



**Manchester  
Metropolitan  
University**

---

Dos'Santos, Thomas ORCID logoORCID: <https://orcid.org/0000-0003-2715-0116>, Thomas, Christopher, Comfort, Paul and Jones, Paul A (2021) Biomechanical Effects of a 6-Week Change-of-Direction Technique Modification Intervention on Anterior Cruciate Ligament Injury Risk. *Journal of Strength and Conditioning Research*, 35 (8). pp. 2133-2144. ISSN 1064-8011

---

**Downloaded from:** <https://e-space.mmu.ac.uk/627958/>

**Version:** Accepted Version

**Publisher:** Lippincott, Williams & Wilkins

**DOI:** <https://doi.org/10.1519/jsc.0000000000004075>

**Usage rights:** Creative Commons: Attribution-Noncommercial 4.0

Please cite the published version

<https://e-space.mmu.ac.uk>

1 **BIOMECHANICAL EFFECTS OF A SIX-WEEK CHANGE OF DIRECTION**  
2 **TECHNIQUE MODIFICATION INTERVENTION ON ANTERIOR CRUCIATE**  
3 **LIGAMENT INJURY RISK**

4 **ABSTRACT**

5 The aim of this study was to evaluate the biomechanical effects of a six-week change of  
6 direction (COD) technique modification intervention on anterior cruciate ligament (ACL)  
7 injury risk (i.e., multiplanar knee joint loads) during 45° (CUT45) and 90° (CUT90) side-step  
8 cutting. A non-randomized, controlled 6-week intervention study was administrated. 15 male  
9 multidirectional sport athletes formed the intervention group (IG) who participated in two 30-  
10 minute COD technique modification sessions per week, while 12 male multidirectional sport  
11 athletes formed the control group (CG) and continued their normal training. Subjects performed  
12 six trials of the CUT45 and CUT90 task whereby pre-to-post intervention changes in lower-  
13 limb and trunk kinetics and kinematics were evaluated using three-dimensional motion and  
14 ground reaction force analysis. Two-way mixed analysis of variances revealed no significant  
15 interaction effects of group for CUT45 and CUT90 multiplanar knee joint loads ( $p \geq 0.116$ ,  
16  $\eta^2 \leq 0.096$ ); however, considerable individual variation was observed (positive ( $n=5-8$ ) and  
17 negative responders ( $n=7-8$ )). Based on IG group means, COD technique modification resulted  
18 in no meaningful reductions in multiplanar knee joint loads. However, individually,  
19 considerable variation was observed, with “higher-risk” subjects generally responding  
20 positively, and subjects initially considered “low-risk” tending to increase their multiplanar  
21 knee joint loads, albeit to magnitudes not considered hazardous or “high-risk”. COD technique  
22 modification training is a simple, effective training method, requiring minimal equipment that  
23 can reduce knee joint loads and potential ACL injury risk in “higher-risk” subjects without  
24 compromising performance.

25 **Keywords:** side-step; side-stepping; cutting; knee abduction moment; injury mitigation

## 26 INTRODUCTION

27 Directional changes are a fundamental movement performed in sports, often performed in  
28 scenarios such as evading an opponent or moving into space to receive a pass (13). Changing  
29 direction, however, is also a key action associated with non-contact anterior cruciate ligament  
30 (ACL) injuries in sports such as soccer (6), rugby (35), and American football (25), due to the  
31 propensity to generate high multiplanar knee joint loading (flexion, rotation, and abduction  
32 loading) during the plant foot contact (7, 8, 29), thus increasing ACL strain (32, 38). ACL  
33 injuries are a debilitating injury with short- and long-term consequences (financial, health, and  
34 psychological) (21, 31), with an elevated and earlier risk of developing osteoarthritis a primary  
35 concern (31). Therefore, training interventions that can mitigate ACL injury risk during COD  
36 are of great interest to practitioners working with multidirectional athletes.

37 Although ACL injury risk factors are multifactorial (anatomical, hormonal,  
38 biomechanical, neuromuscular, and environmental) (21), ACL injuries occur when an applied  
39 load exceeds the ligaments' tolerance (38); thus, to reduce ACL injury risk, particularly non-  
40 contact ACL injury, an effective strategy is to modify an athlete's movement mechanics to  
41 reduce the magnitude of knee joint loading through biomechanically and neuromuscular  
42 informed training interventions (17, 21). COD techniques with a wide lateral foot plant, greater  
43 hip abduction angles, increased internal **initial foot progression angles**, increased initial hip  
44 internal rotation angles, greater initial and peak **knee abduction angles**, reduced **knee flexion**  
45 **angles**, greater lateral trunk flexion, greater ground reaction forces (GRF), and greater approach  
46 velocities are associated with greater knee abduction moments (KAM) (12, 14, 17) and thus  
47 ACL injury risk (22, 32). Additionally, wide lateral foot plant distances, trunk rotation towards  
48 the stance limb, trunk flexion displacements, and hip internal rotation moments are associated  
49 with greater knee internal rotation moments (KIRM) (8, 17), which when combined with  
50 KAMs produces greater ACL strain (multiplanar) compared to uniplanar loading (32, 38). As

51 such, addressing and modifying the aforementioned variables associated with KAMs and  
52 KIRMs could be an effective strategy for reducing ACL loading and thus potential ACL injury  
53 risk during COD (15, 17).

54 As highlighted in a recent scoping review (15), COD technique modification training  
55 is a potentially effective training strategy for reducing “high-risk” COD mechanics and  
56 subsequent knee joint loads (1, 4, 7, 26). Reducing knee joint loads can be achieved via  
57 reducing the magnitude of the moment arm, GRF, or a combination of the two (29). Decreases  
58 in frontal and transverse knee joint loads during cutting have been demonstrated following  
59 acute (8) and chronic (7) COD technique modification via alterations in lateral foot plant  
60 distance and orientation, and trunk alignment. Additionally, increasing knee flexion acutely  
61 and modifying lower-limb and trunk postures can reduce cutting peak KAMs (1), while a 6-  
62 week COD technique modification intervention which encouraged earlier braking during the  
63 penultimate foot contact (PFC), backwards trunk inclination, and a neutral foot posture during  
64 180° turning reduced peak KAMs (26). However, the aforementioned six-week COD technique  
65 modification intervention studies did not have a control group (CG); thus, the result should be  
66 treated with caution because it is uncertain whether such changes were “real”.

67 To our best knowledge, only one study has examined the effect of COD technique  
68 modification on cutting movement quality which contained a CG (11). Interestingly, six-  
69 weeks’ COD speed and technique modification which focused on external cues to encourage  
70 greater PFC braking, trunk lean towards the intended direction of travel, and rapid and forceful  
71 push-off improved cutting performance and cutting movement assessment scores (movement  
72 quality) (11). Although these results are promising, and the **cutting movement assessment score**  
73 has been validated and associated with greater peak KAMs (12), movement quality was  
74 examined qualitatively and therefore must be further evaluated using **three-dimensional** motion

75 and GRF analysis to confirm its efficacy. Therefore, the primary aims of this study were two-  
76 fold: 1) to evaluate the effectiveness of a 6-week COD technique modification intervention on  
77 COD injury risk multiplanar knee joint loads (KAM, KIRM, **knee flexion moment**) during 45°  
78 (CUT45) and 90° (CUT90) side-step cutting; and 2) to identify which kinetic and kinematic  
79 factors explain changes in knee joint loads. Additionally, an individual approach has been  
80 recommended when analyzing the effects of injury mitigation training program because  
81 inferences based on group means only may conceal potentially meaningful information (3, 18).  
82 Therefore, a secondary aim was to examine the individual responses (positive / negative)  
83 following COD technique modification training. The findings of this research may assist in the  
84 development of more effective field-based ACL injury mitigation programs. It was  
85 hypothesized that a COD technique modification program would reduce knee joint loads in  
86 multidirectional athletes, and that changes in technique variables **initial foot progression angle**,  
87 lateral trunk flexion, **knee flexion angle** at initial contact, and PFC **horizontal braking force** will  
88 explain reductions in knee joint loads.

## 89 **METHODS**

### 90 Experimental approach to the problem

91 A non-randomized, controlled 6-week intervention study with a repeated measures pre-to-post  
92 test design was used (Figure 1). Male multidirectional sport athletes were recruited for the  
93 intervention group (IG) and completed a 6-week COD technique modification training program  
94 (Supplementary material 1). Conversely, male multidirectional sport athletes acted as the CG.  
95 Pre-to-post assessments of CUT45 and CUT90 biomechanics were assessed using **three-**  
96 **dimensional** motion and GRF analysis to monitor the training intervention's effectiveness. This  
97 was performed at the same time of day for each subject to control for circadian rhythm.

98 \*\*\* Insert Figure 1 about here\*\*\*

## 99 Subjects

100 30 men from multidirectional sports (amateur/semi-professional) participated in this study.  
101 Based on previous work for pre-to-post (dependent t-test) peak KAMs changes during 180°  
102 turning (26), a minimum sample size of 14 per group was determined from an *a priori* power  
103 analysis using G\*Power (Version 3.1, University of Dusseldorf, Germany) (16). This was  
104 based upon an effect size of 0.73, power of 0.80, and type 1 error of 0.05.

105 Sixteen males (soccer  $n=12$ , rugby  $n=4$ ; age:  $23.5\pm 5.2$  years; height:  $1.80\pm 0.05$ m; mass:  
106  $81.6\pm 11.4$  kg) were recruited for the IG. Conversely, fourteen men (soccer  $n=9$ , rugby  $n=4$ ,  
107 field hockey  $n=1$ ; age:  $22.2\pm 5.0$  years; height:  $1.76\pm 0.08$  m; mass:  $72.7\pm 12.4$  kg) acted as the  
108 CG and continued their normal sport and resistance training sessions. **Non-significant small to**  
109 **moderate differences in age, height, and mass were observed ( $p = 0.066-0.496$ ,  $g = 0.268-$**   
110  **$0.746$ ).** The investigation was approved by the Institutional Ethics Review Board (HSR1617-  
111 131), and all subjects were informed of the benefits and risks of the investigation prior to  
112 signing an institutionally approved consent form to participate in the study. **All subjects from**  
113 **both groups had  $\geq 5$  years training experience in their respective sport and had never sustained**  
114 **a severe knee injury prior to testing. All subjects had minimum one years' resistance training**  
115 **experience, all performed two 60-minute resistance training sessions a week, and were all in a**  
116 **strength mesocycle. At the time of the training intervention, all subjects completed two 90-**  
117 **minute skills sessions and played one competitive match a week.** All procedures were carried  
118 out during the competitive season to ensure that no large physical changes were made because  
119 of the conditioning state. To be included in the study and used for further analysis, subjects  
120 were not allowed to miss more than two of the 12 sessions in total (i.e.,  $\geq 83\%$  compliance rate).  
121 Subsequently, due to match-related injuries or illness, one and two subjects withdrew from the  
122 IG and CG, resulting in sample sizes of 15 and 12 (Figure 1), respectively. IG subjects

123 completed on average  $11.9 \pm 0.4$  sessions ( $98.3 \pm 3.5\%$ ), with 12 subjects completing 12 (100%)  
124 sessions and three completing 11 sessions (91.7%).

## 125 Procedures

126 The warm up, cut, marker placement, and **three-dimensional** motion analysis procedures were  
127 based on previously published methodologies (10, 27, 33). Briefly, each subject performed six  
128 trials of the  $45^\circ$  and  $90^\circ$  (5-m entry and 3-m exit) side-step cut (right limb push-off) as fast as  
129 possible and were provided with standardized footwear to control for shoe-surface interface  
130 (Balance W490, New Balance, Boston, MA, USA). Marker and force data were collected over  
131 the PFC and final foot contact (FFC) using ten Qualisys Oqus 7 (Gothenburg, Sweden) infrared  
132 cameras (240 Hz) operating through Qualisys Track Manager software (Qualisys, version 2.16  
133 (Build 3520), Gothenburg, Sweden) and GRFs were collected from two 600 mm  $\times$  900 mm  
134 AMTI (Advanced Mechanical Technology, Inc, Watertown, MA, USA) force platforms  
135 (Model number: 600900) embedded into the running track sampling at 1200 Hz, respectively.  
136 Using the pipeline function in visual **three-dimensional**, joint coordinate (marker) and force  
137 data were smoothed using a Butterworth low-pass digital filter with cut-off frequencies of 15  
138 and 25 Hz, respectively. The kinematic model process was based on previous reported  
139 methodologies (10, 27, 33). Lower limb joint moments were calculated using an inverse  
140 dynamics approach (42) through Visual **three-dimensional** software (C-motion, version  
141 6.01.12, Germantown, USA) and were defined as external moments, normalized to body mass.  
142 Joint kinematics and GRFs were also calculated using Visual **three-dimensional**, while GRF  
143 braking characteristics were normalized to body weight, with vertical, anterior-posterior, and  
144 medio-lateral corresponding to  $F_z$ ,  $F_x$ , and  $F_y$ , respectively. Horizontal centre of mass velocity  
145 at FFC touch-down was calculated as described previously (27).

## 146 Primary and secondary outcome measures: cutting kinetic and kinematic variables

147 Supplementary material 2 provides a full description the variables examined, definitions, and  
148 calculations. The following kinetic and kinematics were examined during the FFC for both  
149 tasks: peak KAM, KIRM, and **knee flexion moments**, and peak and initial **knee abduction**  
150 **angles**. These were considered the primary injury risk outcome variables and calculated over  
151 weight acceptance (initial contact to maximum knee flexion). Additionally, the following  
152 technical and mechanical variables associated with greater knee joint loads were also  
153 investigated for both tasks (12, 17): peak **vertical braking force**, velocity at FFC, lateral trunk  
154 flexion angle, **initial foot progression angle**, lateral foot plant distance, peak and initial hip  
155 rotation angle, and knee flexion angle (peak, initial, range of motion). Additionally, PFC mean  
156 **horizontal braking force** was examined during the PFC for CUT90 only. Five trials were used  
157 in the analysis for each subject, and the average of individual trial peaks for each variable were  
158 calculated (10). A subset of the sample ( $n=10$ ) performed the cuts on two separate occasions  
159 separated by 7 days to establish between-session reliability with the data considered high  
160 (intraclass correlation coefficient = 0.704-0.928, coefficient of variation = 5.3-14.8%).

#### 161 6-week COD technique modification training intervention

162 A six-week COD technique modification intervention described in Supplementary material 1,  
163 was performed by the IG twice a week (30 minutes per session,  $\geq 48$  hours between sessions).  
164 The intervention was adapted from a previously successful six-week COD speed and technique  
165 modification training intervention (11), which focused on pre-planned low intensity  
166 decelerations, cuts, and turns (weeks 1-2), before progressing intensity via velocity and angle  
167 (weeks 3-4), and introducing a stimulus with increased intensity (weeks 3-6). The duration,  
168 distances, and number of CODs were similar to previous research (11, 26). The sessions were  
169 led by the principle researcher who is a certified strength and conditioning specialist, and took  
170 place in the Human Performance Laboratory using the same surface used for testing. Athlete-



171 to-coach ratios ranged from 5-8:1. The technique modification focused on three aspects based  
172 on the success of a previous COD speed and technique modification intervention and training  
173 recommendations (11, 13, 26): 1) “slam on the brakes” (to reduce cutting limb GRF (for the  
174 90° task only)); 2) “cushion and push/punch the ground away” (to reduce **knee abduction angles**  
175 and encourage active limb at touch-down); and 3) “face towards the direction of travel” (to  
176 reduce lateral trunk flexion and trunk rotation over stance limb). Subjects were given individual  
177 feedback regarding their technique, and external verbal coaching cues were used to facilitate  
178 better motor skill retention (11, 13).

### 179 Statistical Analyses

180 All statistical analyses were performed using SPSS v25 (SPSS Inc., Chicago, IL, USA) and  
181 Microsoft Excel (version 2016, Microsoft Corp., Redmond, WA, USA). Normality was  
182 inspected for all variables using a Shapiro-Wilks test. A two-way mixed analysis of variance  
183 (ANOVA) (group; time) with group as a between-participants factor measured at 2 levels (IG  
184 and CG), and time (pre- and post-training measures) the within-subject factor. This was used  
185 to identify any significant interaction (group  $\times$  time) effects for outcome variables between IG  
186 and CG, pre-to-post testing. A Bonferroni-corrected pairwise comparison design was used to  
187 further analyze the effect of the group when a significant interaction effect was observed.  
188 Partial eta squared effect sizes were calculated for all ANOVAs with the values of 0.010-0.059,  
189 0.060-0.149, and  $\geq 0.150$  considered as small, medium, and large (2), respectively.

190 Pre-to-post changes in variables for each group were assessed using paired sample t-  
191 tests (parametric) and Wilcoxon-sign ranked tests (non-parametric). Magnitudes of differences  
192 were assessed using Hedges' *g* effect sizes with 95% **confidence intervals**, and interpreted as  
193 trivial ( $\leq 0.19$ ), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.00–  
194 3.99), and extremely large ( $\geq 4.00$ ) (24). Group mean changes were also calculated and

195 interpreted as ratios relative to the smallest worthwhile change (SWC). The SWC was  
196 calculated as  $0.2 \times$  between-subject SD. Comparisons in post-intervention primary outcome  
197 variables and changes in outcome variables between the IG and CG were also assessed using  
198 independent sample t-tests or Mann-Whitney U tests, with effect sizes as outlined above.  
199 Furthermore, to link changes in knee joint loads with cutting kinetic and kinematic changes,  
200 Pearson's correlations (parametric) or Spearman's correlations (non-parametric) were  
201 calculated with 95% **confidence intervals**, and  $p$  values Bonferroni corrected to control for type  
202 I error. Correlations were interpreted as trivial (0.00-0.09), small (0.10–0.29), moderate (0.30–  
203 0.49), large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90–0.99), and perfect (1.00)  
204 (23). A correlation cut-off value of  $\geq 0.40$  was considered relevant (41). Statistical significance  
205 was defined as  $p \leq 0.05$  for all tests. Finally, similar to previous work (34), individual analyses  
206 were performed to quantify for each variable and each group the number of positive, negative,  
207 and non-responders. For all variables of interest, positive or negative responses were  
208 considered as an individual change  $\geq$ SWC, while trivial responses (non-responder) was  
209 considered  $\leq$ SWC.

## 210 RESULTS

211 The two-way mixed ANOVAs results are presented in Table 1, and pre-to-post changes in  
212 cutting biomechanics are presented in Tables 2-3.

213 \*\*\*Insert Table 1 here\*\*\*

214 A medium, non-significant interaction effect for CUT45 peak KAM was observed  
215 (Table 1), with the CG showing significantly greater peak KAMs ( $p=0.013$ ,  $g=-1.00$ ) post-  
216 intervention compared to the IG. Small and non-significant increases in IG CUT45 peak KAMs  
217 and KIRMs were observed (Table 2, Figure 2a,b) post-intervention. Large individual variation  
218 for IG changes in peak KAMs and KIRMs were observed, with five positive and eight negative

219 responders (Figures 2a,b). Trivial to moderate differences in age ( $23.8 \pm 2.7$  vs  $23.6 \pm 7.0$  years,  
220  $p = 0.959$ ,  $g = 0.03$ ), height ( $1.78 \pm 0.05$  vs.  $1.82 \pm 0.05$  m,  $p = 0.266$ ,  $g = -0.74$ ), and mass  
221 ( $80.5 \pm 5.2$  vs  $84.0 \pm 13.8$  kg,  $p = 0.606$ ,  $g = -0.31$ ) were observed between positive and negative  
222 responders for CUT45 KAMs and KIRMs. Importantly, large, significant increase in CG peak  
223 KAMs post-intervention (Table 2, Figure 2a) were demonstrated but differences in KIRMs  
224 were non-significant and trivial (Table 2, Figure 2b).

225 No significant interaction effect for knee flexion moments were observed, and peak  
226 knee flexion moment changes were non-significant and trivial and small for the IG and CG  
227 (Table 1-2, Figure 2c), respectively. Initial and peak knee abduction angles significantly  
228 increased for both groups (Table 2). Medium to large significant interaction effects were  
229 observed for peak knee flexion angle and range of motion, and FFC velocity (Table 1). IG  
230 subjects produced small to moderately significantly greater initial foot progression angles,  
231 greater initial hip external rotation, greater FFC velocities, and smaller knee flexion angle range  
232 of motion post-intervention (Table 2). CG subjects demonstrated significantly greater initial  
233 foot progression angles post-intervention only (Table 2). No other significant changes in IG or  
234 CG cutting mechanics were observed post-intervention, including peak vertical braking force,  
235 lateral trunk flexion angle, and lateral foot plant distance; however, considerable variation in  
236 positive and negative responders were observed (Table 2).

237 \*\*\*Insert Table 2 here\*\*\*

238 \*\*\*Insert Figure 2 here\*\*\*

239 No significant interaction effects were observed for CUT90 injury risk variables (Table  
240 1). IG changes in peak KAMs were non-significant and trivial (Table 3, Figure 3a) post-  
241 intervention. Large individual variation in IG peak KAMs changes were observed, with eight  
242 positive and seven negative responders (Table 3, Figure 3a). The CG demonstrated a small,

243 non-significant increase in peak KAMs post-intervention (Table 3, Figure 3a). A small, non-  
244 significant increase in IG peak KIRM was observed (Table 3, Figure 3b) post-intervention.  
245 Large individual variation in IG peak KIRMs changes were observed, with eight positive and  
246 seven negative responders (Table 3, Figure 3b). A small, non-significant reduction in peak  
247 KIRMs were observed for the CG post-intervention (Table 3, Figure 3b). **Trivial to moderate**  
248 **differences in age ( $23.1 \pm 4.7$  vs  $24.0 \pm 6.0$  years,  $p = 0.757$ ,  $g = -0.15$ ), height ( $1.81 \pm 0.05$  vs**  
249  **$1.79 \pm 0.06$  m,  $p = 0.0468$ ,  $g = 0.36$ ), and mass ( $78.2 \pm 10.4$  vs  $85.4 \pm 12.0$  kg,  $p = 0.229$ ,  $g = -$**   
250  **$0.61$ ) were observed between positive and negative responders for CUT90 KAMs and KIRMs.**

251 No **knee flexion moment** significant interaction effect was observed, and changes were  
252 non-significant and trivial for the IG and CG (Tables 1 & 3, Figure 3c). **Initial** and peak **knee**  
253 **abduction angles** moderately significantly increased post-intervention for both groups (Table  
254 3). Large significant interaction effects were observed for **initial foot progression angle** and  
255 **knee flexion angle range of motion** (Table 1). IG subjects produced small to moderately  
256 significantly greater PFC mean **horizontal braking forces**, greater **initial foot progression**  
257 **angles**, greater **initial knee flexion angles**, and smaller **knee flexion angle range of motion**  
258 (Table 3). No other significant changes in IG or CG cutting mechanics were observed post-  
259 intervention, including peak **vertical braking force**, lateral trunk flexion angle, lateral foot plant  
260 distance, and FFC velocity; however, considerable variation in positive and negative  
261 responders were observed (Table 3).

262 \*\*\*Insert Table 3 here\*\*\*

263 \*\*\*Insert Figure 3 here\*\*\*

264 Decreases in CUT45 peak KAM were very largely associated with decreased peak **knee**  
265 **abduction angles**; largely associated with decreased **initial foot progression angle** and peak  
266 **knee flexion moment**; and moderately associated with decreased **initial knee abduction angle**

267 and KIRM (Table 4). Additionally, CUT45 peak KIRM decreases were moderately associated  
268 with decreased peak KAM, decreased **knee flexion moment**, and decreased lateral trunk flexion  
269 (Table 4). Decreases in CUT90 peak KAM were moderately associated with increased PFC  
270 mean **horizontal braking force**, decreased **knee flexion moment**, and decreased FFC velocity  
271 (Table 4). Furthermore, CUT90 peak KIRM decreases were moderately associated with  
272 decreased peak and **initial knee abduction angle**, decreased lateral foot plant distance, and  
273 decreased peak **vertical braking force** (Table 4).

274 \*\*\*Insert Table 4 here\*\*\*

## 275 **DISCUSSION**

276 The primary aims of this study were two-fold: 1) to examine the biomechanical effects of a  
277 COD technique modification intervention on multiplanar knee joint loads associated with  
278 increased ACL loading; and 2) to identify which kinetic and kinematic factors explain changes  
279 in knee joint loads. Based on group means, a 6-week COD technique modification intervention  
280 resulted in no meaningful changes in multiplanar knee joint loads post-intervention (Tables 1-  
281 3, Figures 2-3), refuting the study hypotheses. However, a secondary aim of the intervention  
282 study was to examine the individual responses, and considerable individual variation (i.e.,  
283 positive and negative responders) and mixed responses following the intervention for  
284 multiplanar knee joint loads and mechanical and technical associate variables were observed  
285 (Tables 2-3, Figures 2-3). Generally, subjects who displayed initially (pre-intervention) high  
286 multiplanar knee joint loads and thus considered potentially “high-risk”, responded positively  
287 and demonstrated reductions (Figures 2-3). Conversely, subjects initially considered “low-  
288 risk” tended to increase their multiplanar knee joint loads, albeit to magnitudes not considered  
289 hazardous or “high-risk”. Consequently, COD technique modification is a simple, effective

290 training method for reducing knee joint loads in “higher-risk” subjects without compromising  
291 performance.

292 A key strategy to reduce potential non-contact ACL injury risk is reducing multiplanar knee  
293 loads which strain the ACL (7, 17, 21, 30). COD technique modification is one training strategy  
294 that can acutely reduce knee joint loads during cutting (1, 4, 8), while reductions in peak KAMs  
295 have also been observed following 6-weeks technique modification during COD (7, 26). In the  
296 present study, no significant interaction effects were observed for any knee joint loads (Table  
297 1), and pre-to-post changes in multiplanar knee joint loads for the IG were non-significant with  
298 trivial to small effect sizes (Tables 2-3, Figures 2-3). These results contrast to previous work  
299 (7, 26); however, notably, the IG increased their FFC velocity which can amplify knee joint  
300 loads (14). Additionally, these two previously successful interventions did not contain a CG  
301 (7, 26). The present study contained a CG which notably demonstrated a large increase in  
302 CUT45 peak KAMs, and a non-significant yet small increase in CUT90 peak KAMs post-  
303 intervention (Tables 2-3, Figures 2-3). Although difficult to fully explain this finding, Staynor  
304 et al. (40) also reported increased KAMs and KIRMs for a CG post-intervention (ES = 0.36-  
305 0.56), which was potentially attributed to the lack of specific injury mitigation training  
306 performed in-season. Thus, the lack of specific COD training with corrective feedback for the  
307 CG may partially explain the increased peak KAMs post-intervention in the present study.

308 Dempsey et al. (7) is the only other study to investigate the effects of side-step technique  
309 modification training on knee joint loads and found 6-weeks training produced significant  
310 reductions in peak KAMs, attributed to positive changes in lateral trunk flexion and lateral foot  
311 plant distance. It is worth noting, however, that peak KIRMs remained unchanged (7). The  
312 findings contrast to the present study that observed no meaningful reductions in IG multiplanar  
313 knee joint loads (Tables 1-3). However, this discrepancy could be attributed to differences in

314 the training intervention and methodology. Dempsey et al. (7) had lower athlete-to-coach ratios  
315 of 1-2:1 and also used video feedback to provide biofeedback regarding technique. Harris et  
316 al. (19) has also demonstrated that technique video feedback improved cutting movement  
317 quality in three female soccer players. Conversely, the present study contained higher athlete-  
318 to-coach ratios (~5:1) and provided no video feedback, which may partially explain why no  
319 meaningful reductions in IG knee joint loads, based on group means, were observed. Indeed, it  
320 does appear that COD technique modification with biofeedback is an effective strategy which  
321 practitioners could implement in the field with small athlete-to-coach ratios. However, in “real-  
322 world” environments, practitioners may not have the time and resources to apply biofeedback,  
323 particularly with large work athlete-to-coach ratios, as highlighted by previous research (9).

324 An integral difference between the two studies were the targeted technical  
325 modifications, with Dempsey et al. (7) instructing an upright trunk posture in the frontal plane  
326 and reducing lateral foot plant distance with the use of line markings for acceptable foot  
327 placement. While the present study did aim to alter frontal plane trunk control, subjects were  
328 instructed to “cushion and push the ground way”, while not restricting lateral foot plant distance  
329 because of the potential detrimental effects narrowing may have on medio-lateral impulse and  
330 subsequent performance (13, 20). The present study attempted to increase initial **knee flexion**  
331 **angles**, improve frontal plane knee control, and encourage PFC dominant braking strategies  
332 (for CUT90 only) because these are techniques that could reduce knee joint loads without  
333 negatively impacting performance (13, 17). Finally, Dempsey et al. (7) performed the side-  
334 steps at a controlled approach velocity, whereas CODs were performed as fast as possible in  
335 the present study, to increase ecological validity and improve athlete and coach adherence to  
336 the training intervention (17, 20). Crucially, IG subjects moderately increased their FFC  
337 velocity during CUT45 which may increase knee joint loads (14, 33), whereas CUT90 changes

338 were trivial effect. Consequently, this finding may partially explain the lower number of  
339 CUT45 positive (5 vs. 8) responders following the intervention compared to CUT90.

340         Based on group means, no meaningful changes in IG multiplanar knee joint loads were  
341 observed post-intervention (Tables 1-3). In applied and clinical settings, however, practitioners  
342 do not work with group means but individuals. Figures 2-3 and Tables 2-3 illustrate the IG  
343 multiplanar knee joint loads individual responses following the training intervention, showing  
344 considerable individual variation (i.e., positive and negative responders). This observation  
345 corroborates previous research that has shown individual variation following injury mitigation  
346 training (3, 5, 18, 36). Generally, subjects with initially high multiplanar knee joint loads, and  
347 thus considered to be potentially at higher injury risk (21, 22), responded positively and  
348 demonstrated reductions (Figures 2-3). This observation is similar to previous research that  
349 found “higher-risk” female athletes responded favourably to injury mitigation training by  
350 displaying greater reductions in landing KAMs compared to “lower-risk” athletes (5, 18, 36).  
351 The present study is the first to have examined the individual changes in knee joint loads  
352 following COD technique modification, highlighting that an individual approach is needed  
353 because inferences based on group means only may conceal potentially meaningful information  
354 (3, 18).

355         Changes in postures and mechanics associated with increased knee joint loads were  
356 also assessed in the present study. Contrary to previous research (7), no meaningful changes in  
357 lateral foot plant distance or lateral trunk flexion were observed following COD technique  
358 modification training (Tables 1-3). The finding that lateral foot plant distance did not change,  
359 based on group means, is unsurprising because this was not a specific targeted technical  
360 change. Conversely, it is surprising that lateral trunk flexion angles did not meaningfully  
361 reduced because subjects were specifically given the verbal cue to “lean and face towards the



362 intended direction of travel”. For example, Staynor et al. (40) observed lateral trunk flexion  
363 angles reductions following mixed training (body weight plyometric, resistance, and balance  
364 exercises), while King et al. (28) found a three-phase program (intersegmental control and  
365 strength, intersegmental control during running and COD) reduced lateral trunk flexion angles  
366 during cutting. Potentially, verbal cueing does not provide a sufficient stimulus to evoke frontal  
367 plane trunk control changes and thus, increases in physical capacity and intersegmental control  
368 is needed through direct conditioning (28, 40). However, individual responses revealed eight  
369 and seven subjects positively reduced their lateral trunk flexion angles for CUT45 and CUT90  
370 (Tables 2-3), respectively. As such, the mixed responses to the training intervention conceals  
371 potentially meaningful differences based on group mean analysis, and highlights that an  
372 individual approach is needed when monitoring changes in COD biomechanics (3, 18).

373 Cutting postures with limited knee flexion and high impact GRFs “high-risk”  
374 characteristics of non-contact ACL injury (25, 35) and associated with increased knee joint  
375 loads (32, 38). Although no meaningful reduction in peak **vertical braking force** was observed,  
376 a positive outcome following the intervention was a small increase in initial **knee flexion angle**  
377 (Tables 1-3) and greater PFC mean **horizontal braking force** for CUT90. These technical  
378 changes are likely attributed to the coaching cues to “cushion over weight acceptance” and  
379 “slam on the brakes”. Critically, however, increased **initial** and peak **knee abduction angles**  
380 were observed following the intervention (Tables 1-3). Sigward and Powers (39) suggest that  
381 an internally rotated lower-extremity position might be adopted by athletes to encourage the  
382 centre of mass of the body further away from the centre of pressure, and to facilitate the  
383 directional change to the intended direction of travel through a combination of rotations of the  
384 lower-limb joints. This finding may have been partially attributed to the cue to “lean towards  
385 the intended direction of travel”. Although this cue was intended to alter trunk kinematics,  
386 athletes may have repositioned their lower-limb for more effective alignment towards the

387 intended direction of travel, as evidenced by the moderate increases in **initial foot progression**  
388 **angle** (Tables 1-3). Results from previous research show no meaningful relationships between  
389 **knee abduction angle** and faster cutting performance (20, 33). Nevertheless, these findings  
390 highlight the difficulty in improving frontal plane control during cutting using technical cues  
391 only. Potentially, athletes would benefit from supplemental external hip rotator strengthening  
392 to improve frontal plane knee control during side-stepping (28, 37, 40).

393 Uniquely, the results from this study provide insight into which potential side-step  
394 cutting technical and mechanical variables increase and decrease knee joint loads (Table 4),  
395 and therefore could be used to inform future directions of training. Specifically, peak and **initial**  
396 **knee abduction angle** decreases were moderately to largely associated with reduced CUT45  
397 and CUT90 peak KAMs and KIRMs. Additionally, increased **initial knee flexion angles** were  
398 moderately associated with reductions in CUT45 KAMs, while decreased lateral trunk flexion  
399 was moderately associated with CUT45 KIRMs decreases, and FFC **vertical braking force**  
400 decreases were moderately associated with CUT45 KAMs and CUT90 KIRMs reductions.  
401 Finally, FFC velocity decreases were moderately associated with CUT90 KAMs reductions.  
402 Consequently, these aforementioned variables are specific deficits to target in future training  
403 interventions to reduce multiplanar side-step knee joint loads (15, 17).

404 As COD biomechanical demands are angle- and task-dependent (14), caution is advised  
405 extrapolating the findings from this study to CODs of different angles and actions. Further  
406 research is necessary that investigates the effect of COD technique modification on sharper  
407 **CODs and different COD actions in different populations. Unfortunately, no strength or body**  
408 **composition data was collected in this study. Thus, it is uncertain whether athletes with superior**  
409 **strength or body composition may have responded more favourably to the technique**  
410 **modification intervention, with weaker athletes potentially unable to adopt the desired postures**

411 and targeted technical modifications in this intervention. Future research is needed which  
412 accounts for strength and body composition following COD technique modification.

413 Due to time constraints, there was no initial pre-screening of individuals to specifically  
414 identify targeted deficits to inform technique modification training. Moreover, increased  
415 muscle activation of the hamstrings, gluteal muscles, and soleus, may have the potential to help  
416 unload the knee ligaments (7, 30). The present study did not monitor changes in muscle  
417 activation and is thus a future direction of research. Although this study aimed to examine the  
418 biomechanical effects of COD technique modification on ACL injury risk loading, in applied  
419 settings, athletes would however perform a mixed, multicomponent training program (14, 37)  
420 which incorporates strength, balance, trunk control, plyometrics, and COD/agility training, and  
421 this is recommended for ACL injury mitigation (15, 37). Therefore, future research which  
422 determines the effects of a mixed multicomponent training intervention on COD biomechanics  
423 is needed to increase the ecological validity to “real-world” environments. Lastly, it is unknown  
424 whether the technique can be maintained for extensive periods and it is unclear what happens  
425 to cutting biomechanics when this form of training is discontinued.

## 426 PRACTICAL APPLICATIONS

427 This is the first study to examine the biomechanical effects of a COD technique modification  
428 intervention on surrogates of ACL injury risk while containing a CG. Based on group means,  
429 COD technique modification was ineffective regarding potential injury risk. However,  
430 considerable individual variation was observed (i.e., positive and negative responders).  
431 Generally, subjects who displayed initially high multiplanar knee joint loads and thus  
432 considered potentially “high-risk”, responded positively and demonstrated reductions in knee  
433 joint loads; highlighting the importance of an individual approach when monitoring training  
434 intervention effectiveness. Conversely, subjects with initially low multiplanar knee joint loads

435 tended to increase their multiplanar knee joint loads post-intervention, albeit to levels  
436 considered not potentially hazardous or “high-risk”. COD technique modification training is a  
437 simple, effective training method, requiring minimal equipment that can reduce knee joint  
438 loads in “higher-risk” subjects without compromising performance. Practitioners can consider  
439 incorporating this form of training (2 × 30-minute sessions a week) simply and easily into their  
440 pitch- or court-based training programs to mitigate ACL injury risk.

#### 441 **ACKNOWLEDGEMENTS**

442 The authors would like to thank Callum Stratford, Alistair McBurnie, Laura Smith, and Steve  
443 Horton for their assistance with data collection. This study was funded by the National  
444 Strength and Conditioning Association (NSCA) Foundation, as part of the Doctoral Grant  
445 Scheme (awarded 2018). Funding was used for subject recruitment only. The authors declare  
446 that they have no conflicts or competing interests relevant to the content of this article, and the  
447 findings of the study do not represent the views of the NSCA.

#### 448 **REFERENCES**

- 449 1. Celebrini RG, Eng JJ, Miller WC, Ekegren CL, Johnston JD, and MacIntyre DL. The  
450 effect of a novel movement strategy in decreasing ACL risk factors in female  
451 adolescent soccer players. *J Strength Cond Res* 26: 3406-3417, 2012.
- 452 2. Cohen J. Statistical analysis for the behavioral sciences. *Hillsdale: Lawrence*  
453 *Erlbaum*, 1988.
- 454 3. Cowling E, Steele J, and McNair P. Training quadriceps-hamstring muscle  
455 synchrony: Do group data mask individual lower limb muscle coordination strategies?  
456 *J Sci Med Sport* 6: 90, 2003.
- 457 4. Dai B, William EG, Michael TG, Darin AP, Robin MQ, and Bing Y. The Effects of 2  
458 Landing Techniques on Knee Kinematics, Kinetics, and Performance During Stop-  
459 Jump and Side-Cutting Tasks. *Am J Sport Med* 43: 466-474, 2014.
- 460 5. De Ste Croix M, Hughes J, Ayala F, Taylor L, and Datson N. Efficacy of injury  
461 prevention training is greater for high-risk vs low-risk elite female youth soccer  
462 players. *Am J Sport Med* 46: 3271-3280, 2018.
- 463 6. Della Villa F, Buckthorpe M, Grassi A, Nabiuzzi A, Tosarelli F, Zaffagnini S, and  
464 Della Villa S. Systematic video analysis of ACL injuries in professional male football  
465 (soccer): injury mechanisms, situational patterns and biomechanics study on 134  
466 consecutive cases. *Br J Sports Med*, 2020.
- 467 7. Dempsey AR, Lloyd DG, Elliott BC, Steele JR, and Munro BJ. Changing sidestep  
468 cutting technique reduces knee valgus loading. *Am J Sport Med* 37: 2194-2200, 2009.

- 469 8. Dempsey AR, Lloyd DG, Elliott BC, Steele JR, Munro BJ, and Russo KA. The effect  
470 of technique change on knee loads during sidestep cutting. *Med Sci Sports Exerc* 39:  
471 1765-1773, 2007.
- 472 9. Donnelly CJ, Elliott BC, Doyle TLA, Finch CF, Dempsey AR, and Lloyd DG.  
473 Changes in knee joint biomechanics following balance and technique training and a  
474 season of Australian football. *Br J Sports Med* 46: 917-922, 2012.
- 475 10. Dos'Santos T, Comfort P, and Jones PA. Average of trial peaks versus peak of  
476 average profile: impact on change of direction biomechanics. *Sport Biomech* 19: 483-  
477 492, 2020.
- 478 11. Dos'Santos T, McBurnie A, Comfort P, and Jones PA. The Effects of Six-Weeks  
479 Change of Direction Speed and Technique Modification Training on Cutting  
480 Performance and Movement Quality in Male Youth Soccer Players. *Sports* 7: 205,  
481 2019.
- 482 12. Dos'Santos T, McBurnie A, Donelon T, Thomas C, Comfort P, and Jones PA. A  
483 qualitative screening tool to identify athletes with "high-risk" movement mechanics  
484 during cutting: The cutting movement assessment score (CMAS). *Phys Ther Sport* 38:  
485 152-161, 2019.
- 486 13. Dos'Santos T, McBurnie A, Thomas C, Comfort P, and Jones PA. Biomechanical  
487 Comparison of Cutting Techniques: A Review and Practical Applications. *Strength*  
488 *Cond J* 41: 40-54, 2019.
- 489 14. Dos'Santos T, Thomas C, Comfort P, and Jones PA. The effect of angle and velocity  
490 on change of direction biomechanics: an angle-velocity trade-off. *Sports Med* 48:  
491 2235-2253, 2018.
- 492 15. Dos'Santos T, Thomas C, Comfort P, and Jones PA. The Effect of Training  
493 Interventions on Change of Direction Biomechanics Associated with Increased  
494 Anterior Cruciate Ligament Loading: A Scoping Review. *Sports Med* 49: 1837-1859,  
495 2019.
- 496 16. Faul F, Erdfelder E, Buchner A, and Lang A-G. Statistical power analyses using G\*  
497 Power 3.1: Tests for correlation and regression analyses. *Behav Res Methods* 41:  
498 1149-1160, 2009.
- 499 17. Fox AS. Change-of-Direction Biomechanics: Is What's Best for Anterior Cruciate  
500 Ligament Injury Prevention Also Best for Performance? *Sports Med* 48: 1799-1807,  
501 2018.
- 502 18. Fox AS, Bonacci J, McLean SG, and Saunders N. Exploring individual adaptations to  
503 an anterior cruciate ligament injury prevention programme. *Knee* 25: 83-98, 2018.
- 504 19. Harris M, Casey LB, Meindl JN, Powell D, Hunter WC, and Delgado D. Using  
505 Behavioral Skills Training With Video Feedback to Prevent Risk of Injury in Youth  
506 Female Soccer Athletes. *Behavior Analysis in Practice*: 1-9, 2020.
- 507 20. Havens KL and Sigward SM. Cutting mechanics: relation to performance and anterior  
508 cruciate ligament injury risk. *Med Sci Sports Exerc* 47: 818-824, 2015.
- 509 21. Hewett T. Preventive biomechanics: A paradigm shift with a translational approach to  
510 biomechanics. *Am J Sports Med* 45: 2654-2664, 2017.
- 511 22. Hewett T, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SG, Van den Bogert  
512 AJ, Paterno MV, and Succop P. Biomechanical measures of neuromuscular control  
513 and valgus loading of the knee predict anterior cruciate ligament injury risk in female  
514 athletes a prospective study. *Am J Sport Med* 33: 492-501, 2005.
- 515 23. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 30:  
516 1-15, 2000.
- 517 24. Hopkins WG. A scale of magnitudes for effect statistics. *A new view of statistics*:  
518 Retrieved from <http://sportsci.org/resource/stats/effectmag.html>, 2002.

- 519 25. Johnston JT, Mandelbaum BR, Schub D, Rodeo SA, Matava MJ, Silvers HJ, Cole BJ,  
520 ElAttrache NS, McAdams TR, and Brophy RH. Video analysis of anterior cruciate  
521 ligament tears in professional American football athletes. *Am J Sport Med* 46: 862-  
522 868, 2018.
- 523 26. Jones PA, Barber OR, and Smith LC. Changing pivoting technique reduces knee  
524 valgus moments. Free Communication. Journal of Sports Sciences. *J Sports Sci*  
525 *(BASES Annual Conference)* 33: S62, 2015.
- 526 27. Jones PA, Thomas C, Dos'Santos T, McMahon J, and Graham-Smith P. The Role of  
527 Eccentric Strength in 180° Turns in Female Soccer Players. *Sports* 5: 42, 2017.
- 528 28. King E, Franklyn-Miller A, Richter C, O'Reilly E, Doolan M, Moran K, Strike S, and  
529 Falvey E. Clinical and biomechanical outcomes of rehabilitation targeting  
530 intersegmental control in athletic groin pain: prospective cohort of 205 patients. *Br J*  
531 *Sports Med* 52: 1054-1062, 2018.
- 532 29. Kristianslund E, Faul O, Bahr R, Myklebust G, and Krosshaug T. Sidestep cutting  
533 technique and knee abduction loading: implications for ACL prevention exercises. *Br*  
534 *J Sports Med* 48: 779-783, 2014.
- 535 30. Lloyd DG and Buchanan TS. Strategies of muscular support of varus and valgus  
536 isometric loads at the human knee. *J Biomech* 34: 1257-1267, 2001.
- 537 31. Lohmander LS, Englund PM, Dahl LL, and Roos EM. The long-term consequence of  
538 anterior cruciate ligament and meniscus injuries. *Am J Sport Med* 35: 1756-1769,  
539 2007.
- 540 32. Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GAM, and  
541 Slauterbeck JL. Combined knee loading states that generate high anterior cruciate  
542 ligament forces. *J Orthop Res* 13: 930-935, 1995.
- 543 33. McBurnie A, Dos' Santos T, and Jones PA. Biomechanical Associates of Performance  
544 and Knee Joint Loads During an 70-90° Cutting Maneuver in Sub-Elite Soccer  
545 Players. *J Strength Cond Res*: Published Ahead of print., 2019.
- 546 34. Mendiguchia J, Conceição F, Edouard P, Fonseca M, Pereira R, Lopes H, Morin J-B,  
547 and Jiménez-Reyes P. Sprint versus isolated eccentric training: Comparative effects  
548 on hamstring architecture and performance in soccer players. *Plos one* 15: e0228283,  
549 2020.
- 550 35. Montgomery C, Blackburn J, Withers D, Tierney G, Moran C, and Simms C.  
551 Mechanisms of ACL injury in professional rugby union: a systematic video analysis  
552 of 36 cases. *Br J Sports Med* 52: 944-1001, 2018.
- 553 36. Myer GD, Ford KR, Brent JL, and Hewett TE. Differential neuromuscular training  
554 effects on ACL injury risk factors in " high-risk" versus " low-risk" athletes. *BMC*  
555 *musculoskeletal disorders* 8: 39, 2007.
- 556 37. Padua DA, DiStefano LJ, Hewett TE, Garrett WE, Marshall SW, Golden GM, Shultz  
557 SJ, and Sigward SM. National Athletic Trainers' Association Position Statement:  
558 Prevention of Anterior Cruciate Ligament Injury. *J Athl Training* 53: 5-19, 2018.
- 559 38. Shin CS, Chaudhari AM, and Andriacchi TP. Valgus plus internal rotation moments  
560 increase anterior cruciate ligament strain more than either alone. *Med Sci Sports*  
561 *Exerc* 43: 1484-1491, 2011.
- 562 39. Sigward SM and Powers CM. Loading characteristics of females exhibiting excessive  
563 valgus moments during cutting. *Clin Biomech* 22: 827-833, 2007.
- 564 40. Staynor JM, Nicholas JC, Weir G, Alderson JA, and Donnelly CJ. Targeting  
565 associated mechanisms of anterior cruciate ligament injury in female community-  
566 level athletes. *Sport Biomech* 16: 501-513, 2017.

- 
- 567 41. Welch N, Richter C, Franklyn-Miller A, and Moran K. Principal Component Analysis  
568 of The Associations Between Kinetic Variables In Cutting And Jumping, And Cutting  
569 Performance Outcome. *J Strength Cond Res*: Published ahead of print, 2019.
- 570 42. Winter DA. *Biomechanics and motor control of human movement*. John Wiley &  
571 Sons, 2009.
- 572