Male and female soccer players exhibit different knee joint mechanics during pre-planned change of direction

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Change of direction manoeuvres are important in soccer and associated with non-contact anterior cruciate ligament injury, yet it is not known how the mechanics differentiate between males and females during 180° turns. Twenty-eight soccer players (14 male and 14 female) performed 180° turns with ground reaction forces collected over penultimate and final contacts. A two-way (contact x limb) multivariate analysis of variance (MANOVA) were run to examine differences between contact (penultimate and final) or limb (dominant and nondominant) for sagittal plane hip, knee and ankle peak angles and moments, and frontal plane knee abduction moments and angles between sexes. Average horizontal GRF was increased on the dominant limb, compared to nondominant and for the final contact compared to the penultimate contact. Knee abduction angles were increased in females compared to males, while the opposite was true for knee abduction moments. Statistically significant differences were evident, with increases in peak vertical GRF, peak hip flexion angle, peak knee flexion angle, peak knee extensor moment, and peak ankle dorsiflexion angle observed in the penultimate contact compared to final contact. The results indicate the penultimate contact during turns helps reduce loading on the final contact, yet male and female soccer players exhibit different knee joint mechanics during pre-planned change of direction.

Keywords: word; agility; anterior cruciate ligament; turns; injury; knee abduction moments, 180° turns

Introduction

It has previously been observed that female players have higher rates of non-contact anterior cruciate ligament (ACL) injuries compared with males (Myklebust, Maehlum, Holm, & Bahr, 1998). There is also evidence that knee joint mechanics are differentiated by sex during change of direction (CoD) tasks (cutting and turning), contributing to increased risk of ACL injury (Brophy, Silvers, Gonzales, & Mandelbaum, 2010; McLean, Huang, & van den Bogert, 2008; Sigward, Pollard, & Havens, 2012). Several studies have shown that females display increased knee abduction angles (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; McLean, Lipfert, & van den Bogert, 2004), knee abduction moments (McLean, Huang, & van den Bogert, 2005; McLean et al., 2004; Sigward, Cesar, & Havens, 2015; Sigward et al., 2012), vertical ground reaction forces (GRFs) (Yu, Lin, & Garrett, 2006) and smaller knee flexion angles (Malinzak et al., 2001; McLean et al., 2004; Yu et al., 2006) as compared with their male counterparts during cutting and turning. Moreover, video analysis studies have revealed postures at initial contact such as a dorsiflexed ankle (Boden, Torg, Knowles, & Hewett, 2009), abducted hip (Olsen, Myklebust, Engebretsen, & Bahr, 2004), extended knee joint (Boden et al., 2009; Krosshaug et al., 2007; Olsen et al., 2004), and laterally flexed and rotated torso (Stuelcken, Mellifont, Gorman, & Sayers, 2016) to be associated with ACL injuries during CoD. Similarly, laboratory studies have found these lower limb postures to increase knee abduction moments (Dempsey, Lloyd, Elliott, Steele, & Munro, 2009; Jones, Herrington, & Graham-Smith, 2016a, 2016b), which could lead to increased ACL strain (McLean, Su, & van den Bogert, 2003) and subsequent injury (Hewett et al., 2005).

Previous studies have investigated the influence of sex on CoD biomechanics (Fedie, Carlstedt, Willson, & Kernozek, 2010; McLean et al., 2005, 2004; Sigward et al., 2015, 2012). Pollard et al. (2018) demonstrated healthy male and female participants exhibit similar lower extremity biomechanics during a 45° side-step. These contrasting findings may be due to inconsistency in how the dominant limb is defined, or the velocity and magnitude of the CoD. For example, sex differences in knee abduction moments during 110° turns have been observed, with females greater than males, but no differences were observed in 45° cuts (Sigward et al., 2015). Similarly, females were found to exhibit increased knee valgus angles and internal knee adductor moments during 45 and 110° cutting when compared with males (Sigward et al., 2012). Sharper CoD (i.e. 180° turns) increase the relative lower body loading compared to shallow CoD (<60°) and thus, require substantial braking over several footfalls prior to push-off. Previous work found lower knee flexion angles, yet higher knee abduction angles during a 180° turn compared to a 45° cut (Cortes, Onate, & Van Lunen, 2011), while reductions in knee flexion angle have been observed with sharper CoDs (Schreurs, Benjaminse, & Lemmink, 2017). Furthermore, the knee joint has been found to play a primary role during the deceleration phase of shaper CoDs (Havens & Sigward, 2015a). Further studies on the kinetics and kinematics during turning between male and female soccer players are required to fully understand the biomechanical requirements of 180° CoD and help optimise CoD performance and minimise knee joint loading.

It has been previously observed that up to 70% of non-contact ACL injuries occur during a cutting or CoD maneuver (Boden, Feagin, & Garrett, 2000; Boden, Sheehan, Torg, & Hewett, 2010). Previous research (Brophy et al., 2010), suggests limb dominance (kicking vs. support limb) to influence knee joint mechanics and ACL injury, specifically in soccer players. Although non-contact ACL injuries were evenly distributed (kicking limb = 30; support limb = 28), 74% (20/27) of males suffered a non-contact ACL injury on the kicking limb, compared with 32% (10/31) of females. There have been several studies in the literature reporting the influence of limb dominance on CoD biomechanics (Bencke et al., 2013; Brown, Wang, Dickin, & Weiss, 2014; Greska, Cortes, Ringleb, Onate, & Van Lunen, 2016; Marshall et al., 2014; Mok, Bahr, & Krosshaug, 2018; Pollard et al., 2018), and can be defined as the preferential use of one side of the body when performing a motor task, typically resulting in a more skilful and therefore dominant side (Maloney, 2019). For example, the preferred limb to kick a ball in soccer or change direction is typically used to indicate limb dominance, and as such, could provide coaches and researchers information whether a limb is at heightened risk of increased loading, and thus potential for injury, or not. Early work shows no differences in knee joint mechanics (knee flexion angle, knee abduction angle, knee internal rotation angle, and knee abduction moment) during weight acceptance between preferred and non-preferred limbs in female soccer players (Brown et al., 2014). In contrast, 20 collegiate female soccer players were found to exhibit similar CoD biomechanics (hip and knee moments, and GRFs) between dominant kicking) and nondominant (support) limbs (Greska et al., 2016). Moreover, the dominant limb displayed increased peak knee flexion angles, increased peak internal knee abduction moments, and increased peak vertical GRFs, while the nondominant limb exhibited increased knee abduction angles at initial contact and peak value and increased vertical GRF at peak knee abduction moment. Recently, Thomas et al., (2017) reported that female soccer players adopt different braking strategies between dominant and nondominant limbs in 180° turns, whereby increased horizontal braking force is placed on the penultimate contact by the nondominant limb when turning off the dominant limb. Conversely, an increased force is placed on the final contact when turning off the nondominant limb.

Improving our understanding of limb dominance during CoD may provide further insight into the potential mechanisms of increased loading and help drive performance and injury prevention programmes. Therefore, the primary aim of this study was to investigate differences in kinematics (lower-limb joint angles) and kinetics (GRFs and moments) in the sagittal and frontal planes, between males and females during 180° turns. The secondary aim was to investigate differences in braking strategy (penultimate vs. final contact) on the dominant vs. nondominant limbs during 180° turns in male and female soccer players. Finally, this study aimed to explore kinematic and kinetic differences between penultimate and final contact of 180° turns. It was hypothesised that female players would exhibit increased knee abduction angles and knee abduction moments compared to males (Sigward et al., 2015, 2012). Furthermore, it was hypothesised that female soccer players would demonstrate increased horizontal GRF during the final contact when turning off the nondominant limb (Thomas et al., 2017). It was hypothesised that the penultimate contact would demonstrate increased knee joint flexion angles, peak horizontal GRF, but lower average horizontal GRF during compared to the final contact (Jones et al., 2016b)

Methods

Participants

This study included 28 male (*n* = 14; age = 24.5 ± 4.2 years; height = 1.79 ± 0.05 m; body mass = 78.5 ± 9.6 kg) and female (*n* = 14; age = 20.6 ± 0.6 years; height = 1.65 ± 0.07 m; body mass = 56.2 ± 6.6 kg) soccer players. All participants were of semi-professional level and did not suffer from an ACL injury in the past, or any other lower-limb injury within the last 6 months. Each player was in the preseason phase of training during his or her participation in this study. All participants read and signed a written informed consent form before participation, with consent from the parent or guardian of all participants under the age of 18. Approval for the study was provided by the University of Salford's Institutional Ethics Committee.

Experimental Protocol

Lower-limb kinetic and kinematic data were collected during 180° turns (505 CoD test), performed as fast as possible, on an indoor track (Mondo, SportsFlex, 10 mm; Mondo America Inc., Mondo, Summit, NJ, USA). The 505 involved running towards two force platforms, whereby the first force platform was used to measure GRFs from the penultimate foot contact (2nd to last foot contact with the ground during a pivot before moving into a new intended direction), whilst the 2nd force platform was used to measure

GRFs from the final contact (last foot contact with the ground during a pivot before moving into a new intended direction). Players were instructed to sprint to a line marked on the central portion of 2nd force platform, 15 m from the start, planting their left or right foot on the line, turn 180° and sprint back 5 m through the finish. Prior to maximal trials participants performed at least 3 submaximal trials, turning off each limb at 75% of perceived maximum effort. Players performed a minimum of six acceptable trials (3 left and 3 right) in a randomised and counterbalanced order. If participants slid, turned prematurely, or missed the force platform, the trial was discarded and subsequently performed after a 2-minute rest.

Before the turn task, reflective markers (14 mm spheres) were placed on the following bony landmarks: right and left iliac crests; anterior superior iliac spine; posterior superior iliac spine; greater trochanter; medial epicondyle; lateral epicondyle; lateral malleoli; medial malleoli; heel; and fifth, second, and first metatarsal heads using double-sided adhesive tape. Each player wore a four-marker 'cluster set' (four retroreflective markers attached to a lightweight rigid plastic shell) on the right and left thigh and shin which approximated the motion of these segments during the dynamic trials. All participants wore lycra shorts and female participants wore a compression top (Champion Vapor, Champion, Winston-Salem, NC, USA). Standardised footwear (Balance W490, New Balance, Boston, MA, USA) was provided for all participants to control for shoe-surface interface.

Data Analysis

3D motions of these markers were collected during the turn trials using 10 Qualisys Oqus 7 (Gothenburg, Sweden) infrared cameras (240 Hz) operating through Qualisys Track Manager software (Qualisys, version 2.16, build 3520, Gothenburg, Sweden). The GRFs were collected from two 600 mm x 900 mm AMTI (Advanced Mechanical Technology, Inc, Watertown, MA, USA) force platforms (Model number: 600900) embedded into the running track, sampling at 1200 Hz. From a standing trial, a lower extremity and trunk 6 degrees of freedom kinematic model was created for each player, including pelvis, thigh, shank and foot using Visual3D software (C-motion, version 6.01.12, Germantown, USA). This kinematic model was used to quantify the motion at the hip, knee and ankle joints using a Cardan angle sequence x–y–z (Grood & Suntay, 1983). The local coordinate system was defined at the proximal joint centre for each segment. The static trial position was designated as the subject's neutral (anatomical zero) alignment, and subsequent kinematic measures were related to this position. Segmental inertial characteristics were estimated for each participant (Dempster, 1955). The model used a CODA pelvis orientation (Charnwood Dynamics Ltd., Leicestershire, UK) (Bell, Brand, & Pedersen, 1989) to define the location of the hip joint centre. The knee and ankle joint centres were defined as the mid-point of the line between lateral and medial markers. Lower limb joint moments were calculated using an inverse dynamics approach (Winter, 2009) through Visual3D software and were defined as external moments.

The trials were time normalised for each subject, for ground contact time of the turn task. Initial contact was defined as the point after ground contact that the vertical GRF was higher than 20 N and end of contact was defined as the point where the vertical GRF subsided past 20 N for both penultimate and final contact. The weight acceptance phase of ground contact was defined as from the instant of instant contact (vertical GRF >20 N) to the point of maximum knee flexion during ground contact as used previously (Havens & Sigward, 2015b; Jones et al., 2016b; Jones, Thomas, Dos'Santos, McMahon, & Graham-Smith, 2017). Joint coordinate and force data were smoothed in Visual3D with a Butterworth low pass digital filter with cut-off frequencies of 12 and 25 Hz, respectively. Cut-off frequencies were selected based on *a priori* residual analysis

(Winter, 2009) and visual inspection of the motion data.

For comparisons between penultimate and final contact, peak and average vertical (Fz) and horizontal (Fx) GRFs were determined along with peak hip, knee and ankle dorsiflexion angles and peak hip, knee and ankle moments in the sagittal plane during the weight acceptance phase, and analysed in Microsoft Excel (version 2016, Microsoft Corp., Redmond, WA, USA). Furthermore, peak knee abduction angles and knee abduction moments were calculated during the final contact. Joint moment data were normalised to body mass (Nm/kg). To evaluate the deceleration strategy from penultimate to final contact, a final contact/penultimate contact horizontal (Fx component) horizontal GRF ratio was also calculated (Jones et al., 2016b). In line with recent research (Dos'Santos, Comfort, & Jones, 2020), data were analysed based on the average of trial peaks.

Statistical Analyses

Data are presented as either mean ± *SD*. Normality of data was assessed by Shapiro-Wilk's statistic, while homogeneity of variances was examined using Levene's test. A two-way (contact x limb) multivariate analysis of variance (MANOVA) was used to determine if differences exist between foot contact (penultimate and final) or limb (dominant and nondominant) and between sexes (male and female) when considering all dependent variables in the sagittal plane. Separate 2 × 2 (limb × sex) repeated-measures ANOVA were run to examine differences in completion time, horizontal GRF ratio, knee abduction angles and knee abduction moments. Where significant differences were found, Bonferroni post hoc analyses were completed to detect differences between groups. The dominant limb was defined as the limb with the fastest time to completion during CoD. All statistical analyses were performed in the Jamovi Project for Windows (Jamovi Project, 2019) and the criterion for statistical significance was set at $p \leq 0.05$.

Results

Table 1 shows repeated measures ANOVAs for force-time characteristics, while Table 2 shows repeated measures ANOVAs for sagittal and frontal plane peak joint angle and moment data.

The average approach speed for males (5.2 ± 0.3 m/s) was significantly faster ($p < 0.001$) than females (4.7 ± 0.3 m/s). A significant difference ($p < 0.001$) in completion time was observed between limbs whereby the dominant limb was faster than nondominant. Average horizontal GRFs were increased ($p = 0.013$) for dominant limb compared with nondominant.

A significant difference ($p = 0.034$) in average horizontal GRF ratio was observed between sexes, with females demonstrating an increased ratio than males. There was no other statistically significant main effect or interaction for both average and peak horizontal GRF ratio.

** Insert Table 1 around here **

For the variables peak hip flexion angle, peak vertical GRF, peak knee flexion angle, peak knee extensor moment and peak ankle dorsiflexion angle, although an interaction was not present, there were main effects for contact, indicating increased values in the penultimate compared to final contact when both sexes were combined. Yet, the opposite was true for peak plantarflexor moment whereby values were increased in the final contact compared to penultimate contact. There was no main effect or interaction present for the variable peak horizontal GRF.

** Insert Table 2 around here **

A significant difference ($p < 0.001$) in peak knee abduction angle was observed between sexes, with females demonstrating increased angles than males. In contrast, peak knee abduction moments were significantly ($p = 0.012$) increased for males compared to females. Furthermore, significant differences ($p = 0.006$) were noted between males and females in peak hip flexion angle, with males demonstrating increased values than females. When considering completion time, males were significantly faster ($p <0.001$) compared to females.

Discussion and Implications

Although previous studies have considered the influence of the limb dominance on knee injury risk factors during pre-planned tasks (Brown, Donelon, Smith, & Jones, 2016; Brown et al., 2014; Greska et al., 2016), this is the first study to evaluate the interaction of penultimate and final contact on such factors in both males and females. This is important given that turning movements are common in both sexes (Bloomfield, Polman, & O'Donoghue, 2007; Boden et al., 2010; Brophy et al., 2010). The aims of this study were to: (1) evaluate sex differences in lower-limb kinetics and kinematics between males and females during 180° turns, (2) compare lower-limb kinetics and kinematics between dominant and nondominant limbs, and (3) explore kinetic and kinematic differences between penultimate and final contacts of 180° turns. The most striking result to emerge from the data is that females demonstrated increased knee abduction angles compared to males ($p <0.001$), but the opposite was evident when analysing knee abduction moment ($p = 0.012$). Consistent with previous research, these results suggest that CoD biomechanics are sex-specific and thus, should be interpreted accordingly when informing training and injury prevention interventions. Specifically, practitioners must acknowledge from a technique perspective the 'performance-injury conflict' when coaching and performing CoD, ensuring players have optimal CoD mechanics and physical capacity to tolerate the associative knee joint loading.

Our primary finding was that knee abduction angles were increased in females compared to males, whereas knee abduction moments were increased in males compared to females. This is in agreement with previous work whereby increased knee abduction angles were observed in females compared to males (Sigward et al., 2015), yet in the same study, females exhibited increased knee abduction moments, which is in contrast to our findings. A possible explanation for this might be that Sigward et al. (2015) used a 110° side-step whilst the current study used a 180° turn. Recent work (Schreurs et al., 2017) indicates knee valgus moments tend to stabilise when changing direction to magnitudes >90° in both males and females. It could be that athletes subconsciously restrain this moment from becoming increased when changing direction to increased magnitudes (90-180°). Yet, the male players in the current study demonstrated significantly ($p < 0.001$) faster time to completion than females, due to faster average approach speeds, thus likely contributing to great knee abduction moments. This is in agreement with previous research reporting increases in knee abduction moments from faster running velocities during 60° (Kimura & Sakurai, 2013) and 135° (Nedergaard, Kersting, & Lake, 2014) CoD. This finding has important implications for developing performance and injury prevention programmes. Specifically, faster and sharper CoD increase knee joint loading but are also required for successful performance to evade or close an opponent; thus, causing a performance-injury conflict from a technique perspective (Dos'Santos, Thomas, Comfort, & Jones, 2018), but can be mediated by an athlete's physical capacity. Further research might explore the influence physical capacities (strength and power measures) on lower-limb kinetics and kinematics, as this may help drive sex-specific CoD and ACL prevention programming.

This study has shown that average horizontal GRF was lower for the penultimate contact compared to the final contact. This finding is consistent with that of (Jones et al., 2016b) who found lower average horizontal GRF in the penultimate contact relative to the final contact. The same authors also found peak vertical GRF values to be higher in the penultimate contact compared to the final contact, which also agrees with the findings of the current study. Also, ground contact time were shown to be longer in the final contact of turns than the penultimate contact (0.52 ± 0.08 s vs. 0.38 ± 0.07 s), resulting in an increased horizontal braking impulse (impulse = force x [change in momentum]) in the final contact (Jones et al., 2016b). Taken together, these findings indicate, during turns, the need to bring the horizontal velocity to zero before turning and accelerating back the other way, therefore more substantial braking takes place during the final contact. This may present a problem when athletes may not have the physical capacities (neuromuscular control, high levels of strength) to cope with the increased loading. Thus, it is essential to develop holistic training programmes to optimally prepare and enhance CoD performance and reduce risk of injury. Specifically, strength, plyometric, sprint, CoD and combination training are all found to be effective modalities of improving CoD ability (Falch, Rædergård, & van den Tillaar, 2019), while others have found reductions in KAM resulting from technique modification interventions (Dempsey et al., 2009; Jones, Barber, & Smith, 2015). Most recently, Dos'Santos (Dos'Santos, McBurnie, Comfort, & Jones, 2019) found improvements in CoD completion time and cutting technique following a 6-week CoD technique intervention in male youth soccer players, indicating CoD technique training, in addition to normal skills and strength training improves cutting performance and movement quality. Indeed, athletes with increased levels of isokinetic eccentric knee extensor strength are shown to be better able to decelerate during the penultimate contact from faster approach velocities during 180° turns (Jones et al., 2017). Furthermore, peak horizontal braking forces during penultimate contact are shown to significantly associate with CoD performance times (Graham-Smith, Atkinson, Barlow, & Jones, 2009) and horizontal GRF ratio (Dos' Santos, Thomas, Jones, & Comfort, 2017), with faster athletes demonstrating significantly lower horizontal braking force ratio than slower athletes. These findings may help us to understand the interaction between strength, speed, and technique regarding CoD performance and risk of injury.

In this study, females demonstrated increased average horizontal GRF ratio compared to males, indicating an increased proportion of braking took place during the final contact relative to the penultimate contact, compared to males. This result is in accord with recent studies indicating faster CoD performances to exhibit lower horizontal GRF ratio as compared with slower performances (Dos' Santos et al., 2017). Also, earlier studies found lower horizontal GRF ratio to associate with lower knee abduction moments during turns (Jones et al., 2016a), yet this was in female participants and turning off one leg only. Further work is required to evaluate the role of the penultimate contact and final contact in 180° turns in male and female soccer players to better understand the optimal technique for changing direction.

The joint angle data revealed a significant main effect for peak hip flexion angle, indicating increased hip flexion was observed during the penultimate contact compared to final contact. This finding is likely to be related to help absorb loading through an increased range of motion compared with final contact, thus facilitating longer braking force application, thus impulse, resulting in an increased reduction in whole-body velocity (impulse = change in momentum). Indeed, the role of the penultimate contact has been described as a 'preparatory step' demonstrating hip and knee flexion throughout the stance phase as the athlete transitions from penultimate contact to final contact (Jones et al., 2016b). This helps provide an optimal body position at final contact (lower centre of mass) and allows the final contact leg to be planted out in front of the body. Another important finding was that males exhibited increased hip flexion angles during weight acceptance than females. There are similarities between the finding in this study and those described by (Sigward et al., 2015) whereby males demonstrated increased hip abduction angle at initial contact than females. It seems possible that these results are because male athletes better prepare themselves for the CoD by either absorbing GRFs (hip flexion) or pre-rotate to the new direction (hip abduction). This finding, while preliminary, suggests that male athletes may better self-regulate their CoD technique, which may lead to a faster overall CoD performance. Indeed, earlier work suggests a lack of hip flexion/extensor moments to be a gender technique deficit, potentially leading to increased knee loading (Pollard, Sigward, & Powers, 2007).

For the variables peak knee flexion angle and peak knee extensor moment, there were significant main effects for contact, with increased values observed during penultimate contact compared to final contact. These results match those of earlier studies whereby the penultimate contact resulted in increased knee flexion angles and knee extensor moments in 180° turns (Graham-Smith et al., 2009; Greig, 2009; Jones et al., 2016b). These results are likely to be related to the fact that, during 180° turns, the knee goes through an increased range of knee flexion during penultimate contact compared to final contact. These findings suggest that increased knee flexion is maintained in the transition from penultimate contact to final contact to lower centre of mass and allow for an optimal final contact, with data showing maximum knee flexion typically occurs at the end of penultimate contact ground contact in 180° turns (Jones et al., 2016b). Another finding was that increased peak ankle dorsiflexion angle was observed in the penultimate contact compared to final contact, but the opposite was true for peak plantarflexor moment, with increased values in the final contact compared to penultimate contact. These findings are in agreement with those who found increased ankle dorsiflexor moments during final contact compared to penultimate contact (Jones et al., 2016b). These results may be explained by the fact that participants initially made the final contact with a forefoot plant, evoking an ankle dorsiflexor moment, whereas during penultimate contact an initial rearfoot plant may have led to increased plantarflexor moments. Furthermore, increased ankle dorsiflexion occurs to help absorb the loading and facilitate longer braking force application during penultimate contact in 180° turns.

Overall, the findings of this study provide insights into the role of limb dominance during the task of 180° turns. While many studies have explored biomechanical differences between limbs during CoD (Brown et al., 2016; Mok et al., 2018; Pollard et al., 2018; Thomas et al., 2017), this investigation is the first to examine the differences between dominant and nondominant limb across penultimate contact and final contact, in male and female soccer players. The results of this study indicate a significant main effect for limb for the variable average horizontal GRF; whereby increased values were observed when turning off the dominant limb compared to the nondominant limb. A way of interpreting this might be that when turning with the dominant limb increased average braking forces are experienced across the final two foot contacts, likely due to technical and coordination differences. The other main effects observed in this study suggest average horizontal GRFs are increased in the final contact than penultimate contact, which agrees with past literature (Jones et al., 2016a, 2016b). This combination of findings may provide some support for the conceptual premise that the role of limb dominance on CoD biomechanics may be less in such shallow angles of direction change (<90°), but more so for sharper CoD (90-180°). Thus, further research is required to investigate whether limb dominance influences the braking strategy during these manoeuvres.

A limitation of the current study is the pre-planned execution of the CoD task, whereas unanticipated CoD has been shown to elevate knee joint loads during cutting (Besier, Lloyd, Ackland, & Cochrane, 2001). In addition, it can only be assumed that knee valgus and knee abduction moments are risk factors for ACL injury due to the lack of evidence. Also, females wore compression garments, but males did not; therefore, it is unknown the amount of movement artefact when comparing markers and clusters attached to a compression garment compared with those attached to skin. Furthermore, the findings of the current study can only be extrapolated to male and female soccer participants performing 180° turns. Except for knee abduction angles and moments, this study only featured lower-limb joint angles and moments in the sagittal plane. Despite hip abduction and rotation angles, such as the motion on the frontal and transverse planes, are commonly investigated in cutting studies (Kristianslund, Faul, Bahr, Myklebust, & Krosshaug, 2014; Kristianslund & Krosshaug, 2013), whole-body deceleration takes place in the sagittal plane during 180° turns. In future studies, it might be possible to investigate the influence of these parameters on braking strategy and knee joint mechanics during 180° turns.

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No potential conflict of interest was reported by the authors.

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