ON-FIELD ASSESSMENT OF CHANGE-OF-DIRECTION (COD) MOVEMENTS: ADAPTATION IN LEG AND TRUNK POSTURE THROUGHOUT A COD SEQUENCE

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This study investigated adaptations in change-of-direction (COD) movement strategies throughout a sequence of maximum-speed CODs in an on-field testing scenario that involved complex decision making and limited time for motor preparation. Twenty soccer players completed randomized sequences of pre-planned and unplanned 45°-135° CODs and their joint movements were tracked using inertial measurement units. For 90°-135° turns, the last vs. first CODs showed a more extended knee and rotated trunk at initial contact. These kinematic features may reflect insufficient time to prepare for the ground contact of a COD that immediately follows a previous COD and are more consistent with postures observed during non-contact ACL injuries. Testing COD sequences rather than isolated CODs may be more sensitive for detecting ACL injury-prone movement strategies.

KEYWORDS: knee injury, sidestepping, wearable sensors, inertial motion capture

INTRODUCTION: Ruptures of the anterior cruciate ligament (ACL) often occur during rapid change-of-direction (COD) maneuvers in multi-directional sports with no or indirect contact to an opponent (Chia et al., 2022). At the initial contact of the affected leg, athletes have been observed to demonstrate typical injury-prone kinematic patterns, which are thought to increase knee joint forces and the strain experienced by the ACL (Beaulieu et al., 2023). In soccer, these kinematic risk factors include – among others – more-than-normal knee extension and hip abduction as well as lateral trunk tilt and rotation (Della Villa et al., 2020). Consequently, standardized laboratory tests are often used to study whole-body movements and knee joint loading during high-speed COD movements and learn how the kinematic pattern adapts to certain interventions, e.g. neuromuscular training (Mohr et al., 2024).
Although valuable from a study design perspective, the laboratory environment has important limitations when trying to gain deeper insight into the ACL injury mechanism: First, kinematic patterns during CODs – particularly at the initial contact – are significantly different when observed on-field compared to in a laboratory (Di Paolo et al., 2023), likely due to the pre-defined movement path, constrained foot placement, and the missing environmental context in the laboratory. Second, although previous lab-based investigations have included divided attention and decision-making paradigms, the constrained laboratory space usually limits the number of COD choices to two or three (Hughes & Dai, 2021), which likely falls short of on-field CODs. Third, lab-based investigations are usually based on isolated repetitions of a single COD movement sequence, i.e. run-up, COD, and exit towards some target. During match play, however, high-speed movements such as CODs do not typically occur in isolation but are part of so-called ‘worst-case scenarios’, which are short time periods that involve repeated high-speed sprints, CODs, and tackles (Johnston et al., 2014). It is conceivable that an isolated COD movement as tested in the laboratory may not adequately reflect the on-field situation where the athletes’ attention is still on the previous high-effort movement with limited time and attentional resources to plan for the subsequent movement (Gokeler et al., 2023). Consequently, CODs that immediately follow preceding high-intensity movements may show abnormal timing and coordination of preparatory movements for ground contact and result in an initial contact posture that is more prone to ACL injuries (Hughes & Dai, 2021).

The purpose of this study was to overcome the above limitations and investigate COD kinematic patterns in soccer players during an on-field COD protocol that involves a sequence of repeated COD movements, complex decision-making with multiple angle and direction options, and reduced constraints on the athletes’ foot placement during the CODs. We hypothesized that during both pre-planned and unplanned conditions and across COD angles, the last COD within a movement sequence would show a posture at initial contact that is most consistent with the ACL injury-prone kinematic pattern described above.

METHODS: Twenty male recreational soccer players (mean±SD: 24±3 years old, 74±6 kg body mass, 180±5 cm height, 17±2 years of experience with COD movements) volunteered and provided written informed consent to participate in this study. All participants completed multiple COD movement sequences on an artificial turf field on two separate days; a first day to familiarize with the COD protocol and a second day for the actual measurements. On the second day, each player performed a total of twelve COD sequences at their maximum speed, alternating between pre-planned and unplanned sequences. Each COD sequence consisted of three COD maneuvers: A first COD (45°, 90°, or 135°), a second 180° COD, and the last COD (45°, 90°, or 135°). The order of COD angles was balanced randomized such that every player performed each COD angle at least once per anticipation condition and per COD number (first vs. last). For pre-planned sequences, players knew all three COD angles in advance. For unplanned sequences, players received an auditory signal (color of a target cone) at a distance of 3 m from the designated COD area (diameter of 0,7 m). For a successful COD sequence, players had to complete the first and last COD into the correct direction and place at least one foot into the center circle. During all sequences, player movements were tracked with IMU sensors (Noraxon Ultium Motion) secured to the left and right foot, shank, thigh as well as the sacrum and upper back. Knee flexion, hip abduction, trunk lateral tilt (towards the stance leg), and trunk rotation (towards the stance leg) traces were computed with Noraxon myoResearch® software. The initial contact of the dedicated sidestepping foot was estimated according to a peak in the foot resultant acceleration. Linear mixed effects models ($\alpha = 0.05$) with the fixed factors 'angle' (45°, 90° ,135°), 'number' (first vs. last COD), and 'angle x number' interaction and the random factor 'player' were used to investigate systematic changes in the above joint angles at initial contact with varying COD angle and COD number. In the presence of significant interaction effects, we conducted post-hoc comparisons based on simple effects analyses of the factor 'number' with the moderator variable 'angle'.

RESULTS: There were significant 'angle x number' interaction effects with respect to the initial knee flexion angle for both pre-planned ($F(2,211) = 7.21$, $p < 0.001$, Fig. 1a) and unplanned ($F(2,215) = 6.73$, $p = 0.001$, Fig. 1b) COD sequences. For both conditions post-hoc comparisons showed that players were in significantly more knee extension in the last vs. first COD for the 90° (pre-planned: $p = 0.009$; unplanned: $p < 0.001$) and 135° (pre-planned: $p = 0.002$; unplanned: $p = 0.023$) but not the 45° angle (pre-planned: $p = 0.096$; unplanned: $p = 0.525$).
There were significant main effects of 'number' on the initial trunk rotation angle for both pre-planned ($F(1,212) = 6.96$, $p = 0.009$, Fig. 1g) and unplanned ($F(1,212) = 8.86$, $p = 0.003$, Fig. 1h) COD sequences. On average, players contacted the ground with more trunk rotation towards the stance leg during the last vs. first COD for all COD conditions.
There were no further significant main effects of 'number' nor significant 'angle x number' interaction effects with respect to initial hip abduction or trunk lateral tilt. There were significant main effects of 'angle' on the initial hip abduction (Fig 1c-d), initial trunk lateral tilt (Fig. 1e-f), and initial trunk rotation (Fig. 1g-h) for both pre-planned and unplanned conditions. Given that the angle comparisons were not the main focus of this analysis, we omitted the statistical results.

DISCUSSION: This study investigated adaptations in COD movement patterns between the first and last movement in a sequence of three maximum-speed CODs within a complex on-field COD protocol allowing for six different combinations of COD angles and directions. At the initial contact of the last COD vs. first COD, we observed a more extended knee during 90° and 135° CODs and more trunk rotation towards the stance leg (opposite to the movement direction) across all COD angles. A more extended knee and increased trunk rotation during the initial contact phase of CODs are thought to increase the risk of ACL injury as these kinematic features can increase knee shear forces and valgus moments, respectively (Beaulieu et al., 2023; Critchley et al., 2020). Therefore, our findings support our hypothesis that the initial posture during the last COD of a movement sequence is more consistent with ACL injury-prone kinematic patterns compared to the first COD of a movement sequence.

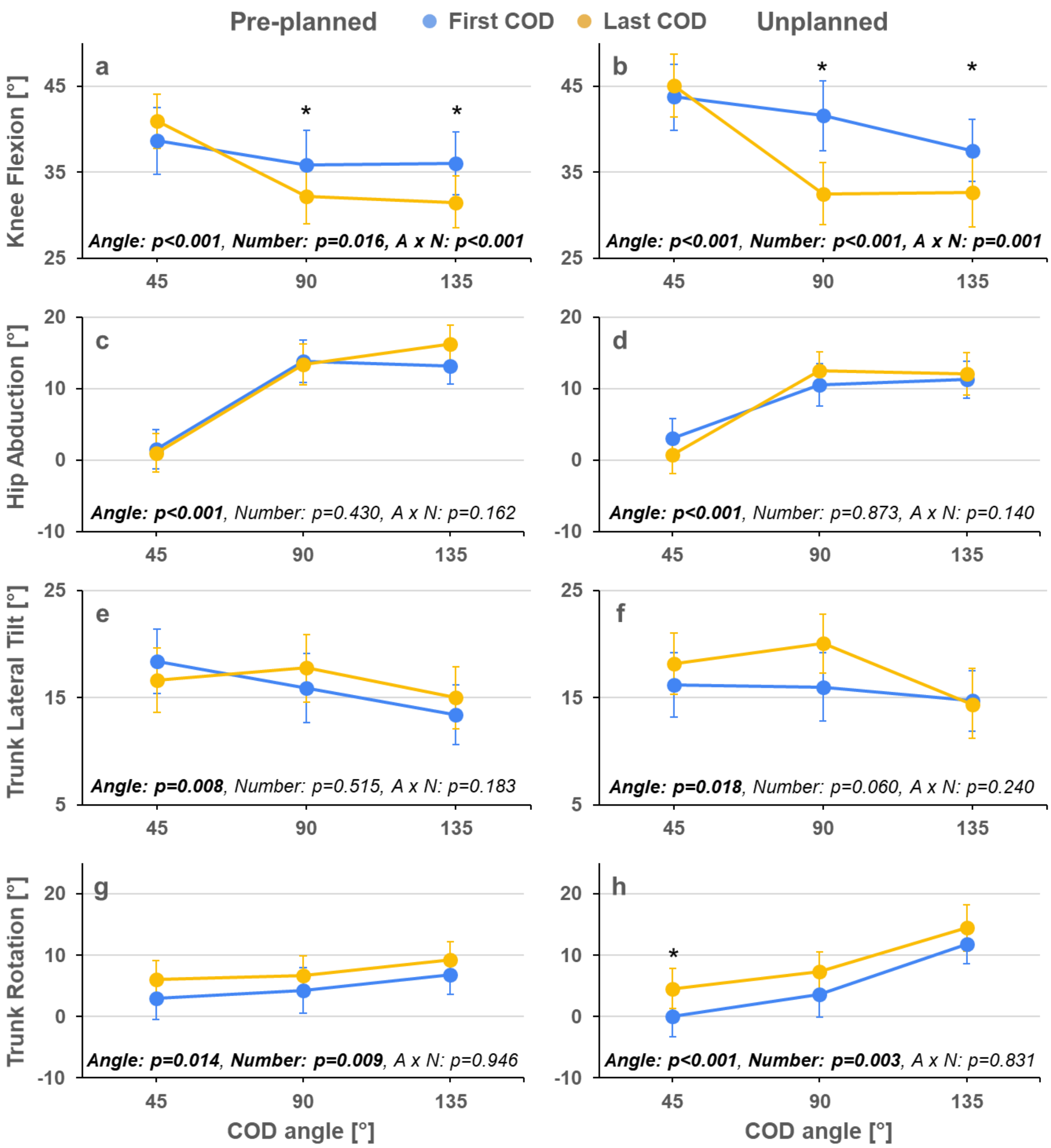

Figure 1: Initial knee flexion (a,b), hip abduction (c,d), trunk lateral tilt (e,f), and trunk rotation (g,h) as a function of COD angle during the first (blue) and last (orange) COD of pre-planned (a,c,e,g) and unplanned (b,d,f,h) COD sequences. Dots and error bars represent estimated marginal means and 95% confidence intervals from the underlying linear mixed effects models. Main and/or interaction effects of COD number (N) and angle (A) are listed in each figure panel. Asterisks mark significant pairwise differences between the first and last COD for a given COD angle.

Our proposed mechanism for the observed adaptations was that the time and cognitive resources available for motor planning and preparatory movements for ground contact is reduced during a COD that immediately follows a previous high-intensity motion (i.e. our last COD) compared to an isolated COD (i.e. our first COD). While our findings do not dismiss this mechanism, it was a surprising observation that the adaptations from first to last COD were consistent between pre-planned and unplanned COD sequences. One prediction of the proposed mechanism would be that the last vs. first COD should show even more pronounced kinematic adaptations in an unplanned vs. pre-planned scenario given a further reduction of time for preparing the COD ground contact. This trend is not apparent in our data. One possible explanation for this could be that the main cognitive challenge for players during the run-up to the last COD was to regain spatial orientation after the preceding 180° COD and that this cognitive challenge drove the observed kinematic adaptations irrespective of the knowledge about the subsequent movement direction. A current limitation of our study is that we monitored the COD approach speed only for the first but not last COD. A reduction in COD approach speed during the last vs. first COD, e.g. due to fatigue, could act as a confounding variable – at least with respect to the observation of a more extended knee. Apart from this, systematic changes in IMU-based joint angles over time could be due to insufficient drift correction within the underlying IMU sensor fusion algorithms rather than due to motor control reasons. However, given that such drift effects should be independent of the executed COD angles, this explanation may only apply to differences seen in trunk rotation (see Figure 1g & 1h).

CONCLUSION: In a sequence of three high-intensity COD movements, the last movement compared to the first movement showed increased knee extension and trunk rotation opposite to the intended movement direction during the initial contact phase of pre-planned and unplanned 90° and 135° CODs. These kinematic features may result from insufficient time to prepare for the ground contact during a COD that immediately follows a previous COD and are more consistent with initial contact postures commonly observed during non-contact ACL injuries. These findings suggest that movement screenings for detecting ACL injury-prone movement strategies during COD may be more sensitive when based on a sequence of COD maneuvers rather than isolated movements.

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