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1 **Biomechanical Effects of a Six-Week Change of Direction Speed and Technique**

2 **Modification Intervention: Implications for **Change of Direction Side-Step** Performance**

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## 20 ABSTRACT

21 The aim of this study was to evaluate biomechanical effects of change of direction (COD)  
22 speed and technique modification training on COD performance (completion time, ground  
23 contact time [GCT], and exit velocity) during 45° (CUT45) and 90° (CUT90) side-step cutting.  
24 A non-randomized, controlled 6-week intervention study was administrated. 15 male  
25 multidirectional sport athletes (age:23.5±5.2 years;height:1.80±0.05 m;mass:81.6±11.4 kg)  
26 formed the intervention group (IG) who participated in two 30-minute COD speed and  
27 technique modification sessions per week, while 12 male multidirectional sport athletes  
28 (age:22.2±5.0 years;height:1.76±0.08 m;mass:72.7±12.4 kg) formed the control group (CG)  
29 and continued their normal training. All subjects performed six trials of the CUT45 and CUT90  
30 task whereby pre-to-post intervention changes in lower-limb and trunk kinetics and kinematics  
31 were evaluated using three-dimensional motion and ground reaction force analysis. Two-way  
32 mixed analysis of variances revealed significant main effects for time (pre-to-post changes) for  
33 CUT45 completion time, exit velocity and CUT90 completion time ( $p \leq 0.045$ ,  $\eta^2 = 0.152-0.539$ ),  
34 and significant interaction effects of time and group were observed for CUT45 completion  
35 time, GCT, exit velocity and CUT90 completion time ( $p \leq 0.010$ ,  $\eta^2 = 0.239-0.483$ ), with the IG  
36 displaying superior performance post-intervention compared to the CG ( $p \leq 0.109$ ,  $g = 0.83-$   
37 1.35). Improvements in cutting performance were moderately to very largely associated  
38 ( $p \leq 0.078$ ,  $r$  or  $\rho = 0.469-0.846$ ) with increased velocity profiles, increased propulsive forces  
39 over shorter GCTs, and decreased knee flexion. COD speed and technique modification is a  
40 simple, effective training method, requiring minimal equipment, that can enhance COD  
41 performance which practitioners should consider incorporating into their **pitch- or court-based**  
42 training programs.

43 **Keywords:** side-step; side-stepping; cutting; kinetics, external cues

## 44 INTRODUCTION

45 Change of direction (COD) ability is a fundamental movement associated with successful  
46 performance in multidirectional sports (7, 29). Athletes can perform a range of angled  
47 directional changes in sport (11, 12), and there are various different COD actions (side-step,  
48 crossover cut, split step, pivot, spin maneuverer) performed which have their own distinct  
49 biomechanical differences, advantages, and disadvantages (11). Specifically, side-step cutting  
50 is characterised by a lateral foot plant to push-off towards the opposite direction (11), and this  
51 is an important and frequently performed action linked to **decisive agility moments, such as**  
52 **evading tackles to gain territorial advantage and pressing opponents (defensive agility) in**  
53 **multidirectional sports (11, 16, 40). Additionally, athletes also sprint and side-step to**  
54 **predetermined locations on a pitch or court (29), such as wide-receiver running a pre-planned**  
55 **“slant” route in American Football or a baseball player running around the bases to score a run.**  
56 Consequently, training interventions that can enhance an athlete’s mechanical ability to side-  
57 step cut are of great interest to practitioners working in cutting dominant sports.

58 Specifically, COD speed is defined as “the ability to decelerate, reverse or change  
59 movement direction and accelerate again” (22) and the determinants of COD speed are  
60 multifaceted, underpinned by interactions between velocity (linear speed), mechanics (kinetics,  
61 technique and postures), deceleration (braking strategy), and physical capacity (strength  
62 capacity, maximal and rapid force production, neuromuscular control, and muscle activation)  
63 (11-13, 24, 28). Results of a recent meta-analysis confirmed that plyometric training, strength  
64 training, COD speed training, and combined training methods positively enhance COD speed  
65 and manoeuvrability performance (14). However, it worth noting that COD speed and  
66 manoeuvrability performance during the successful training interventions is generally assessed  
67 via completion time using electronic timing gates (31). Thus, because the majority of the time  
68 during these assessments is spent linear sprinting, these tasks are biased towards faster athletes

69 and confounded by linear speed (31). Importantly, the underlying biomechanical mechanisms  
70 which are responsible for enhanced COD speed performance are currently unclear. By only  
71 assessing COD performance using completion time, it is uncertain whether an athlete's  
72 mechanical ability to COD has indeed improved, or whether reductions in completion times  
73 have improved due to improvement linear speed capabilities. Consequently, for a better  
74 understanding of whether training interventions improve an athlete's mechanical ability to  
75 **change direction**, more detailed analysis into COD biomechanics such as kinetics, ground  
76 contact time (GCT), and velocity of centre of mass (COM) are required, which are suggested  
77 to be better measures of COD ability (31, 33).

78 Kinetic, technical, and mechanical determinants of faster side-step cutting (30-90°)  
79 performance include greater medio-lateral propulsive forces (MLPF) over short GCTs, greater  
80 ankle power and plantar-flexor moments, torso lean and pelvis rotation towards the intended  
81 direction of travel, greater hip power and extensor moments, rapid knee and hip extension,  
82 wider lateral foot plants, reduced hip and knee flexion, low COM, faster velocity profiles, and  
83 greater penultimate foot contact (PFC) horizontal braking forces (HBF) (for 90° cuts only) (11,  
84 13, 19, 24, 27, 28, 37). Therefore, teaching and modifying athletes' side-step cutting technique  
85 by promoting the aforementioned favourable postures and mechanics associated with faster  
86 cutting (e.g., reduced knee flexion, medial trunk lean and pelvis rotation, greater MLPFs, faster  
87 velocity profiles, greater PFC braking forces) could be an effective and simple training strategy  
88 for enhancing side-step cutting performance (5, 9, 23). For example, in male soccer players,  
89 six-weeks' COD speed and technique modification training focusing on earlier and greater PFC  
90 braking, trunk lean towards the intended direction of travel, and rapid and forceful push-off  
91 improved 70° side-cutting performance completion times and COD deficits (9). Acutely,  
92 modifying knee flexion range of motion (ROM) has shown to influence GCT and exit velocity  
93 during 45° side-step cutting (5), and 6-weeks' 180° COD technique modification training (PFC



## 118 Subjects

119 **Thirty** men from multidirectional sports (amateur/semi-professional level) were recruited and  
120 participated in this study. Based on previous work (23), a minimum sample size of 14 per group  
121 was determined from an *a priori* power analysis using G\*Power (Version 3.1, University of  
122 Dusseldorf, Germany) (15). This was based upon an effect size of 0.74 (pre-to-post change  
123 completion time), a power of 0.80, and alpha level of 0.05.

124 Sixteen males (soccer  $n = 12$ , rugby  $n = 4$ ; age:  $23.5 \pm 5.2$  years; height:  $1.80 \pm 0.05$  m;  
125 mass:  $81.6 \pm 11.4$  kg) were recruited for the IG. Conversely, fourteen men (soccer  $n = 9$ , rugby  
126  $n = 4$ , 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)  
127 acted as the CG and continued their normal sport and resistance training sessions. The  
128 investigation was approved by the Institutional Ethics Review Board (HSR1617-131), and all  
129 subjects were informed of the benefits and risks of the investigation prior to signing an  
130 institutionally approved consent form to participate in the study. All subjects from both groups  
131 possessed at least five years' training experience in their respective sport and had never  
132 sustained a severe knee injury prior to testing. All subjects had minimum one years' resistance  
133 training experience, all performed two resistance training sessions a week and were all in a  
134 strength mesocycle. At the time of the training intervention, all subjects completed two skills  
135 sessions and played one competitive match a week. All of the procedures were carried out  
136 during the competitive season to ensure that no large physical changes were made as a result  
137 of the conditioning state . To remain as an active subject in the study and used for further  
138 analysis, subjects were not allowed to miss more than two of the 12 sessions in total (i.e.,  $\geq$   
139 83% compliance rate). Subsequently, due to match-related injuries or illness, one and two  
140 subjects withdrew from the IG and CG, **respectively**, resulting in sample sizes of 15 and 12

141 (Figure 1). Subjects in the IG completed on average  $11.9 \pm 0.4$  sessions ( $98.3 \pm 3.5\%$ ), with 12  
142 subjects completing 12 (100%) sessions and three completing 11 sessions (91.7%).

### 143 Procedures

144 The warm up, cut, marker placement, and 3D motion analysis and procedures were based on  
145 previously published methodologies (8, 24, 25, 28). In summary, each subject performed six  
146 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  
147 possible and were provided with standardized footwear to control for shoe-surface interface  
148 (Balance W490, New Balance, Boston, MA, USA). Completion time was assessed using two  
149 sets of Brower timing lights placed at hip height at the start and finish (Draper, UT, USA), and  
150 subjects adopted a two-point staggered stance, 0.5 m behind the start line. Marker and force  
151 data were collected over the PFC and final foot contact (FFC) using ten Qualisys Oqus 7  
152 (Gothenburg, Sweden) infrared cameras (240 Hz) operating through Qualisys Track Manager  
153 software (Qualisys, version 2.16 (Build 3520), Gothenburg, Sweden) and GRF's were  
154 collected from two  $600 \text{ mm} \times 900 \text{ mm}$  AMTI (Advanced Mechanical Technology, Inc,  
155 Watertown, MA, USA) force platforms (Model number: 600900) embedded into the running  
156 track sampling at 1200 Hz, respectively. Using the pipeline function in visual 3D, joint  
157 coordinate (marker) and force data were smoothed using a Butterworth low-pass digital filter  
158 with cut-off frequencies of 15 and 25 Hz, respectively, based on *a priori* residual analysis (39)  
159 and visual inspection of motion data. The kinematic model process was based on previous  
160 reported methodologies (8, 24, 25, 28). Lower limb joint moments were calculated using an  
161 inverse dynamics approach (39) through Visual 3D software (C-motion, version 6.01.12,  
162 Germantown, USA) and were defined as external moments and normalised to body mass. Joint  
163 kinematics and GRFs were also calculated using Visual 3D, while GRF braking and propulsive  
164 characteristics were normalised relative to body weight, with vertical, anterior-posterior, and



165 medio-lateral corresponding to Fz, Fx, and Fy, respectively. Horizontal COM velocity profiles  
166 over key instances of the COD were calculated as described previously (24, 25).

167 Supplemental digital content 2 provides a full description the variables examined,  
168 definitions, and calculations. Briefly, the following kinetic and kinematics were examined  
169 during the FFC for both tasks: GCT and velocity at FFC (touchdown) and exit velocity (toe-  
170 off); mean and peak MLPF; hip, knee, ankle dorsi-flexion moments and ROM (sagittal plane  
171 joint moment and angles); lateral trunk flexion angle, forward trunk inclination angle, pelvis  
172 rotation angle, initial foot progression angle (IFPA), and lateral foot plant distance (trunk,  
173 pelvis, and foot variables). Additionally, mean horizontal propulsive force was examined  
174 during the FFC for CUT90, mean HBF was examined during the FFC and PFC only during  
175 CUT90, while PFC GCT and approach velocity (velocity at PFC) was also examined.  
176 Completion time, GCT, and exit velocity were the considered primary outcome variables while  
177 approach velocity, velocity at FFC, and cut angle were also secondary variables to assess  
178 cutting performance. Five trials were used in the analysis of each subject based and the average  
179 of individual trial peaks for each variable were calculated (8). A subset of the sample ( $n=10$ )  
180 performed the cuts on two separate occasions separated by 7 days to establish between-session  
181 reliability. The reliability measures for COD biomechanics data was considered high (intraclass  
182 correlation coefficient = 0.704-0.958, coefficient of variation = 2.4-11.9%).

### 183 6-week COD speed and technique modification training intervention

184 A six-week COD speed and technique modification intervention described in Supplemental  
185 digital content 1, was performed by the IG twice a week (30 minutes per session), with  
186 minimum 48 hours between sessions. The intervention was slightly adapted from a previously  
187 successful six-week COD speed and technique modification training intervention (9), which  
188 focused on pre-planned low intensity decelerations, cuts, and turns (weeks 1-2), before



213 observed for time and group. Partial eta squared effect sizes were calculated for all ANOVAs  
214 with the values of 0.010-0.059, 0.060-0.149, and  $\geq 0.150$  considered as small, medium, and  
215 large, respectively (4).

216 Pre-to-post changes in variables for each group were assessed using paired sample t-  
217 tests (parametric) and Wilcoxon-sign ranked tests (non-parametric). Magnitudes of differences  
218 were assessed using Hedges' *g* effect sizes with 95% CIs, and interpreted as trivial ( $\leq 0.19$ ),  
219 small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.00–3.99), and  
220 extremely large ( $\geq 4.00$ ) (21). Mean changes were also calculated and interpreted as ratios  
221 relative to the smallest worthwhile change (SWC). The SWC was calculated as  $0.2 \times$  between-  
222 subject SD. Comparisons in post-intervention primary outcome variables and changes in  
223 outcome variables between the IG and CG were also assessed using independent sample t-tests  
224 or Mann-Whitney U tests, with effect sizes as outlined above. Furthermore, to link changes in  
225 COD performance with cutting kinetic and kinematic changes, Pearson's correlations  
226 (parametric) or Spearman's correlations (non-parametric) were calculated with 95% CIs, with  
227 *p* values Bonferroni corrected to control for type 1 error. Correlations were interpreted as trivial  
228 (0.00-0.09), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–  
229 0.89), nearly perfect (0.90–0.99), and perfect (1.00) (20). A correlation cut-off value of  $\geq 0.40$   
230 was considered relevant (36). Thus, correlations greater than this value are only reported.  
231 Statistical significance was defined as  $p \leq 0.05$  for all tests.

## 232 RESULTS

233 Results of the two-way mixed ANOVAs are presented in Tables 2 and 4, and pre-to-post  
234 changes in cutting biomechanics for the IG and CG are presented in Tables 3 and 5, containing  
235 descriptive statistics, *p* values, effect sizes, and mean differences.

236 CUT45: Pre-to-post changes in cutting biomechanical variables

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

238 Large and significant interaction effects of time and group for all CUT45 performance  
239 variables were observed (Table 2), with the IG displaying moderately to largely better  
240 performance variables post-intervention compared to the CG ( $p \leq 0.109$ ,  $g = 0.62-1.21$ ).  
241 Moderate and significant improvements in completion time, exit velocity, approach velocity,  
242 and velocity at FFC were observed for the IG only, while a small and significantly shorter GCT  
243 was also observed (Table 3). Medium to large significant interaction effects of time and group  
244 were observed for CUT45 peak and mean MLPF, and knee flexion angle (KFA) ROM (Table  
245 2). Intervention group subjects produced significantly small to moderately greater peak and  
246 mean MLPFs, greater IFPAs, and smaller knee and ADFA ROMs post-intervention (Table 3).  
247 Control group subjects demonstrated significantly greater IFPAs post-intervention only (Table  
248 3).

249 \*\*\*Insert Figure 2 here\*\*\*

250 \*\*\*Insert Table 3 here\*\*\*

251 CUT90: Pre-to-post changes in performance biomechanical variables

252 \*\*\*Insert Table 4 here\*\*\*

253 A large and significant interaction effect of time and group for CUT90 completion time was  
254 observed (Table 4), with the IG showing significantly faster post-intervention completion times  
255 ( $p = 0.031$ ,  $g = -1.35$ ) compared to the CG. Additionally, a medium and non-significant  
256 interaction effect was observed for exit velocity (Table 4), with the IG showing significantly  
257 greater exit velocities ( $p = 0.035$ ,  $g = 0.83$ ) post-intervention compared to the CG. A large and  
258 moderate significant improvement was observed for completion time and exit velocity (Table  
259 5 and Figure 3), respectively, for the IG only. Medium to large significant interaction effects

260 of time and group were observed for CUT90 mean MLPF, peak and mean HPF, FFC mean  
261 HBF, FFC peak ADFM, IFPA, and knee and ADFA ROM (Table 4). **Intervention group**  
262 **subjects** produced significantly small to moderately greater peak ADFMs, greater peak and  
263 mean MLPFs, greater peak and mean HPFs, and greater FFC and PFC mean HBFs (Table 5).  
264 Additionally, **IG subjects** demonstrated significantly small to moderately greater forward trunk  
265 inclination angles, greater pelvic rotation angles, greater IFPAs, smaller KFA ROM, and  
266 greater ADFA ROM post-intervention (Table 5). **Control group** subjects produced significantly  
267 greater peak MLPFs and greater forward trunk inclination angles post-intervention only (Table  
268 5).

269 \*\*\*Insert Figure 3 here\*\*\*

270 \*\*\*Insert Table 5 here\*\*\*

271 Associations between changes in performance primary outcome variables with cutting  
272 mechanical and technical variables

273 Improvements in CUT45 completion time were very largely associated with increased exit  
274 velocity; largely associated with decreased FFC GCT; and moderately associated with  
275 decreased KFA ROM, increased mean MLPF, and increased FFC velocity (Table 6).  
276 Additionally, CUT45 FFC GCT **improvements** were very largely associated with decreased  
277 **KFA ROM**; and largely associated with increased approach and exit velocity (Table 6). Finally,  
278 CUT45 exit velocity **improvements** were very largely associated with increased FFC velocity;  
279 and largely associated with decreased KFA ROM and FFC GCT, and increased approach  
280 velocity (Table 6).

281 Improvements in CUT90 completion time were largely associated with increased peak  
282 KFM, increased FFC peak HBF, and decreased PFC GCT; and moderately associated with

283 increased ADFA ROM (Table 6). Additionally, CUT90 FFC GCT improvements were very  
284 largely associated with increased FFC velocity, and decreased hip and knee flexion ROM; and  
285 largely associated with increased exit velocity and lateral foot plant distance (Table 6). Finally,  
286 CUT90 exit velocity improvements were very largely associated with increased FFC velocity;  
287 largely associated with decreased FFC GCT, decreased HFA ROM, increased PFC mean HBF;  
288 and moderately associated with increased FFC peak KFM, and lateral foot plant distance (Table  
289 6).

290 \*\*\*Insert Table 6 here\*\*\*

## 291 DISCUSSION

292 The aims of this study were two-fold: 1) to examine the biomechanical effects of a 6-week  
293 COD speed and technique modification intervention on side-step cutting performance; and 2)  
294 to understand which technical and mechanical changes during cutting explained improvements  
295 in performance. The primary findings were that COD speed and technique modification  
296 resulted in meaningful improvements in cutting performance, which were meaningfully greater  
297 than the CG (Tables 2-5 Figures 2-3), supporting the study hypotheses. The positive  
298 improvements in cutting performance were primarily attributed to increases in velocity at key  
299 instances of the PFC and FFC, increases in propulsive force over shorter GCTs, and reduced  
300 knee flexion, supporting the study hypotheses. Consequently, COD speed and technique  
301 modification appears to be a training strategy effective for improving COD performance, which  
302 practitioners can simply and easily administer on the pitch or court.

303 COD speed training has been reported to enhance COD completion time (9, 14);  
304 however, the technical and biomechanical mechanisms underpinning the improvements in  
305 COD performance are relatively unknown, and it is not fully understood whether the  
306 improvements in completion time were attributed to improvements in COD ability or linear

307 speed (31). This study is one of the first to provide a novel insight into the mechanical and  
308 technical changes underpinning improvements in 45° and 90° cutting performance. Although  
309 clear improvements in cutting completion times were observed in the present study (Table 3 &  
310 5, Figure 2-3), importantly shorter GCTs, greater propulsive forces, and enhancements in  
311 velocity at key instances of the COD were observed. Thus, these results confirm that the  
312 athletes' mechanical ability to COD has indeed improved via COD speed and technique  
313 modification training with external verbal cues. External cueing has been recommended for  
314 speed development (38) and has been shown to enhance COD performance (32), while  
315 promoting changes in side-stepping technique (2). Additionally, external cues are reported to  
316 be effective for motor skill development and retention (2, 11, 38). In the present study, we  
317 found the specific external cues, in addition to COD speed and technique modification training,  
318 “slam on the bakes”, “cushion and push the ground away”, and “face towards the direction of  
319 travel”, to be effective in improving side-step performance and promoting favourable  
320 techniques and mechanics linked to faster performance (Table 3 & 5).

321 Importantly, the present study was able to explore some of the underlying technical and  
322 mechanical mechanisms responsible for enhanced cutting performance. The key and primary  
323 changes in cutting mechanics were as follows: increased velocity at key instances of the PFC  
324 and FFC, increased mean and peak propulsive forces in shorter FFC GCTs, reduced knee  
325 flexion ROM, and greater PFC mean HBFs (90° cut only) which were moderately to very  
326 largely associated with improvements in cutting performance (Table 6). The fact that the  
327 abovementioned variables were associated with improvements in COD performance are  
328 unsurprising because they have been identified as key determinants of faster COD performance  
329 (11, 13, 19, 27, 28, 37). For example, Hader et al. (18) demonstrated greater minimum  
330 velocities and velocity maintenance were strong determinants of faster 45° and 90° cut  
331 performance, thus increasing an athlete's ability to attain greater horizontal displacements in

332 shorter times. Greater propulsive forces increase impulse which, based on the impulse-  
333 momentum relationship, leads to greater changes in momentum, thus velocity (11), and this  
334 was confirmed by the moderate association between MLPF changes and exit velocity (Table  
335 6).

336 Additionally, shorter GCTs are associated with faster performance (10, 27, 34, 36, 37),  
337 which is advantageous because the athletes will spend less time braking and propelling, thus  
338 less time performing the COD action, and potentially greater utilisation of the stretch-  
339 shortening cycle (3, 36). IG subjects demonstrated smaller ADFA ROMs for CUT45  
340 performance post-intervention (Table 3). Reduced ankle dorsi-flexion has been reported to play  
341 a critical role in early acceleration sprint performance, mostly likely contributing to a stiffer  
342 ankle joint; thus, potentially contributing to the faster performance observed in the present  
343 study. Finally, reduced KFA ROM is important for reducing GCT and increasing exit velocity,  
344 as confirmed by the results from this study and previous research (5). This potentially results  
345 in a rapid transition from braking (eccentric) to propulsion (concentric) and therefore  
346 facilitating a shorter GCT and greater utilisation of the stretch shortening cycle (increased  
347 elastic energy) to permit more effective force generation (3). **This positive adaptation could be**  
348 **attributed to the COD speed and technique modification training with the external cue to “push**  
349 **or punch the ground away.”**

350 High propulsive forces (10, 19, 28, 33, 34, 36) over short GCTs (10, 27, 28, 34, 36, 37)  
351 are strong determinants of faster COD performance. The finding of increased propulsive force  
352 production in shorter GCTs following COD technique modification training is a positive  
353 outcome (Tables 3 & 5), and is similar to de Hoyo et al. (6) who found 10-weeks eccentric  
354 overload training resulted in likely to almost certain increases in relative peak braking and  
355 propulsive forces, shorter braking and propulsive times thus shorter GCTs, and increases in



356 relative total and braking impulse during side-step cutting. Unfortunately, de Hoyo et al. (6)  
357 did not examine completion time or exit velocity; however, improvements in completion time  
358 training have been observed following flywheel eccentric training (17, 35); thus, it is speculated  
359 that the improved side-step kinetics from flywheel training should improve COD speed  
360 performance. Similarly, Bencke et al. (1) reported improvements in vertical propulsive force,  
361 GCT, and concentric phase duration following 12-weeks neuromuscular warm-up,  
362 corroborating the mechanism of improved completion time in the present study.

363 To author's knowledge, King et al. (26) is the only other research group to document  
364 changes in cutting biomechanics and some performance indices following a training  
365 intervention. No significant changes in approach velocity were observed following a  
366 multicomponent training programme (resistance training, running drills, and COD drills with  
367 focus on intersegmental control); however, a small reduction in GCT was observed which is  
368 an important determinant of COD performance. Unfortunately, King et al. (26) did not examine  
369 completion time or exit velocity, but did report reductions in lateral trunk flexion, increased  
370 pelvic rotation towards the intended direction, increased COM to centre of pressure distance,  
371 increased ankle plantar-flexor moments, and decreased peak KFA, which have all been  
372 associated with faster cutting completion times (5, 19, 27, 37). Although no significant changes  
373 in lateral trunk flexion or foot plant distance were observed in the present study (Tables 3 &  
374 5), similar to King et al. (26), subjects post-intervention in the IG demonstrated increased pelvic  
375 rotation, decreased KFA ROM, and increased ADFMs, which have previously been associated  
376 with faster cutting performance (5, 19, 27, 37). Nevertheless, the results from this study confirm  
377 that COD speed and technique modification training with external verbal coaching cues  
378 regarding technique result in positive improvements in side-stepping performance. Therefore,  
379 practitioners should consider implementing this form of training in their **pitch- or court-based**  
380 training programs when working with multidirectional athletes.

381 It is worth noting that the present study has several limitations. Firstly, it should be  
382 acknowledged that only CUT45 and CUT90 side-stepping was investigated with a right limb  
383 push-off. As the biomechanical demands are angle- and task-dependent (12, 31), caution is  
384 advised extrapolating the findings from the present study to CODs of different angles, actions  
385 and populations. Therefore, further research is necessary that investigates the effect of COD  
386 technique modification on sharper CODs and different COD actions (i.e. crossover cut, split  
387 step). Similarly, it is worth acknowledging that the cutting actions were examined in a pre-  
388 planned, controlled laboratory environment. Future research should consider investigating the  
389 effect of COD speed and technique modification training on agility performance. Lastly, it is  
390 unknown whether the technique can be maintained for extensive periods and unknown what  
391 happens to cutting biomechanics when this form of training is discontinued. Thus, further  
392 investigation into short- and long-term retention of modified cutting technique is required to  
393 improve our understanding of training prescription and dosages. **Notwithstanding these**  
394 **limitations, COD provides the mechanical and physical basis for agility (29), thus**  
395 **improvements in the mechanical ability to change direction (i.e., fast mover) should partially**  
396 **transfer to improved agility (7, 29, 30). Additionally, athletes sprint and change direction to**  
397 **pre-determined locations on a court or pitch (29), thus the findings of this study have important**  
398 **implications for the development of effective COD speed training programs.**

## 399 PRACTICAL APPLICATIONS

400 This is the first study to comprehensively examine the biomechanical effects of COD speed  
401 and technique modification on side-step cutting performance, finding meaningful  
402 improvements in side-step cutting performance. The positive improvements in performance  
403 were primarily attributed to increases in velocity at key instances of the COD, increases in  
404 propulsive force production over shorter GCTs, and decreased KFA ROM. Consequently, 6-

405 weeks' COD speed and technique modification training with externally directed verbal  
406 coaching cueing (“slam on the bakes, cushion and push the ground away, and face towards the  
407 direction of travel”) is an effective training strategy to enhance COD performance. Practitioners  
408 should therefore consider incorporating this form of training (2 × 30-minute sessions a week)  
409 simply and easily into their pitch- or court-based training programs to enhance side-step cutting  
410 performance.

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