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Thomas, Christopher, Dos'Santos, Thomas , Comfort, Paul and Jones, Paul A (2024) Male and female soccer players exhibit different knee joint mechanics during pre-planned change of direction. *Sports Biomechanics*, 23 (1). pp. 118-131. ISSN 1476-3141

DOI: <https://doi.org/10.1080/14763141.2020.1830160>

Publisher: Taylor and Francis

Version: Accepted Version

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1 **Male and female soccer players exhibit different knee joint mechanics**
2 **during pre-planned change of direction**

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18 **Male and female soccer players exhibit different knee joint mechanics**
19 **during pre-planned change of direction**

20 Change of direction manoeuvres are important in soccer and associated with non-
21 contact anterior cruciate ligament injury, yet it is not known how the mechanics
22 differentiate between males and females during 180° turns. Twenty-eight soccer
23 players (14 male and 14 female) performed 180° turns with ground reaction forces
24 collected over penultimate and final contacts. A two-way (contact x limb)
25 multivariate analysis of variance (MANOVA) were run to examine differences
26 between contact (penultimate and final) or limb (dominant and nondominant) for
27 sagittal plane hip, knee and ankle peak angles and moments, and frontal plane knee
28 abduction moments and angles between sexes. Average horizontal GRF was
29 increased on the dominant limb, compared to nondominant and for the final contact
30 compared to the penultimate contact. Knee abduction angles were increased in
31 females compared to males, while the opposite was true for knee abduction
32 moments. Statistically significant differences were evident, with increases in peak
33 vertical GRF, peak hip flexion angle, peak knee flexion angle, peak knee extensor
34 moment, and peak ankle dorsiflexion angle observed in the penultimate contact
35 compared to final contact. The results indicate the penultimate contact during turns
36 helps reduce loading on the final contact, yet male and female soccer players
37 exhibit different knee joint mechanics during pre-planned change of direction.

38 Keywords: word; agility; anterior cruciate ligament; turns; injury; knee abduction
39 moments, 180° turns

40 **Introduction**

41 It has previously been observed that female players have higher rates of non-contact
42 anterior cruciate ligament (ACL) injuries compared with males (Myklebust, Maehlum,
43 Holm, & Bahr, 1998). There is also evidence that knee joint mechanics are differentiated
44 by sex during change of direction (CoD) tasks (cutting and turning), contributing to
45 increased risk of ACL injury (Brophy, Silvers, Gonzales, & Mandelbaum, 2010; McLean,
46 Huang, & van den Bogert, 2008; Sigward, Pollard, & Havens, 2012). Several studies have
47 shown that females display increased knee abduction angles (Malinzak, Colby,

48 Kirkendall, Yu, & Garrett, 2001; McLean, Lipfert, & van den Bogert, 2004), knee
49 abduction moments (McLean, Huang, & van den Bogert, 2005; McLean et al., 2004;
50 Sigward, Cesar, & Havens, 2015; Sigward et al., 2012), vertical ground reaction forces
51 (GRFs) (Yu, Lin, & Garrett, 2006) and smaller knee flexion angles (Malinzak et al., 2001;
52 McLean et al., 2004; Yu et al., 2006) as compared with their male counterparts during
53 cutting and turning. Moreover, video analysis studies have revealed postures at initial
54 contact such as a dorsiflexed ankle (Boden, Torg, Knowles, & Hewett, 2009), abducted
55 hip (Olsen, Myklebust, Engebretsen, & Bahr, 2004), extended knee joint (Boden et al.,
56 2009; Krosshaug et al., 2007; Olsen et al., 2004), and laterally flexed and rotated torso
57 (Stuelcken, Mellifont, Gorman, & Sayers, 2016) to be associated with ACL injuries
58 during CoD. Similarly, laboratory studies have found these lower limb postures to
59 increase knee abduction moments (Dempsey, Lloyd, Elliott, Steele, & Munro, 2009;
60 Jones, Herrington, & Graham-Smith, 2016a, 2016b), which could lead to increased ACL
61 strain (McLean, Su, & van den Bogert, 2003) and subsequent injury (Hewett et al., 2005).
62 Previous studies have investigated the influence of sex on CoD biomechanics (Fedie,
63 Carlstedt, Willson, & Kernozek, 2010; McLean et al., 2005, 2004; Sigward et al., 2015,
64 2012). Pollard et al. (2018) demonstrated healthy male and female participants exhibit
65 similar lower extremity biomechanics during a 45° side-step. These contrasting findings
66 may be due to inconsistency in how the dominant limb is defined, or the velocity and
67 magnitude of the CoD. For example, sex differences in knee abduction moments during
68 110° turns have been observed, with females greater than males, but no differences were
69 observed in 45° cuts (Sigward et al., 2015). Similarly, females were found to exhibit
70 increased knee valgus angles and internal knee adductor moments during 45 and 110°
71 cutting when compared with males (Sigward et al., 2012). Sharper CoD (i.e. 180° turns)
72 increase the relative lower body loading compared to shallow CoD (<60°) and thus,

73 require substantial braking over several footfalls prior to push-off. Previous work found
74 lower knee flexion angles, yet higher knee abduction angles during a 180° turn compared
75 to a 45° cut (Cortes, Onate, & Van Lunen, 2011), while reductions in knee flexion angle
76 have been observed with sharper CoDs (Schreurs, Benjaminse, & Lemmink, 2017).
77 Furthermore, the knee joint has been found to play a primary role during the deceleration
78 phase of sharper CoDs (Havens & Sigward, 2015a). Further studies on the kinetics and
79 kinematics during turning between male and female soccer players are required to fully
80 understand the biomechanical requirements of 180° CoD and help optimise CoD
81 performance and minimise knee joint loading.

82 It has been previously observed that up to 70% of non-contact ACL injuries occur during
83 a cutting or CoD maneuver (Boden, Feagin, & Garrett, 2000; Boden, Sheehan, Torg, &
84 Hewett, 2010). Previous research (Brophy et al., 2010), suggests limb dominance
85 (kicking vs. support limb) to influence knee joint mechanics and ACL injury, specifically
86 in soccer players. Although non-contact ACL injuries were evenly distributed (kicking
87 limb = 30; support limb = 28), 74% (20/27) of males suffered a non-contact ACL injury
88 on the kicking limb, compared with 32% (10/31) of females. There have been several
89 studies in the literature reporting the influence of limb dominance on CoD biomechanics
90 (Bencke et al., 2013; Brown, Wang, Dickin, & Weiss, 2014; Greska, Cortes, Ringleb,
91 Onate, & Van Lunen, 2016; Marshall et al., 2014; Mok, Bahr, & Krosshaug, 2018; Pollard
92 et al., 2018), and can be defined as the preferential use of one side of the body when
93 performing a motor task, typically resulting in a more skilful and therefore dominant side
94 (Maloney, 2019). For example, the preferred limb to kick a ball in soccer or change
95 direction is typically used to indicate limb dominance, and as such, could provide coaches
96 and researchers information whether a limb is at heightened risk of increased loading, and
97 thus potential for injury, or not. Early work shows no differences in knee joint mechanics

98 (knee flexion angle, knee abduction angle, knee internal rotation angle, and knee
99 abduction moment) during weight acceptance between preferred and non-preferred limbs
100 in female soccer players (Brown et al., 2014). In contrast, 20 collegiate female soccer
101 players were found to exhibit similar CoD biomechanics (hip and knee moments, and
102 GRFs) between dominant kicking) and nondominant (support) limbs (Greska et al.,
103 2016). Moreover, the dominant limb displayed increased peak knee flexion angles,
104 increased peak internal knee abduction moments, and increased peak vertical GRFs,
105 while the nondominant limb exhibited increased knee abduction angles at initial contact
106 and peak value and increased vertical GRF at peak knee abduction moment. Recently,
107 Thomas et al., (2017) reported that female soccer players adopt different braking
108 strategies between dominant and nondominant limbs in 180° turns, whereby increased
109 horizontal braking force is placed on the penultimate contact by the nondominant limb
110 when turning off the dominant limb. Conversely, an increased force is placed on the final
111 contact when turning off the nondominant limb.

112 Improving our understanding of limb dominance during CoD may provide further insight
113 into the potential mechanisms of increased loading and help drive performance and injury
114 prevention programmes. Therefore, the primary aim of this study was to investigate
115 differences in kinematics (lower-limb joint angles) and kinetics (GRFs and moments) in
116 the sagittal and frontal planes, between males and females during 180° turns. The
117 secondary aim was to investigate differences in braking strategy (penultimate vs. final
118 contact) on the dominant vs. nondominant limbs during 180° turns in male and female
119 soccer players. Finally, this study aimed to explore kinematic and kinetic differences
120 between penultimate and final contact of 180° turns. It was hypothesised that female
121 players would exhibit increased knee abduction angles and knee abduction moments
122 compared to males (Sigward et al., 2015, 2012). Furthermore, it was hypothesised that

123 female soccer players would demonstrate increased horizontal GRF during the final
124 contact when turning off the nondominant limb (Thomas et al., 2017). It was hypothesised
125 that the penultimate contact would demonstrate increased knee joint flexion angles, peak
126 horizontal GRF, but lower average horizontal GRF during compared to the final contact
127 (Jones et al., 2016b)

128 **Methods**

129 *Participants*

130 This study included 28 male ($n = 14$; age = 24.5 ± 4.2 years; height = 1.79 ± 0.05 m; body
131 mass = 78.5 ± 9.6 kg) and female ($n = 14$; age = 20.6 ± 0.6 years; height = 1.65 ± 0.07 m;
132 body mass = 56.2 ± 6.6 kg) soccer players. All participants were of semi-professional
133 level and did not suffer from an ACL injury in the past, or any other lower-limb injury
134 within the last 6 months. Each player was in the preseason phase of training during his or
135 her participation in this study. All participants read and signed a written informed consent
136 form before participation, with consent from the parent or guardian of all participants
137 under the age of 18. Approval for the study was provided by the University of Salford's
138 Institutional Ethics Committee.

139 *Experimental Protocol*

140 Lower-limb kinetic and kinematic data were collected during 180° turns (505 CoD test),
141 performed as fast as possible, on an indoor track (Mondo, SportsFlex, 10 mm; Mondo
142 America Inc., Mondo, Summit, NJ, USA). The 505 involved running towards two force
143 platforms, whereby the first force platform was used to measure GRFs from the
144 penultimate foot contact (2nd to last foot contact with the ground during a pivot before
145 moving into a new intended direction), whilst the 2nd force platform was used to measure

146 GRFs from the final contact (last foot contact with the ground during a pivot before
147 moving into a new intended direction). Players were instructed to sprint to a line marked
148 on the central portion of 2nd force platform, 15 m from the start, planting their left or
149 right foot on the line, turn 180° and sprint back 5 m through the finish. Prior to maximal
150 trials participants performed at least 3 submaximal trials, turning off each limb at 75% of
151 perceived maximum effort. Players performed a minimum of six acceptable trials (3 left
152 and 3 right) in a randomised and counterbalanced order. If participants slid, turned
153 prematurely, or missed the force platform, the trial was discarded and subsequently
154 performed after a 2-minute rest.

155 Before the turn task, reflective markers (14 mm spheres) were placed on the
156 following bony landmarks: right and left iliac crests; anterior superior iliac spine;
157 posterior superior iliac spine; greater trochanter; medial epicondyle; lateral epicondyle;
158 lateral malleoli; medial malleoli; heel; and fifth, second, and first metatarsal heads using
159 double-sided adhesive tape. Each player wore a four-marker ‘cluster set’ (four
160 retroreflective markers attached to a lightweight rigid plastic shell) on the right and left
161 thigh and shin which approximated the motion of these segments during the dynamic
162 trials. All participants wore lycra shorts and female participants wore a compression top
163 (Champion Vapor, Champion, Winston-Salem, NC, USA). Standardised footwear
164 (Balance W490, New Balance, Boston, MA, USA) was provided for all participants to
165 control for shoe-surface interface.

166 ***Data Analysis***

167 3D motions of these markers were collected during the turn trials using 10 Qualisys Oqus
168 7 (Gothenburg, Sweden) infrared cameras (240 Hz) operating through Qualisys Track
169 Manager software (Qualisys, version 2.16, build 3520, Gothenburg, Sweden). The GRFs
170 were collected from two 600 mm x 900 mm AMTI (Advanced Mechanical Technology,

171 Inc, Watertown, MA, USA) force platforms (Model number: 600900) embedded into the
172 running track, sampling at 1200 Hz. From a standing trial, a lower extremity and trunk 6
173 degrees of freedom kinematic model was created for each player, including pelvis, thigh,
174 shank and foot using Visual3D software (C-motion, version 6.01.12, Germantown, USA).
175 This kinematic model was used to quantify the motion at the hip, knee and ankle joints
176 using a Cardan angle sequence x–y–z (Grood & Suntay, 1983). The local coordinate
177 system was defined at the proximal joint centre for each segment. The static trial position
178 was designated as the subject’s neutral (anatomical zero) alignment, and subsequent
179 kinematic measures were related to this position. Segmental inertial characteristics were
180 estimated for each participant (Dempster, 1955). The model used a CODA pelvis
181 orientation (Charnwood Dynamics Ltd., Leicestershire, UK) (Bell, Brand, & Pedersen,
182 1989) to define the location of the hip joint centre. The knee and ankle joint centres were
183 defined as the mid-point of the line between lateral and medial markers. Lower limb joint
184 moments were calculated using an inverse dynamics approach (Winter, 2009) through
185 Visual3D software and were defined as external moments.

186 The trials were time normalised for each subject, for ground contact time of the
187 turn task. Initial contact was defined as the point after ground contact that the vertical
188 GRF was higher than 20 N and end of contact was defined as the point where the vertical
189 GRF subsided past 20 N for both penultimate and final contact. The weight acceptance
190 phase of ground contact was defined as from the instant of instant contact (vertical GRF
191 >20 N) to the point of maximum knee flexion during ground contact as used previously
192 (Havens & Sigward, 2015b; Jones et al., 2016b; Jones, Thomas, Dos’Santos, McMahon,
193 & Graham-Smith, 2017). Joint coordinate and force data were smoothed in Visual3D with
194 a Butterworth low pass digital filter with cut-off frequencies of 12 and 25 Hz,
195 respectively. Cut-off frequencies were selected based on *a priori* residual analysis

196 (Winter, 2009) and visual inspection of the motion data.

197 For comparisons between penultimate and final contact, peak and average vertical
198 (Fz) and horizontal (Fx) GRFs were determined along with peak hip, knee and ankle
199 dorsiflexion angles and peak hip, knee and ankle moments in the sagittal plane during the
200 weight acceptance phase, and analysed in Microsoft Excel (version 2016, Microsoft
201 Corp., Redmond, WA, USA). Furthermore, peak knee abduction angles and knee
202 abduction moments were calculated during the final contact. Joint moment data were
203 normalised to body mass (Nm/kg). To evaluate the deceleration strategy from penultimate
204 to final contact, a final contact/penultimate contact horizontal (Fx component) horizontal
205 GRF ratio was also calculated (Jones et al., 2016b). In line with recent research
206 (Dos'Santos, Comfort, & Jones, 2020), data were analysed based on the average of trial
207 peaks.

208 ***Statistical Analyses***

209 Data are presented as either mean \pm *SD*. Normality of data was assessed by Shapiro-
210 Wilk's statistic, while homogeneity of variances was examined using Levene's test. A
211 two-way (contact x limb) multivariate analysis of variance (MANOVA) was used to
212 determine if differences exist between foot contact (penultimate and final) or limb
213 (dominant and nondominant) and between sexes (male and female) when considering all
214 dependent variables in the sagittal plane. Separate 2×2 (limb \times sex) repeated-measures
215 ANOVA were run to examine differences in completion time, horizontal GRF ratio, knee
216 abduction angles and knee abduction moments. Where significant differences were
217 found, Bonferroni post hoc analyses were completed to detect differences between
218 groups. The dominant limb was defined as the limb with the fastest time to completion
219 during CoD. All statistical analyses were performed in the Jamovi Project for Windows
220 (Jamovi Project, 2019) and the criterion for statistical significance was set at $p \leq 0.05$.

221 **Results**

222 Table 1 shows repeated measures ANOVAs for force-time characteristics, while
223 Table 2 shows repeated measures ANOVAs for sagittal and frontal plane peak joint angle
224 and moment data.

225 The average approach speed for males (5.2 ± 0.3 m/s) was significantly faster (p
226 <0.001) than females (4.7 ± 0.3 m/s). A significant difference (p <0.001) in completion
227 time was observed between limbs whereby the dominant limb was faster than
228 nondominant. Average horizontal GRFs were increased (p = 0.013) for dominant limb
229 compared with nondominant.

230 A significant difference (p = 0.034) in average horizontal GRF ratio was observed
231 between sexes, with females demonstrating an increased ratio than males. There was no
232 other statistically significant main effect or interaction for both average and peak
233 horizontal GRF ratio.

234 ** Insert Table 1 around here **

235 For the variables peak hip flexion angle, peak vertical GRF, peak knee flexion
236 angle, peak knee extensor moment and peak ankle dorsiflexion angle, although an
237 interaction was not present, there were main effects for contact, indicating increased
238 values in the penultimate compared to final contact when both sexes were combined. Yet,
239 the opposite was true for peak plantarflexor moment whereby values were increased in
240 the final contact compared to penultimate contact. There was no main effect or interaction
241 present for the variable peak horizontal GRF.

242 ** Insert Table 2 around here **

243 A significant difference (p <0.001) in peak knee abduction angle was observed
244 between sexes, with females demonstrating increased angles than males. In contrast, peak
245 knee abduction moments were significantly (p = 0.012) increased for males compared to

246 females. Furthermore, significant differences ($p = 0.006$) were noted between males and
247 females in peak hip flexion angle, with males demonstrating increased values than
248 females. When considering completion time, males were significantly faster ($p < 0.001$)
249 compared to females.

250 **Discussion and Implications**

251 Although previous studies have considered the influence of the limb dominance
252 on knee injury risk factors during pre-planned tasks (Brown, Donelon, Smith, & Jones,
253 2016; Brown et al., 2014; Greska et al., 2016), this is the first study to evaluate the
254 interaction of penultimate and final contact on such factors in both males and females.
255 This is important given that turning movements are common in both sexes (Bloomfield,
256 Polman, & O'Donoghue, 2007; Boden et al., 2010; Brophy et al., 2010). The aims of this
257 study were to: (1) evaluate sex differences in lower-limb kinetics and kinematics between
258 males and females during 180° turns, (2) compare lower-limb kinetics and kinematics
259 between dominant and nondominant limbs, and (3) explore kinetic and kinematic
260 differences between penultimate and final contacts of 180° turns. The most striking result
261 to emerge from the data is that females demonstrated increased knee abduction angles
262 compared to males ($p < 0.001$), but the opposite was evident when analysing knee
263 abduction moment ($p = 0.012$). Consistent with previous research, these results suggest
264 that CoD biomechanics are sex-specific and thus, should be interpreted accordingly when
265 informing training and injury prevention interventions. Specifically, practitioners must
266 acknowledge from a technique perspective the 'performance-injury conflict' when
267 coaching and performing CoD, ensuring players have optimal CoD mechanics and
268 physical capacity to tolerate the associative knee joint loading.

269 Our primary finding was that knee abduction angles were increased in females
270 compared to males, whereas knee abduction moments were increased in males compared

271 to females. This is in agreement with previous work whereby increased knee abduction
272 angles were observed in females compared to males (Sigward et al., 2015), yet in the
273 same study, females exhibited increased knee abduction moments, which is in contrast to
274 our findings. A possible explanation for this might be that Sigward et al. (2015) used a
275 110° side-step whilst the current study used a 180° turn. Recent work (Schreurs et al.,
276 2017) indicates knee valgus moments tend to stabilise when changing direction to
277 magnitudes >90° in both males and females. It could be that athletes subconsciously
278 restrain this moment from becoming increased when changing direction to increased
279 magnitudes (90-180°). Yet, the male players in the current study demonstrated
280 significantly ($p < 0.001$) faster time to completion than females, due to faster average
281 approach speeds, thus likely contributing to great knee abduction moments. This is in
282 agreement with previous research reporting increases in knee abduction moments from
283 faster running velocities during 60° (Kimura & Sakurai, 2013) and 135° (Nedergaard,
284 Kersting, & Lake, 2014) CoD. This finding has important implications for developing
285 performance and injury prevention programmes. Specifically, faster and sharper CoD
286 increase knee joint loading but are also required for successful performance to evade or
287 close an opponent; thus, causing a performance-injury conflict from a technique
288 perspective (Dos'Santos, Thomas, Comfort, & Jones, 2018), but can be mediated by an
289 athlete's physical capacity. Further research might explore the influence physical
290 capacities (strength and power measures) on lower-limb kinetics and kinematics, as this
291 may help drive sex-specific CoD and ACL prevention programming.

292 This study has shown that average horizontal GRF was lower for the penultimate
293 contact compared to the final contact. This finding is consistent with that of (Jones et al.,
294 2016b) who found lower average horizontal GRF in the penultimate contact relative to
295 the final contact. The same authors also found peak vertical GRF values to be higher in

296 the penultimate contact compared to the final contact, which also agrees with the findings
297 of the current study. Also, ground contact time were shown to be longer in the final
298 contact of turns than the penultimate contact (0.52 ± 0.08 s vs. 0.38 ± 0.07 s), resulting in
299 an increased horizontal braking impulse (impulse = force x [change in momentum]) in
300 the final contact (Jones et al., 2016b). Taken together, these findings indicate, during
301 turns, the need to bring the horizontal velocity to zero before turning and accelerating
302 back the other way, therefore more substantial braking takes place during the final
303 contact. This may present a problem when athletes may not have the physical capacities
304 (neuromuscular control, high levels of strength) to cope with the increased loading. Thus,
305 it is essential to develop holistic training programmes to optimally prepare and enhance
306 CoD performance and reduce risk of injury. Specifically, strength, plyometric, sprint,
307 CoD and combination training are all found to be effective modalities of improving CoD
308 ability (Falch, Rædergård, & van den Tillaar, 2019), while others have found reductions
309 in KAM resulting from technique modification interventions (Dempsey et al., 2009;
310 Jones, Barber, & Smith, 2015). Most recently, Dos'Santos (Dos'Santos, McBurnie,
311 Comfort, & Jones, 2019) found improvements in CoD completion time and cutting
312 technique following a 6-week CoD technique intervention in male youth soccer players,
313 indicating CoD technique training, in addition to normal skills and strength training
314 improves cutting performance and movement quality. Indeed, athletes with increased
315 levels of isokinetic eccentric knee extensor strength are shown to be better able to
316 decelerate during the penultimate contact from faster approach velocities during 180°
317 turns (Jones et al., 2017). Furthermore, peak horizontal braking forces during penultimate
318 contact are shown to significantly associate with CoD performance times (Graham-Smith,
319 Atkinson, Barlow, & Jones, 2009) and horizontal GRF ratio (Dos' Santos, Thomas, Jones,
320 & Comfort, 2017), with faster athletes demonstrating significantly lower horizontal

321 braking force ratio than slower athletes. These findings may help us to understand the
322 interaction between strength, speed, and technique regarding CoD performance and risk
323 of injury.

324 In this study, females demonstrated increased average horizontal GRF ratio
325 compared to males, indicating an increased proportion of braking took place during the
326 final contact relative to the penultimate contact, compared to males. This result is in
327 accord with recent studies indicating faster CoD performances to exhibit lower horizontal
328 GRF ratio as compared with slower performances (Dos' Santos et al., 2017). Also, earlier
329 studies found lower horizontal GRF ratio to associate with lower knee abduction moments
330 during turns (Jones et al., 2016a), yet this was in female participants and turning off one
331 leg only. Further work is required to evaluate the role of the penultimate contact and final
332 contact in 180° turns in male and female soccer players to better understand the optimal
333 technique for changing direction.

334 The joint angle data revealed a significant main effect for peak hip flexion angle,
335 indicating increased hip flexion was observed during the penultimate contact compared
336 to final contact. This finding is likely to be related to help absorb loading through an
337 increased range of motion compared with final contact, thus facilitating longer braking
338 force application, thus impulse, resulting in an increased reduction in whole-body
339 velocity (impulse = change in momentum). Indeed, the role of the penultimate contact
340 has been described as a 'preparatory step' demonstrating hip and knee flexion throughout
341 the stance phase as the athlete transitions from penultimate contact to final contact (Jones
342 et al., 2016b). This helps provide an optimal body position at final contact (lower centre
343 of mass) and allows the final contact leg to be planted out in front of the body. Another
344 important finding was that males exhibited increased hip flexion angles during weight
345 acceptance than females. There are similarities between the finding in this study and those

346 described by (Sigward et al., 2015) whereby males demonstrated increased hip abduction
347 angle at initial contact than females. It seems possible that these results are because male
348 athletes better prepare themselves for the CoD by either absorbing GRFs (hip flexion) or
349 pre-rotate to the new direction (hip abduction). This finding, while preliminary, suggests
350 that male athletes may better self-regulate their CoD technique, which may lead to a faster
351 overall CoD performance. Indeed, earlier work suggests a lack of hip flexion/extensor
352 moments to be a gender technique deficit, potentially leading to increased knee loading
353 (Pollard, Sigward, & Powers, 2007).

354 For the variables peak knee flexion angle and peak knee extensor moment, there
355 were significant main effects for contact, with increased values observed during
356 penultimate contact compared to final contact. These results match those of earlier studies
357 whereby the penultimate contact resulted in increased knee flexion angles and knee
358 extensor moments in 180° turns (Graham-Smith et al., 2009; Greig, 2009; Jones et al.,
359 2016b). These results are likely to be related to the fact that, during 180° turns, the knee
360 goes through an increased range of knee flexion during penultimate contact compared to
361 final contact. These findings suggest that increased knee flexion is maintained in the
362 transition from penultimate contact to final contact to lower centre of mass and allow for
363 an optimal final contact, with data showing maximum knee flexion typically occurs at the
364 end of penultimate contact ground contact in 180° turns (Jones et al., 2016b). Another
365 finding was that increased peak ankle dorsiflexion angle was observed in the penultimate
366 contact compared to final contact, but the opposite was true for peak plantarflexor
367 moment, with increased values in the final contact compared to penultimate contact.
368 These findings are in agreement with those who found increased ankle dorsiflexor
369 moments during final contact compared to penultimate contact (Jones et al., 2016b).
370 These results may be explained by the fact that participants initially made the final contact

371 with a forefoot plant, evoking an ankle dorsiflexor moment, whereas during penultimate
372 contact an initial rearfoot plant may have led to increased plantarflexor moments.
373 Furthermore, increased ankle dorsiflexion occurs to help absorb the loading and facilitate
374 longer braking force application during penultimate contact in 180° turns.

375 Overall, the findings of this study provide insights into the role of limb dominance
376 during the task of 180° turns. While many studies have explored biomechanical
377 differences between limbs during CoD (Brown et al., 2016; Mok et al., 2018; Pollard et
378 al., 2018; Thomas et al., 2017), this investigation is the first to examine the differences
379 between dominant and nondominant limb across penultimate contact and final contact, in
380 male and female soccer players. The results of this study indicate a significant main effect
381 for limb for the variable average horizontal GRF; whereby increased values were
382 observed when turning off the dominant limb compared to the nondominant limb. A way
383 of interpreting this might be that when turning with the dominant limb increased average
384 braking forces are experienced across the final two foot contacts, likely due to technical
385 and coordination differences. The other main effects observed in this study suggest
386 average horizontal GRFs are increased in the final contact than penultimate contact,
387 which agrees with past literature (Jones et al., 2016a, 2016b). This combination of
388 findings may provide some support for the conceptual premise that the role of limb
389 dominance on CoD biomechanics may be less in such shallow angles of direction change
390 (<90°), but more so for sharper CoD (90-180°). Thus, further research is required to
391 investigate whether limb dominance influences the braking strategy during these
392 manoeuvres.

393 A limitation of the current study is the pre-planned execution of the CoD task,
394 whereas unanticipated CoD has been shown to elevate knee joint loads during cutting
395 (Besier, Lloyd, Ackland, & Cochrane, 2001). In addition, it can only be assumed that

396 knee valgus and knee abduction moments are risk factors for ACL injury due to the lack
397 of evidence. Also, females wore compression garments, but males did not; therefore, it is
398 unknown the amount of movement artefact when comparing markers and clusters
399 attached to a compression garment compared with those attached to skin. Furthermore,
400 the findings of the current study can only be extrapolated to male and female soccer
401 participants performing 180° turns. Except for knee abduction angles and moments, this
402 study only featured lower-limb joint angles and moments in the sagittal plane. Despite
403 hip abduction and rotation angles, such as the motion on the frontal and transverse planes,
404 are commonly investigated in cutting studies (Kristianslund, Faul, Bahr, Myklebust, &
405 Krosshaug, 2014; Kristianslund & Krosshaug, 2013), whole-body deceleration takes
406 place in the sagittal plane during 180° turns. In future studies, it might be possible to
407 investigate the influence of these parameters on braking strategy and knee joint mechanics
408 during 180° turns.

409 **Acknowledgements**

410 The authors thank the participants for taking part in the study.

411 **Disclosure Statement**

412 No potential conflict of interest was reported by the authors.

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