performance on surfaces and at radii typical of those of athletic sprint events.

Maximal-effort sprinting produces lower velocity on the bend compared with straight line sprinting (Churchill, Salo & Trewartha, 2015). This is mainly because of increased ground contact time leading to a significant reduction in step frequency during the left step on the bend compared with the straight, and because of decreased flight times leading to a reduced step length during the right step on the bend (Churchill et al., 2015). Furthermore, bend sprinting is asymmetrical in nature between left and right steps (Churchill et al., 2015; Ishimura & Sakurai, 2016). Churchill et al. (2015) reported greater values for the left step for ground contact time, touchdown distance, body sagittal lean range of motion (ROM) and the amount of turning achieved during the contact phase. Additionally, greater inward lean was reported during the right step compared with the left step (Churchill et al., 2015). Indeed, left step ground contact time has been shown to be longer than the right at maximal (Churchill et al., 2015; Ishimura & Sakurai, 2016) and submaximal velocities on the bend (Alt, Heinrich, Funken & Potthast, 2015; Stoner & Ben-Sira, 1979). It is likely that the effect of the bend on

these variables lessens as the tightness of the bend radius decreases, i.e. in the outer lanes,

because of less requirement for centripetal force generation to produce the turn. However,

empirical evidence of the effect of the bend radius on sprint performance variables is lacking

in the literature.

Thus, the aim of the present study was to investigate the effect of running in different lanes

on bend sprinting performance at radii that are typical of those experienced in athletic sprint

events. Specifically, we considered how well previously presented mathematical models from

the literature matched the experimental data. Additionally, the study aimed to assess the

effect of the lane on selected kinematic variables which have been shown to be affected by

bend sprinting. It was hypothesised that velocity would decrease as bend radius decreased.

Further, it was hypothesised that this would be due to right step length and left step frequency

decreasing from outside lanes to inside lanes, as bend radius decreased. These changes were

envisaged to occur mainly because of longer contact time on the left step and shorter flight

time on the right step, when the radius decreases, in line with previous literature comparing

bend and straight sprinting.

Methods

Participants

Nine male sprinters (mean age, 21.5 ± 3.2 years; mass, 79.4 ± 10.1 kg; height, 1.82 ± 0.06 m)

participated in the study. All were experienced in bend sprinting (200 m or 400 m) and

regularly competed in national and/or international competitions. Personal best (PB) times for

the 200 m ranged from 21.1 s to 22.6 s for eight of the athletes. The ninth athlete, who had no

recent 200 m time, had a 400 m PB of 47.36 s. Examination of data for this athlete running in

lane 2 in the present study ranked him third fastest within the participant group indicating that

73   his 200 m time would be well within the group range. The study procedures were approved

74   by the Bath Local Research Ethics Committee and all participants provided written informed

75   consent before data collection.

76

77   *Data collection*

78   Using a repeated measures design, three dimensional (3D) video analyses were performed on

79   the athletes undertaking two 60 m maximal-effort sprints around the bend in each of lanes 8,

80   5 and 2 (radii:45.10, 41.41 and 37.72 m, respectively) of a standard outdoor polyurethane

81   running track. The order in which the lanes were run was pseudo-randomised for different

82   athletes based on which data collection sessions they took part in. Trials were completed

83   following the athletes' typical competition warm up. Athletes wore tight leggings/shorts and

84   vest tops and their own spiked sprint shoes. They started from a standing start or three-point

85   start, as per personal preference. Recovery time between trials within a lane was

86   approximately 8 min and between the lanes approximately 15 min. Generally, all six trials

87   were undertaken during a single training session. For two athletes this was not possible and

88   consequently four trials were completed in one training session with the remaining two trials

89   being completed in their next training session.

90

91   Two high-speed video cameras (MotionPro HS-1, Redlake, USA) recorded the athletes

92   running in each lane at the 40-48 m section of the 60 m enabling analysis of two consecutive

93   steps (Figure 1). The cameras operated at a 200 Hz frame rate with a shutter speed of

94   1/1000 s, and recorded with an image resolution of 1280 × 1024 pixels. An 18 point 3D

95   calibration volume (6.50 m long × 1.60 m wide × 2.00 m high) was recorded before the

96   athletes' trials taking place in each lane.

97

98   **Figure 1 near here**

5

99

Data processing

101 All trials were manually digitised using Vicon Motus software (Version 9.2, Vicon, UK). A

102 $2 \times$ zoom function was used during digitisation which increased the effective resolution of

103 the screen to 2560×2048 pixels. For most trials the two video cameras were genlocked.

104 However, on one data collection session the genlocking failed. In this case, the two video

105 streams were synchronised using two sets of synchronised 20 LED displays (Wee Beasty

106 Electronics, UK) as in Churchill et al. (2015). Digitising of calibration and running trial

107 videos, identification of gait events, filtering, creation of the kinematic model and calculation

108 of body centre of mass (CoM) followed exactly the methods of Churchill et al. (2015).

109

Calculation of variables

111 Variables measured were constrained by those identified by Churchill et al. (2015) as being

112 affected by maximum sprinting on the bend (in comparison with straight line sprinting). Left

113 and right steps were measured separately with a step being defined from touchdown of one

114 foot to next contralateral touchdown. Steps were assigned 'left' or 'right' based on the

115 touchdown limb that initiated the step. The following variables were analysed (full methods

116 for their calculation can be found in Churchill et al., 2015): race velocity (the velocity with

117 respect to the official race distance), race step length (the magnitude of the race distance

118 covered during the step), step frequency, ground contact time, flight time, touchdown

119 distance, turn of the CoM during ground contact (the change in trajectory of the CoM during

120 the ground contact phase of each step), body lateral lean at touchdown and take-off, and body

121 sagittal lean ROM.

122

Statistical analysis

124 Individual mean values for each variable in each lane were calculated for all athletes. These

125 values were then used for further statistical analyses (SPSS v 14.0, SPSS Inc., USA). A one-

126 way repeated measures ANOVA was performed to measure the effect of the lane on each

127 variable for the left and right steps separately. Where a main lane effect was found, pairwise

128 comparisons were conducted. To assess the presence of any asymmetries within a lane, left

129 step variables were compared with right step variables within that lane for each variable using

130 paired samples t-tests. Significance was set at $p < 0.05$. To reduce the chances of committing

131 a Type II error, and thus potentially missing important variables that might be affected by

132 bend radius, no adjustments for multiple comparisons were made. Effect sizes between lanes

133 and between left and right steps within a lane for each variable were calculated using Cohen's

134 d (Cohen, 1988). Interpretation of effect sizes was based on Cohen's guidelines, with $0.20 \leq$

135 $d < 0.50$ indicating a small difference, $0.50 \leq d < 0.80$ a moderate difference, and $d \geq 0.80$ a

136 large difference between the means.

137

138 **Results**

139 There was a general trend for mean race velocity to decrease as bend radius decreased from

140 lane 8 to lane 2 (Figure 2, Table 1). From lane 8 to lane 5 the reduction in race velocity was

141 0.20 m/s for the left step (p = 0.010, d = 0.42) and 0.19 m/s for the right step (p = 0.029, d =

142 0.40). However, there were no statistically significant reductions in performance in lane 2

143 relative to lane 5 at the group level. In each lane, race velocity was greater for the left step

144 than the right step and these asymmetries were statistically significant in lanes 8 ($p = 0.042$, d

145 = 0.16) and 5 ($p = 0.027$, $d = 0.11$; Table 1). The standard deviations of the race velocity

146 showed that as bend radius decreased, the variation in performance between participants

147 increased (Table 1, Figure 2).

148

149   ***Figure 2 near here***

150

151   The shortest race step lengths were observed in lane 5 for both the left and right steps

152   (Table 1). This was significant for lane 5 compared to lane 2 for the left step ($p = 0.005$,

153    $d = 0.44$). Step frequencies for left and right steps within a lane were similar in all lanes.

154   However, there was a general trend for step frequency to decrease as bend radius decreased.

155   While the only significant difference for step frequency was between lane 5 and 2 for the left

156   step ($p = 0.037$, $d = 0.47$, Table 1), moderate effect sizes were observed between lane 8 and

157   lane 2 for both the left and right steps (left: $d = 0.61$, right: $d = 0.56$).

158

159   There was a general trend for the left step mean ground contact time to increase as bend

160   radius decreased with a significant difference observed between lane 8 and 2 ($p = 0.004$,

161    $d = 0.69$). During the right step, ground contact time was similar across lanes. However,

162   statistically significant asymmetries between left and right ground contact time were present

163   in all lanes ($p < 0.01$, Table 1).

164

165   Significantly more turning of the CoM was achieved during the left ground contact phase

166   compared with the right ground contact phase in all three lanes ($p < 0.01$, Table 1). For the

167   right step, there was significantly more turning of the CoM (37% and 45%, respectively) in

168   lanes 5 ($p = 0.013$, $d = 1.04$) and 2 ($p = 0.002$, $d = 1.44$) compared with lane 8. For the left

169   step, none of the turning of the CoM difference reached significant level or moderate effect

170   size. There was a trend of increased inward (more negative) body lateral lean at touchdown as

171   radius decreased for both the left and right steps. The only comparison for which this was not

172   statistically significant was between lane 5 and lane 2 for the left step ($p = 0.353$). A

173 significant difference between left and right steps within each lane was also found for inward

174 lean at touchdown, with more lean for the right step (Table 1).

175

176 ***Table 1 near here***

177

178 **Discussion and Implications**

179 We evaluated the effect of running in different lanes of a standard athletics track on bend

180 sprinting performance variables. Race velocity decreased as bend radius decreased and

181 variation between participants increased as the bend became tighter. The reductions in race

182 velocity equated to a 2.1% and 2.0% decrease in race velocity from lane 8 to lane 5 for the

183 left and right steps, respectively. There was a further 0.2% reduction in velocity from lane 5

184 to lane 2 for the left step only, meaning that differences between lane 5 and lane 2 were

185 negligible. Reductions in race velocity were because of a general trend for step frequency to

186 decrease as radius decreased for both the left and right steps. Additionally, step lengths were

187 shorter in lanes 5 and 2 than in lane 8, with the shortest step lengths being observed,

188 surprisingly, in lane 5 for both the left and right steps. These findings allow us to accept the

189 research hypotheses (reductions in performance variables as radius decreased) for velocity

190 and left step frequency, but not for right step length.

191

192 Race velocities similar to the present study have been reported in the literature for lane 2 (left

193 step: 9.34-9.40 m/s, right step: 9.29-9.34 m/s; Churchill et al., 2015; Churchill, Trewartha,

194 Bezodis & Salo, 2016) indicating the performances in the present study were comparable

195 with previous datasets. The decrease in race velocity as bend radius decreased shows that

196 athletes in the inner lanes are at a biomechanical disadvantage. These results provide

197 empirical evidence to add to previously proposed mathematical models. However, based on

9

198 these results, the discrepancy between running lanes might be much larger than had been

199 previously suspected. Depending on the model used, the difference between running a 200 m

200 sprint in lane 1 (radius 38.50 m) compared with lane 7 (radius 45.72 m) of an outdoor track

201 has previously been suggested to be 0.069 s (Jain, 1980) to 0.123 s (Greene, 1985). The

202 potential effect of decreases in race velocity on race performance can be estimated based on

203 the present experimental data using a number of assumptions and simplifications. The

204 average race velocity of the left and right steps in lane 8 was 9.53 m/s in this study. On a

205 standard outdoor track, the distance run on the bend is approximately 115 m for all lanes

206 (International Association of Athletics Federations, 2008). If we assume that the acceleration

207 at the start takes 40 m, it leaves a further 75 m for the rest of the bend. If we extrapolate the

208 aforementioned velocity of lane 8 for the rest of the bend, this equates to a time of 7.87 s to

209 cover the bend from 40 m to 115 m. The average race velocity over the left and right steps

210 was 9.33 m/s in lane 5 equating to a respective time of 8.04 s, and in lane 2 the average race

211 velocity was 9.32 m/s equating to 8.05 s. Using these estimates, the difference in race times

212 between lane 8 and lane 5 would be 0.170 s and between lane 8 and lane 2 it would be

213 0.180s. We acknowledge that it is unlikely that any athlete can keep the maximum velocity

214 for the whole 75 m. However, any slight decrease in the velocity is very likely to be relatively

215 similar to aforementioned values between the lanes resulting in a minimal change to these

216 estimated times.

217

218 The above estimates, based on real experimental data, are larger than the predicted

219 differences between lanes 1 and 7 given by Jain (1980) and Greene (1985). We recognise that

220 these are estimates based on some assumptions, but they still provide the first full

221 quantification of the challenges facing athletes allocated the inner lanes. Furthermore, these

222 workings do not yet take into account the likely negative affect that bend radius has on the

223   acceleration phase, given that velocity has been shown to reduce on the bend compared with

224   the straight during the acceleration phase of sprinting (Stoner & Ben-Sira, 1979).

225   Additionally, since the velocity would be lower coming off the bend into the straight in the

226   inner lanes, the straight line velocity would also be affected, further increasing the difference

227   between the inside and outside lanes. Thus, our estimates might even be at the lower end of

228   possibilities. The magnitude of the effect of the bend will likely be different between

229   individuals. Indeed the standard deviations for the race velocities in the present study showed

230   greater variation as bend radius decreased. This suggests that some athletes were better than

231   others at maintaining their velocity as the bends got tighter. Thus, while these initial estimates

232   of differences in 200 m race times because of different lanes might be larger or smaller for

233   different athletes, they do suggest that the magnitude of disadvantage of being in the inner

234   lanes might be greater than previously suspected.

235

236   There was a general trend for step frequency to decrease as radius decreased for both the left

237   and right steps, where mean step frequency reduced from 4.48 Hz for both left and right steps

238   in lane 8 to 4.35 Hz and 4.36 Hz, respectively, in lane 2 (Table 1), which represented a

239   moderate effect size. Usherwood and Wilson (2006) postulated that athletes would increase

240   ground contact times when bend sprinting to meet the additional requirement to generate

241   centripetal force and consequently reduce step frequencies. The observed decrease in step

242   frequency as bend radius decreased in the present study provides some support for

243   Usherwood and Wilson's (2006) model. However, while step frequency decreased because of

244   an increase in ground contact time for the left step, ground contact times for the right step

245   were actually similar between lanes, but flight times varied and this also affected step

246   frequency. Thus, the mechanism for changes in step frequency was different between left and

247   right steps. The trend for increased contact time for the left step when the radius decreased

248 followed our secondary hypothesis, although the difference only became statistically

249 significant between lanes 8 and 2.

250

251 The present study showed that the bend radius had an effect on step length, but perhaps

252 surprisingly it did not necessarily decrease as radius decreased. Left step length was 0.05 m

253 longer in lane 2 than in lane 5. This significant increase in left race step length from lane 5 to

254 lane 2 was accompanied by a significant decrease in left step frequency. It is possible that

255 when running in lane 2, the athletes might have tried to compensate for reductions in step

256 frequency caused by the tightness of the bend by increasing step length, or vice versa.

257 Negative interaction of this kind has been observed in straight line sprinting (Hunter,

258 Marshall & McNair, 2004). It is, therefore, important to question whether increasing step

259 length rather than step frequency at tighter bend radii is a beneficial strategy, or whether

260 strategies to maintain step frequency aiming to prevent reductions in velocity would be more

261 advantageous. Further research into the strategies employed by 'better bend runners', i.e.

262 those athletes whose performance decreases the least on the bend compared with their

263 straight line velocity, may aid this.

264

265 From a practical perspective this study has a number of implications. The standard deviations

266 revealed that there was an increase in the degree of variation between participants for race

267 velocity as bend radius decreased from lane 8 to lane 5 and then to lane 2. This might be

268 indicative of different athletes being better able to 'cope' with the demands of the tighter lane

269 than others. It is possible that this type of information could and perhaps should be used by

270 coaches to identify training needs. For example, if an athlete has a larger deterioration in

271 performance as bend radius decreases then more bend-specific training might be required.

272 Churchill et al. (2016) indicated bend sprinting to have large, specific and different force

273   demands to that of straight line sprinting. Based on training specificity, it can be speculated

274   that athletes' main way to learn to tolerate these forces is by sprinting on the bend at high

275   velocities. Additionally, this information might facilitate event choice for athletes and

276   coaches, or might influence how the athletes approach the different rounds of competition.

277   The usual process for lane allocation in outdoor competitions is that during first round lanes

278   are randomly assigned. Subsequent rounds are allocated based on the ranking of each athlete

279   within the heats, where the four highest ranked athletes are allocated lanes three to six at

280   random, the fifth and sixth ranked athletes allocated lanes seven and eight at random, and the

281   final two athletes allocated lanes one and two at random (International Association of

282   Athletics Federations, 2014). Thus, those athletes who are less able to maintain performance

283   in the inner lanes might have a greater requirement to 'qualify well' for subsequent rounds to

284   ensure a better lane draw.

285

286   There were some limitations to the study. The number of participants was limited because of

287   the requirement to have experienced bend sprinters of high calibre. Whilst more participants

288   would have been desirable, it was our aim to avoid testing less experienced athletes which

289   might have meant that the results were confounded by the novelty of the task. The limited

290   number of participants might have meant that stronger trends in the data were masked by low

291   statistical power. This might explain the fact that a number of the trends in the data yielded

292   only small effect sizes, although some of them might have a meaningful impact in

293   performance from an applied perspective. An example of this would be reductions in race

294   velocity from lane 8 to lane 2, where small effect sizes were seen for both steps (left: $d =$

295   0.42, right: $d = 0.40$), but a 2% decrease in performance would be very important to an

296   athlete or coach. Although the results for race velocity suggest a possible non-linear effect of

297   running lane on performance, this cannot be fully established without data collected in more

298 lanes. There are clear challenges in trying to obtain more runs per athlete in the same session.

299 Thus, the practical constraints of the number of trials that could be completed by the athletes

300 meant that analysis of three lanes was considered sufficient to obtain an overall picture of the

301 effect of the lane. However, the possibility of a non-linear relationship warrants further

302 investigation. These limitations notwithstanding, this is the first study to empirically measure

303 the effect of running lane on performance during sprinting at radii and on surfaces typical of a

304 standard outdoor track and to provide ecologically valid between-lane differences.

305 Furthermore, the study provides practically useful information about the effect of altering

306 bend radius on performance and is a useful platform for further research.

307

308 **Conclusion**

309 Bend sprinting performance, as identified by race velocity, decreased as bend radius

310 tightened from lane 8 to 5 to 2. The results showed that the effect of running lane on race

311 times may be greater than previous mathematical models have suggested and may easily be in

312 the region of 0.180 s between lane 8 and lane 2 during a 200 m race. Increased variability in

313 performance between participants as bend radius decreased might be indicative of athletes

314 possessing different abilities to cope with the demands of the inner lanes, which might have

315 implications for training, event selection, or competition approach.

316

317 **Acknowledgement**

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319

320 **Disclosure statement**

321 The authors have no financial or personal conflicts of interest to declare.

322

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369

370

371   Figure captions:

372   Figure 1. Camera set-up for lane 2 trials (not to scale). Note that the cameras were in the

373   same position for lane 5 (radius: 41.41 m) and lane 8 trials (radius: 45.10 m), but the 'front

374   view' camera was adjusted in order that the centre of the lane of interest was in the centre of

375   the field of view, and the zoom of the side view camera adjusted to maintain the 8 m wide

376   field of view in the relevant lane. The start and end positions for the runs were adjusted so

377   that the athlete started 40 m from the filming area in each lane.

378

379   Figure 2. a) Left and b) right step race velocity on the bend in lanes 8, 5, and 2 for individual
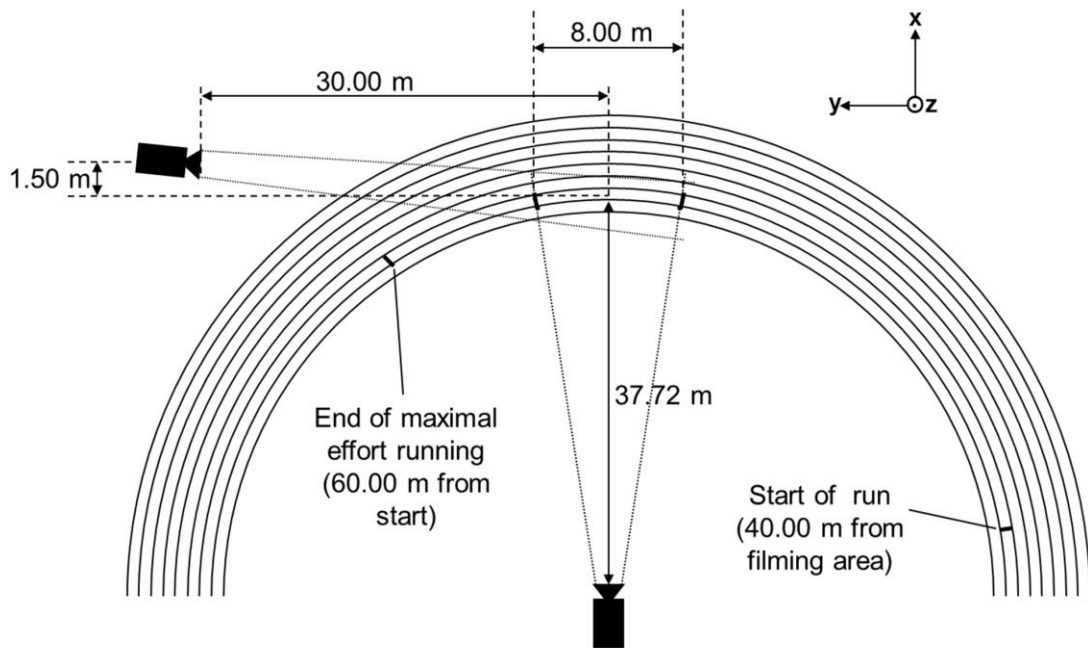
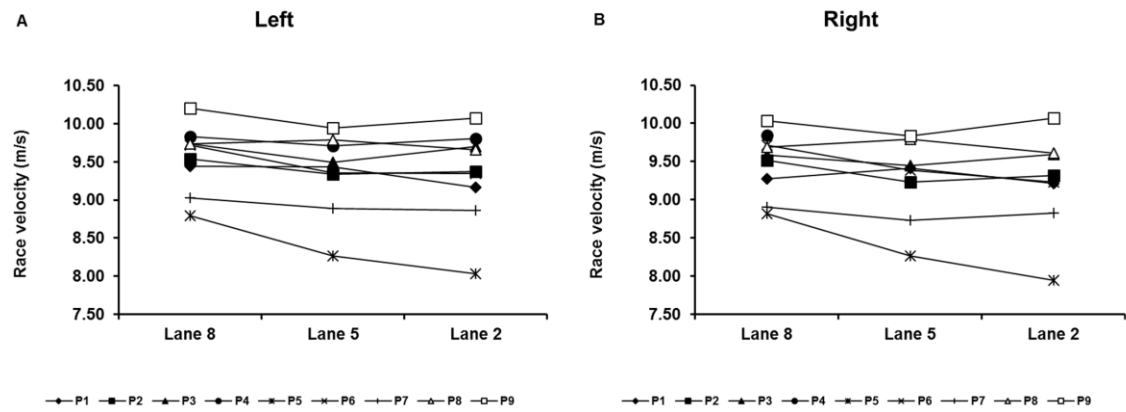380   participants (P1-P9).

Figure 1

Figure 2

Table 1. Left and right step group mean values (± SD) and significant differences for selected kinematic variables during bend running in lanes 8, 5, and 2.

	Lane 8		Lane 5		Lane 2		Significant differences								
	Left	Right	Left	Right	Left	Right	Left vs. right L8	Left vs. right L5	Left vs. right L2	L8 vs. L5 Left	L8 vs. L5 Right	L8 vs. L2 Left	L8 vs. L2 Right	L5 vs. L2 Left	L5 vs. L2 Right
Race velocity (m/s)	9.56 ± 0.43	9.49 ± 0.41	9.36 ± 0.51	9.30 ± 0.51	9.34 ± 0.61	9.30 ± 0.63	**a**	**a**		**a**	**a**	**a**			
Race step length (m)	2.13 ± 0.08	2.12 ± 0.11	2.10 ± 0.11	2.10 ± 0.10	2.15 ± 0.09	2.13 ± 0.12									**a**
Step frequency (Hz)	4.48 ± 0.19	4.48 ± 0.18	4.45 ± 0.21	4.43 ± 0.17	4.35 ± 0.25	4.36 ± 0.22									**a**
Ground contact time (s)	0.116 ± 0.006	0.109 ± 0.006	0.119 ± 0.009	0.111 ± 0.009	0.121 ± 0.008	0.111 ± 0.008	**b**	**b**	**c**				**b**		
Flight time (s)	0.113 ± 0.009	0.109 ± 0.009	0.112 ± 0.010	0.109 ± 0.006	0.117 ± 0.012	0.111 ± 0.008									
Touchdown distance (m)	0.38 ± 0.04	0.34 ± 0.04	0.39 ± 0.04	0.33 ± 0.04	0.39 ± 0.03	0.32 ± 0.05	**c**	**c**	**c**						
Turn of CoM (°)	4.0 ± 0.7	1.7 ± 0.6	4.4 ± 1.1	2.4 ± 0.6	4.3 ± 0.7	2.5 ± 0.4	**c**	**b**	**b**			**a**		**b**	
Body sagittal lean ROM (°)	57.0 ± 3.2	53.6 ± 3.6	58.0 ± 3.0	53.9 ± 3.7	58.4 ± 3.2	53.4 ± 3.5	**c**	**c**	**c**						
Body lateral lean at TD[1] (°)	-8.4 ± 1.5	-12.7 ± 2.4	-9.4 ± 2.2	-14.2 ± 1.8	-9.9 ± 2.5	-15.1 ± 1.9	**b**	**c**	**c**	**a**	**a**	**a**	**b**		**a**
Body lateral lean at TO[1] (°)	-6.8 ± 1.1	-12.3 ± 2.2	-7.5 ± 1.7	-13.2 ± 1.8	-7.5 ± 2.0	-14.1 ± 2.0	**c**	**c**	**c**					**b**	

Note: ROM, range of motion; TD, touchdown; TO take off; L8, lane 8; L5, lane 5; L2, lane 2; [1] a negative value for body lateral lean indicates inward lean; **a:** $p < 0.05$; **b**: $p < 0.01$; **c:** $p < 0.001$.