Biomechanical Effects of a Six-Week Change of Direction Speed and Technique Modification Intervention: Implications for Change of Direction Side-Step Performance

ABSTRACT

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

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

INTRODUCTION

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

Specifically, COD speed is defined as "the ability to decelerate, reverse or change movement direction and accelerate again" (22) and the determinants of COD speed are multifaceted, underpinned by interactions between velocity (linear speed), mechanics (kinetics, technique and postures), deceleration (braking strategy), and physical capacity (strength capacity, maximal and rapid force production, neuromuscular control, and muscle activation) (11-13, 24, 28). Results of a recent meta-analysis confirmed that plyometric training, strength training, COD speed training, and combined training methods positively enhance COD speed and manoeuvrability performance (14). However, it worth noting that COD speed and manoeuvrability performance during the successful training interventions is generally assessed via completion time using electronic timing gates (31). Thus, because the majority of the time during these assessments is spent linear sprinting, these tasks are biased towards faster athletes and confounded by linear speed (31). Importantly, the underlying biomechanical mechanisms which are responsible for enhanced COD speed performance are currently unclear. By only assessing COD performance using completion time, it is uncertain whether an athlete's mechanical ability to COD has indeed improved, or whether reductions in completion times have improved due to improvement linear speed capabilities. Consequently, for a better understanding of whether training interventions improve an athlete's mechanical ability to change direction, more detailed analysis into COD biomechanics such as kinetics, ground contact time (GCT), and velocity of centre of mass (COM) are required, which are suggested to be better measures of COD ability (31, 33).

Kinetic, technical, and mechanical determinants of faster side-step cutting (30-90°) performance include greater medio-lateral propulsive forces (MLPF) over short GCTs, greater ankle power and plantar-flexor moments, torso lean and pelvis rotation towards the intended direction of travel, greater hip power and extensor moments, rapid knee and hip extension, wider lateral foot plants, reduced hip and knee flexion, low COM, faster velocity profiles, and greater penultimate foot contact (PFC) horizontal braking forces (HBF) (for 90° cuts only) (11, 13, 19, 24, 27, 28, 37). Therefore, teaching and modifying athletes' side-step cutting technique by promoting the aforementioned favourable postures and mechanics associated with faster cutting (e.g., reduced knee flexion, medial trunk lean and pelvis rotation, greater MLPFs, faster velocity profiles, greater PFC braking forces) could be an effective and simple training strategy for enhancing side-step cutting performance (5, 9, 23). For example, in male soccer players, six-weeks' COD speed and technique modification training focusing on earlier and greater PFC braking, trunk lean towards the intended direction of travel, and rapid and forceful push-off improved 70° side-cutting performance completion times and COD deficits (9). Acutely, modifying knee flexion range of motion (ROM) has shown to influence GCT and exit velocity during 45°side-step cutting (5), and 6-weeks' 180° COD technique modification training (PFC braking, backwards trunk inclination, and neutral foot position) improved completion times in female netballers (23). Although these results are promising, further research into the biomechanical effects of COD speed and technique modification training is required to assist in the development of more effective pitch- or court-based COD training programs for practitioners working in multidirectional sports.

The aims of this study were two-fold: 1) to evaluate the effectiveness of a 6-week COD speed and technique modification intervention on COD performance (completion time, GCT, and exit velocity) during 45° (CUT45) and 90° (CUT90) side-step cutting; and 2) to identify which kinetic and kinematic factors explain changes in performance. It was hypothesized that a COD speed and technique modification program would improve COD performance in multidirectional athletes, and changes in GCT, velocity at key instances of the COD, propulsive forces, knee flexion ROM, and pelvic rotation will explain improvements in performance.

METHODS

Experimental approach to the problem

A non-randomized, controlled 6-week intervention study with a repeated measures pre-to-post design was used (Figure 1). Male multidirectional sport athletes were recruited for the intervention group (IG) which consisted of a 6-week COD speed and technique modification training program (Supplemental digital content 1), consisting of two 30-minute sessions per week. Conversely, male multidirectional sport athletes acted as the control group (CG). Pre-to-post assessments of 45° and 90° cutting performance and COD biomechanics were assessed using three-dimensional (3D) motion and ground reaction force (GRF) analysis to monitor the effectiveness of the training intervention. Pre-and post-intervention testing was performed at the same time of day for each subject to control for circadian rhythm.

Insert Figure 1 here

Subjects

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

Sixteen males (soccer n = 12, rugby n = 4; age: 23.5 ± 5.2 years; height: 1.80 ± 0.05 m; mass: 81.6 ± 11.4 kg) were recruited for the IG. Conversely, fourteen men (soccer n = 9, rugby n = 4, field hockey n = 1; age: 22.2 ± 5.0 years; height: 1.76 ± 0.08 m; mass: 72.7 ± 12.4 kg) acted as the CG and continued their normal sport and resistance training sessions. The investigation was approved by the Institutional Ethics Review Board (HSR1617-131), and all subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved consent form to participate in the study. All subjects from both groups possessed at least five years' training experience in their respective sport and had never sustained a severe knee injury prior to testing. All subjects had minimum one years' resistance training experience, all performed two resistance training sessions a week and were all in a strength mesocycle. At the time of the training intervention, all subjects completed two skills sessions and played one competitive match a week. All of the procedures were carried out during the competitive season to ensure that no large physical changes were made as a result of the conditioning state . To remain as an active subject in the study and used for further analysis, subjects were not allowed to miss more than two of the 12 sessions in total (i.e., ≥ 83% compliance rate). Subsequently, due to match-related injuries or illness, one and two subjects withdrew from the IG and CG, respectively, resulting in sample sizes of 15 and 12

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

Procedures

The warm up, cut, marker placement, and 3D motion analysis and procedures were based on previously published methodologies (8, 24, 25, 28). In summary, each subject performed six trials of the 45° and 90° (5 m entry and 3 m exit) side-step cut (right limb push- off) as fast as possible and were provided with standardized footwear to control for shoe-surface interface (Balance W490, New Balance, Boston, MA, USA). Completion time was assessed using two sets of Brower timing lights placed at hip height at the start and finish (Draper, UT, USA), and subjects adopted a two-point staggered stance, 0.5 m behind the start line. Marker and force data were collected over the PFC and final foot contact (FFC) using ten Qualisys Oqus 7 (Gothenburg, Sweden) infrared cameras (240 Hz) operating through Qualisys Track Manager software (Qualisys, version 2.16 (Build 3520), Gothenburg, Sweden) and GRF's were collected from two 600 mm × 900 mm AMTI (Advanced Mechanical Technology, Inc, Watertown, MA, USA) force platforms (Model number: 600900) embedded into the running track sampling at 1200 Hz, respectively. Using the pipeline function in visual 3D, joint coordinate (marker) and force data were smoothed using a Butterworth low-pass digital filter with cut-off frequencies of 15 and 25 Hz, respectively, based on *a priori* residual analysis (39) and visual inspection of motion data. The kinematic model process was based on previous reported methodologies (8, 24, 25, 28). Lower limb joint moments were calculated using an inverse dynamics approach (39) through Visual 3D software (C-motion, version 6.01.12, Germantown, USA) and were defined as external moments and normalised to body mass. Joint kinematics and GRFs were also calculated using Visual 3D, while GRF braking and propulsive characteristics were normalised relative to body weight, with vertical, anterior-posterior, and medio-lateral corresponding to Fz, Fx, and Fy, respectively. Horizontal COM velocity profiles over key instances of the COD were calculated as described previously (24, 25).

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

<u>6-week COD speed and technique modification training intervention</u>

A six-week COD speed and technique modification intervention described in Supplemental digital content 1, was performed by the IG twice a week (30 minutes per session), with minimum 48 hours between sessions. The intervention was slightly adapted from a previously successful six-week COD speed and technique modification training intervention (9), which focused on pre-planned low intensity decelerations, cuts, and turns (weeks 1-2), before progressing intensity via velocity and angle (weeks 3-4) and introducing a stimulus with increased intensity (weeks 3-6) to increase complexity, target technique integrity (reinforce optimal technical), and to provide variation within the COD development framework (7, 11, 30). The COD program was in accordance with COD speed training recommendations (7, 13), and the duration, distances, and number of CODs were similar to previous research (9, 23). The sessions were led by the principle researcher who is a certified strength and conditioning specialist with extensive experience in coaching COD speed and agility drills. All sessions took place in the Human Performance Laboratory, on the same surface as used for 3D motion analysis. Athlete to coach ratios ranged from 5-8:1.

The COD technique modification intervention focused on three aspects outlined in Table 1 based on the success of a previous COD speed and technique modification and training recommendations (7, 9, 11, 23, 28). Subjects were given individual feedback regarding their technique, and external verbal coaching cues were used to promote faster performance and facilitate better motor skill retention (11, 32, 38).

Insert Table 1 here

Statistical Analyses

All statistical analyses were performed using SPSS v 25 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (version 2016, Microsoft Corp., Redmond, WA, USA). Normality was inspected for all variables using a Shapiro-Wilks test. A two-way mixed analysis of variance (ANOVA) (group; time) with group as a between-subjects factor measured at 2 levels (IG and CG), and time (pre- and post-training measures) the within-subject factor. This was used to identify any significant main (time) or interaction (group × time) effects for outcome variables between IG and CG, pre-to-post testing. A Bonferroni-corrected pairwise comparison design was used to further analyze the effect of the group when a significant interaction effect was observed for time and group. Partial eta squared effect sizes were calculated for all ANOVAs with the values of 0.010-0.059, 0.060-0.149, and ≥0.150 considered as small, medium, and large, respectively (4).

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

RESULTS

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

<u>CUT45: Pre-to-post changes in cutting biomechanical variables</u>

Insert Table 2 here

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

Insert Figure 2 here

Insert Table 3 here

<u>CUT90: Pre-to-post changes in performance biomechanical variables</u>

Insert Table 4 here

A large and significant interaction effect of time and group for CUT90 completion time was observed (Table 4), with the IG showing significantly faster post-intervention completion times ($p=0.031$, $g=-1.35$) compared to the CG. Additionally, a medium and non-significant interaction effect was observed for exit velocity (Table 4), with the IG showing significantly greater exit velocities ($p=0.035$, $g=0.83$) post-intervention compared to the CG. A large and moderate significant improvement was observed for completion time and exit velocity (Table 5 and Figure 3), respectively, for the IG only. Medium to large significant interaction effects of time and group were observed for CUT90 mean MLPF, peak and mean HPF, FFC mean HBF, FFC peak ADFM, IFPA, and knee and ADFA ROM (Table 4). Intervention group subjects produced significantly small to moderately greater peak ADFMs, greater peak and mean MLPFs, greater peak and mean HPFs, and greater FFC and PFC mean HBFs (Table 5). Additionally, IG subjects demonstrated significantly small to moderately greater forward trunk inclination angles, greater pelvic rotation angles, greater IFPAs, smaller KFA ROM, and greater ADFA ROM post-intervention (Table 5). Control group subjects produced significantly greater peak MLPFs and greater forward trunk inclination angles post-intervention only (Table 5).

Insert Figure 3 here

Insert Table 5 here

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

Improvements in CUT45 completion time were very largely associated with increased exit velocity; largely associated with decreased FFC GCT; and moderately associated with decreased KFA ROM, increased mean MLPF, and increased FFC velocity (Table 6). Additionally, CUT45 FFC GCT improvements were very largely associated with decreased KFA ROM; and largely associated with increased approach and exit velocity (Table 6). Finally, CUT45 exit velocity improvements were very largely associated with increased FFC velocity; and largely associated with decreased KFA ROM and FFC GCT, and increased approach velocity (Table 6).

Improvements in CUT90 completion time were largely associated with increased peak KFM, increased FFC peak HBF, and decreased PFC GCT; and moderately associated with increased ADFA ROM (Table 6). Additionally, CUT90 FFC GCT improvements were very largely associated with increased FFC velocity, and decreased hip and knee flexion ROM; and largely associated with increased exit velocity and lateral foot plant distance (Table 6). Finally, CUT90 exit velocity improvements were very largely associated with increased FFC velocity; largely associated with decreased FFC GCT, decreased HFA ROM, increased PFC mean HBF; and moderately associated with increased FFC peak KFM, and lateral foot plant distance (Table 6).

Insert Table 6 here

DISCUSSION

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

COD speed training has been reported to enhance COD completion time (9, 14); however, the technical and biomechanical mechanisms underpinning the improvements in COD performance are relatively unknown, and it is not fully understood whether the improvements in completion time were attributed to improvements in COD ability or linear speed (31). This study is one of the first to provide a novel insight into the mechanical and technical changes underpinning improvements in 45˚ and 90˚ cutting performance. Although clear improvements in cutting completion times were observed in the present study (Table 3 & 5, Figure 2-3), importantly shorter GCTs, greater propulsive forces, and enhancements in velocity at key instances of the COD were observed. Thus, these results confirm that the athletes' mechanical ability to COD has indeed improved via COD speed and technique modification training with external verbal cues. External cueing has been recommended for speed development (38) and has been shown to enhance COD performance (32), while promoting changes in side-stepping technique (2). Additionally, external cues are reported to be effective for motor skill development and retention (2, 11, 38). In the present study, we found the specific external cues, in addition to COD speed and technique modification training, "slam on the bakes", "cushion and push the ground away", and "face towards the direction of travel", to be effective in improving side-step performance and promoting favourable techniques and mechanics linked to faster performance (Table 3 & 5).

Importantly, the present study was able to explore some of the underlying technical and mechanical mechanisms responsible for enhanced cutting performance. The key and primary changes in cutting mechanics were as follows: increased velocity at key instances of the PFC and FFC, increased mean and peak propulsive forces in shorter FFC GCTs, reduced knee flexion ROM, and greater PFC mean HBFs (90° cut only) which were moderately to very largely associated with improvements in cutting performance (Table 6). The fact that the abovementioned variables were associated with improvements in COD performance are unsurprising because they have been identified as key determinants of faster COD performance (11, 13, 19, 27, 28, 37). For example, Hader et al. (18) demonstrated greater minimum velocities and velocity maintenance were strong determinants of faster 45˚ and 90˚ cut performance, thus increasing an athlete's ability to attain greater horizontal displacements in shorter times. Greater propulsive forces increase impulse which, based on the impulse-momentum relationship, leads to greater changes in momentum, thus velocity (11), and this was confirmed by the moderate association between MLPF changes and exit velocity (Table 6).

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

High propulsive forces (10, 19, 28, 33, 34, 36) over short GCTs (10, 27, 28, 34, 36, 37) are strong determinants of faster COD performance. The finding of increased propulsive force production in shorter GCTs following COD technique modification training is a positive outcome (Tables 3 & 5), and is similar to de Hoyo et al. (6) who found 10-weeks eccentric overload training resulted in likely to almost certain increases in relative peak braking and propulsive forces, shorter braking and propulsive times thus shorter GCTs, and increases in relative total and braking impulse during side-step cutting. Unfortunately, de Hoyo et al. (6) did not examine completion time or exit velocity; however, improvements in completion time training have been observed following flywheel eccentric training (17, 35); thus, it is speculated that the improved side-step kinetics from flywheel training should improve COD speed performance. Similarly, Bencke et al. (1) reported improvements in vertical propulsive force, GCT, and concentric phase duration following 12-weeks neuromuscular warm-up, corroborating the mechanism of improved completion time in the present study.

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

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

PRACTICAL APPLICATIONS

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

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

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