BODY ROTATION AFFECTS KNEE MECHANICS DURING SIDESTEP CUTTING… EVEN WHEN CONTROLLING FOR CHANGE OF DIRECTION ANGLE

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The effect of cutting technique on knee joint loading during change of direction (CoD) manoeuvres has been widely studied in the context of anterior cruciate ligament (ACL) injury. However, experimental inter-technique variation in the actual CoD angle achieved during the CoD step may affect results and influence conclusions. The purpose of this study was to compare cutting techniques with different amounts of torso rotation whilst experimentally controlling for CoD angle. Seven participants competed a 45° CoD task under three different cue conditions while ground reaction force and optical motion capture data were collected simultaneously. When CoD angle was controlled, techniques with greater body rotation in the direction of travel were generally associated with knee kinetics and kinematics that have been previously linked to lower ACL loading.

KEYWORDS: sidestep cutting; change of direction; ACL; knee

INTRODUCTION: Change of direction (CoD) manoeuvres are ubiquitous in team field sports and involve altering the direction the body is travelling in whilst, in many cases, also simultaneously rotating the body to face a new heading direction. As CoD is the single most common inciting event for non-contact anterior cruciate ligament (ACL) rupture, it has received considerable attention in the context of understanding how movement technique affects lower-limb musculoskeletal loading. In particular, a number of studies have focused on loading patterns associated with the positioning of the torso and the amount of body rotation towards the new direction of travel observed in the CoD step. The reason for this is multi-fold: (i) The torso is a relatively high-mass body segment and its positioning thus tends to have a substantial influence on musculoskeletal loading elsewhere in the kinetic chain (Frank et al., 2013); (ii) Body orientation has been highlighted as a feature of ACL rupture-inducing manoeuvres in observational studies (Della Villa et al., 2020); and (iii) Across the spectrum of sports in which CoD is a key determinant of performance, a variety of different requirements for body rotation and positioning during change of direction can be found – from a lateral step with virtually no body rotation to a complete 180° body rotation to reverse running direction.
Differentiation is often made between ‘sidestep’ tasks, in which the athlete changes the direction the body centre of mass (CoM) is travelling in without substantially altering the direction the body is facing (e.g. a sideways step to dodge a defender), and turns in which the body is rotated concomitant with the change in CoM direction of travel (e.g. a standard running cut to alter the direction of travel). An understanding of the differences in musculoskeletal loading in these two basic techniques would not only have impact for understanding the sport-specific demands of CoD manoeuvres and informing rehabilitation progression after injury but would also provide insight into how these two fundamental components of turning, rotating the body and redirecting the CoM, interact to determine the demands on the musculoskeletal system (Daniels et al., 2021). However, previous research on this topic has led to mixed findings: Tanikawa et al. (2013) reported greater peak knee extensor moments and lower peak external rotation moments in sidesteps than in turns with body rotation but did not identify any kinematic differences in knee joint motion, whilst Mok et al. (2018) found greater peak knee flexion, abduction and both internal and external rotation moments alongside greater peak knee abduction and internal rotation angles.
A potential explanation for these mixed findings is that CoM deflection angle (the angular change in the direction of travel of the CoM during the CoD step stance phase) is not typically controlled or monitored experimentally, and thus can vary systematically between conditions. As CoM deflection angle appears to have a substantial independent effect on lower-limb kinematics and kinetics (McFadden et al., 2024), it follows that any apparent observed differences between techniques may result from, or be confounded by, systematic differences in CoM deflection angles. For example, if athletes performing a ‘45 degree’ CoD manoeuvre

have a systematically lower CoM deflection angle when completing CoDs with body rotation than when completing sidestep CoDs, a researcher could erroneously conclude that differences in knee joint loading observed between the two conditions were a direct consequence of technique differences rather than simply reflecting the fact that the athlete was performing different angles of turn. It is already known that ‘target’ turn angles defined using lines or cones/timing gates in experimental studies correspond poorly to the actual CoM deflection that takes place in the analysed step (likely because participants distribute the turn across multiple gait cycles), and that the magnitude of error is affected by approach speed and target turn angle (Vanrenterghem et al., 2012), so it would not be surprising if the CoM deflection angle exhibited for a given target turn angle was also technique-dependent.
To address this issue, we developed an experimental set-up in which CoM deflection angle and approach speed could be monitored ‘live’ from trial to trial. This allowed us to conduct a study in which different CoD techniques could be compared at matched approach speed and CoM deflection angle, allowing experimental isolation of technique as a factor in lower-limb kinematic and kinetic differences between conditions. We hypothesised that the greater tri-planar peak knee moments previously reported for sidesteps in comparison with body-rotated turns would be observed even when CoM deflection angle was controlled. Support for this hypothesis would allow us to robustly conclude that the observed differences in joint loading were truly technique-dependent and not simply an artefact caused by variation in CoM deflection angle across conditions.

METHODS: Seven healthy able-bodied male participants (age 24 ± 2.9 years; height, 1.79 ± 0.06 m; body mass 66.9-124 kg; preferred kicking leg right = 6, left = 1) provided informed written consent and took part in the study. All regularly took part in a multidirectional field sport at a club/recreational level. Participants completed a standardised warm-up and then three blocks of experimental trials, each comprising a set of CoD trials in which the participant cut from their right leg and turned to the left after a 4 m run-up. The manoeuvre took place on a force platform (9677AA 900x1200, Kistler GmbH, Vienna, Austria) recording at 1000 fps and whole-body optical motion capture data were simultaneously captured at 250 fps by a 16-camera Vicon system (Nexus version 2.14, Vicon Motion Systems Ltd, Oxon, UK). Both CoM deflection angle and approach speed (instantaneous velocity of the CoM 1 m before reaching the near edge of the force platform) were extracted after each trial. Only trials in which approach speed was in the range 2.3-2.7 $m.s^{-1}$ and CoM deflection angle was in the range 40-55° were accepted. This was achieved by allowing the participant 1-3 initial practice trials in which feedback on speed was provided, and by positioning a cone for the participant to run towards that could be positioned as needed. In one block (non-cued cuts), no additional cues regarding body rotation were provided. In another block (sidesteps), the participant was instructed to ‘sidestep’ rather than rotating the body and only trials in which total pelvis rotation during stance phase was less than 15° were accepted. In the remaining block (body-rotated cuts), the participant was instructed to rotate the body in the new running direction during stance phase and only trials in which total pelvis rotation was 40-55° were accepted. Block order was randomised for each participant and two trials meeting all criteria were collected per block.
Data were filtered using a 4^{th} order zero-lag Butterworth filter with a corner frequency of 15 Hz then processed using the Vicon Plug-in Gait model to calculate knee kinematics, knee external joint moments, and the position of the body CoM. Peak knee angles and external moments in all three planes of motion were then extracted for further analysis. One-way repeated measures ANOVA models were used to test for the effect of technique (sidestep, body-rotated cut, non-cued) on the knee kinematic and kinetic variables (using the mean of the two trials per participant). Significance was accepted at $\alpha = .05$ and post-hoc tests conducted where a significant main effect was identified.

RESULTS: CoD technique affected peak knee flexion angle ($F(2,12) = 5.45$, $p = .02$), peak knee abduction angle ($F(2,12) = 4.69$, $p = .03$), peak knee internal rotation angle ($F(2,12) = 8.61$, $p = .005$), peak knee flexor moment ($F(2,12) = 15.29$, $p < .001$) peak knee abduction moment ($F(2,12) = 5.82$, $p = .02$) and peak knee external rotator moment ($F(2,12) = 5.90$, $p = .05$). Peak abduction angle was greater for sidesteps than for body-rotated cuts ($p < .001$). Sidestep cuts also had greater peak abduction moments ($p = .03$) and internal rotation angles ($p = .002$) than non-cued cuts, whilst body-rotated cuts had greater peak external rotator moments than non-cued cuts ($p = .01$). Both sidesteps and body-rotated cuts had greater peak flexion angles (sidesteps: $p = .01$; body-rotated cuts $p = .04$) and smaller peak extensor moments (sidesteps: $p = .03$; body-rotated cuts $p = .001$) than non-cued cuts.

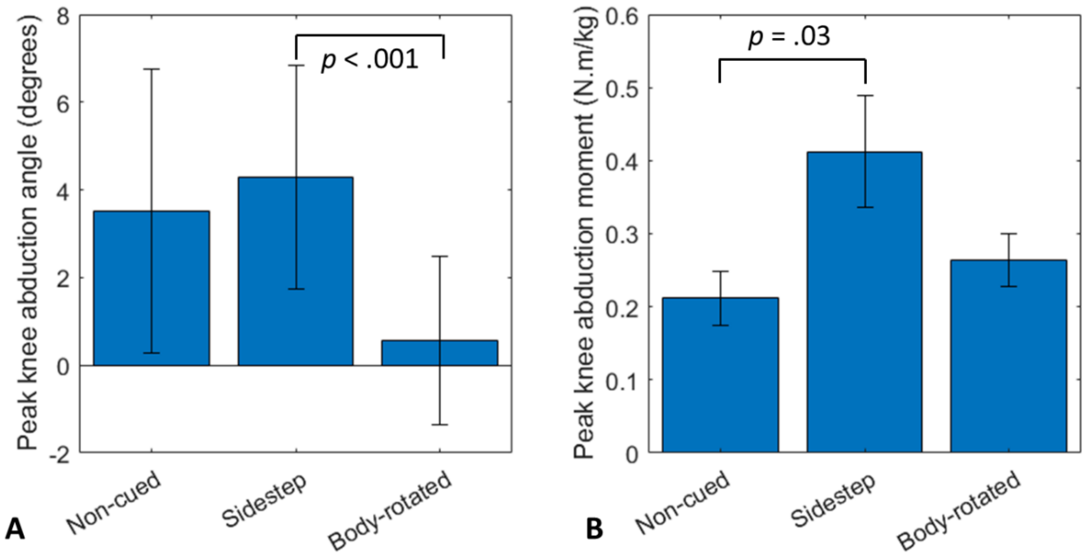

Figure 1: Peak knee abduction angle (A) and moment (B) during change of direction step stance phase for each of the three technique conditions. Error bars represent standard error of the mean.

DISCUSSION: Differences in tri-planar knee angles and moments were evident in a 45° cutting task even when CoM deflection angle during stance phase and approach speed were controlled experimentally. Sidestep cuts had greater peak abduction angles, peak abduction moments and peak internal rotation angles than at least one of the other conditions, suggesting that this technique may be associated with greater ACL loading and potentially injury risk for a given speed and CoM deflection angle, whereas body-rotated cuts were associated with mechanics that may be associated with a reduction in ACL loading. Both technique-cued conditions resulted in greater peak knee flexion angles and smaller peak extensor moments than the non-cued condition.

We note that we had to adjust the position of the 'target' cones defining the exit direction for the different technique conditions in order to achieve comparable CoM deflection angles during the CoD step stance phase, which suggests that experimental standardisation of CoD angles simply using floor markings/cones/timing gates would be expected to lead to systematic differences in 'actual' CoD angle when different techniques are compared. Given the known independent effects of CoD angle on lower-limb joint mechanics (e.g. McFadden et al., 2024), we thus suggest that CoM deflection angle is monitored and reported in any experimental or clinical context for which interpretation of results may be confounded by these differences.

We collected data from a convenience sample of male club/recreational field sport athletes so our findings cannot necessarily be extrapolated to female and/or elite-level athletes. We also constrained the analysis to manoeuvres with a CoM deflection angle of 40-55°, so more or less acute CoDs may have elicited different responses, as may reactive rather than pre-planned CoDs. An additional limitation of our study is that the CoM deflection and body rotation angle requirements were relatively broad, spanning 15° for each condition, to minimise the number of trials that needed to be repeated. In combination with the relatively low sample size, this may have limited the power of our analysis. Finally, the cued techniques were almost certainly less familiar to the participant than the non-cued technique. Whilst we did not observe any

apparent learning effect during the data collection session, it is possible that we would have obtained different results if participants had been given a more extended familiarisation period for the sidestep and body-rotated conditions.
It is interesting to note that the two cued conditions were both associated with greater peak knee flexion angles and smaller peak extension moments than the non-cued condition, despite the non-cued condition falling 'in between' the two cued conditions in terms of required body rotation. We might speculate that both cues led to a more internally directed focus of attention during the sidestep and body-rotated condition trials than the non-cued trials, and this had an additional independent effect on the mechanics of the manoeuvre. Focus of attention (internal *vs* external) has previously been shown to affect intersegmental coordination and mechanics for other multi-joint lower limb tasks (e.g. Harry et al., 2019) so it may be that a similar phenomenon was observed in our study.

CONCLUSION: We found that, for a given CoM deflection angle range, turns with less body rotation in the direction of travel during the CoD step stance phase were associated with lower peak knee abduction angles and moments - and thus potentially with lower ACL loading. Practitioners may wish to consider the greater non-sagittal plane joint loading introduced by sidesteps without rotation of the body towards the new direction of travel when designing return-to-sport pathways or attempting to relate movement techniques to knee injury risk in their athletes. From a methodological perspective, we note that different CoD exit pathways needed to be specified for the different techniques in order to achieve comparable CoM deflection angles. Thus, we recommend that 'actual' rather than just 'target' CoD angles (mean and SD) are recorded and reported in any situation whereby interpretation of results may be affected. Future work should explore how these effects are manifested across other lower-limb joints (hip and ankle) and whether they are consistent at different approach speeds and CoD angles.

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