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EFFECT OF FATIGUE ON KINEMATICS AND LANDING STRATEGIES OF THE ANKLE DURING OPEN SIDE CUTTING IN 120-MIN SIMULATED SOCCER MATCH-PLAY

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ABSTRACT

The ankle's capacity to absorb ground reaction forces during dynamic movements is critical for ACL injury prevention, yet the biomechanical changes in ankle kinematics and foot strike patterns induced by soccer-specific fatigue during high-risk maneuvers like side-cutting remain poorly understood, hindering the development of holistic injury risk assessment and mitigation strategies. The purpose of this study was to investigate the effects of fatigue on sagittal plane ankle angles during initial contact of side cutting tasks and observe the landing strategies recruited during such tasks in a simulated soccer match-play. Eighteen (n = 18) male, recreational participants (age: 23.1 ± 4.7, height: 1.7 ± 0.1 m; body mass: 70.6 ± 10.0 kg) volunteered for the study. Participants completed 120 minutes of simulated soccer match-play with a 15-minute passive half-time rest period interceding at the 45-minute mark and another 5-minute rest period at the end of 90 minutes of simulated soccer match-play and performed 5 successful trials of side cutting for both dominant and non-dominant limbs at all time points (time: 0 min, 45 min, 60 min, 105 min, 110 min, 125 min, 140 min) during the simulation. A 2 (limb: dominant, non-dominant) × 7 (time: 0 min, 45 min, 60 min, 105 min, 110 min, 125 min, 140 min) mixed within-between analysis of variance was conducted for each dependent variable while the occurrence for different landing strategies was also recorded. There was a significant main effect of time on the ankle angles ($F_{3.493, 104.803}$ =3.521, p = 0.013, partial η^2 = 0.105). However, no significant interaction effect was observed ($F_{3.349, 104.803}$ = 0.419, p = 0.769, partial η^2 = 0.014), suggesting that limb dominance does not play a role in the changes occurring in the ankle angles over time. The probabilities for rearfoot landings appear to increase over time to over 0.75, whereas forefoot landing probabilities appear to drop to below 0.20. This pattern could introduce multiplanar challenges to the anterior cruciate ligament, aligning the structure awkwardly and increasing the forces acting on the ligament. Researchers and practitioners

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may consider exploring the efficacy of targeted interventions to offset the effects of fatigue on landing strategies and kinematics among soccer players.

Keywords: *ACL injury, soccer, ankle dorsiflexion, plantar flexion, rearfoot strike*

INTRODUCTION

In the study of biomechanical anterior cruciate ligament (ACL) injury, the ankle plays a vital role as an absorber of ground reaction forces during landing (Devita & Skelly, 1992). Devita and Skelly (1992), Kovacs et al. (1999), and Fong et al. (2011) discussed the influence of ankle motion on hip and knee flexion kinematics and kinetics with great aspiration to increase understanding on the ankle kinematics as a clinical measure for screening ACL injury risk. A rearfoot landing could result in increased landing forces (Stearne et al., 2014), whereas a forefoot landing could promote greater hip and knee flexion displacements upon landing. These pieces of information have been addressed taken into consideration into the development of the Landing Error Scoring System (LESS) (Padua et al., 2015; Padua et al., 2009) where foot positions, forefoot, flat and rearfoot landings and ankle internal/external rotations are considered in the assessment of ACL injury risk.

In soccer, several epidemiological studies have also emerged, noting increased tendencies of the injury occurring towards the end of each match-play halves (Ekstrand et al., 2011; Hawkins et al., 2001) and has started a trend of research in ACL injury risk assessments observing biomechanical changes during landings in a fatigued state, demonstrating how the hip and knee biomechanics could be altered following the progression of fatigue (Asleh et al., 2017; Greig, 2009; Hamdan, Ismail, et al., 2018; Hamdan, Mohd Noh, et al., 2018; Mat Daud et al., 2017; Raja Azidin et al., 2015; Sanna & O'Connor, 2008).

The study by Mat Daud et al. (2017) was a noteworthy observation that mentioned a dissection of the LESS scores into the hip, knee and ankle parameters to understand the how the magnitude of changes in each region from fatigue could reveal their influence in loading the ACL. Unfortunately, not much information could be revealed with regards to the ankle biomechanics during fatigued landings due to small number of the LESS's 17 items looking into the ankle biomechanics. Perhaps due to the locality of the ACL, the hip and knee biomechanics during landings have been subjected greater focus, with attention towards the ankle biomechanics considerably less (Fong et al., 2011). Hence, there is a need to further explore the kinematic changes of the ankles following fatigue during landing tasks. In this study, two observations are of interest regarding the ankle landing kinematics: a) the effects of fatigue from soccer match-play simulations on ankle angles during initial contact of side cutting tasks, and b) the probability and occurrence of forefoot, midfoot and rearfoot landings during side cutting tasks as fatigue develops from a soccer match-play simulation.

METHODOLOGY

To address the research objectives of this study, repeated measures design research was implemented. Details of the research methodology are as the following:

Participants

Eighteen (n = 18) male, recreational participants (age: 23.1 ± 4.7, height: 1.7 ± 0.1 m; body mass: 70.6 ± 10.0 kg) volunteered for the study. An a-priori calculation using the statistical software, G*Power (version 3.1.9.2, Universität Kiel, Germany), determined to achieve an estimated, moderate effect size *f* of 0.25 and 80% statistical power with alpha (α) set at 0.05, a minimum total sample size of 18 samples is required. Each participant represented a dominant and non-dominant limb; therefore, this study can achieve significant statistical power with a minimum of 9 participants. All participants fulfilled at least 1 training day per week with 1 to 2 training hours for every session. Participants were inquired for injury background, and none had suffered ACL injury and were free from lower limb injury for the prior 6 months which may render their side cutting tasks unsuccessful and void (i.e. ankle sprain, patellofemoral pain, hamstring strain injury). This criterion was crucial as any injury could interfere the participants' performance during the soccer match simulation. All participants wore tight fitting compression suits and standardized indoor footwear. A written informed consent was obtained from every participant, and the study was conducted according to the guidelines set by the university ethics committee.

Experimental Design

This study is a single group, repeated measures design. Each participant attended to the laboratory on two separate occasions (one familiarization session, and one testing session). The familiarization session consisted of a pre-exercise screening procedure, side-cutting tasks, and a 15-minute simulated soccer match-play exertion. The testing session begins after a Fédération Internationale de Football Association (FIFA) standard procedure of 15-minute dynamic warm-up followed by a 10-minute passive rest preceding the soccer match simulation. Participants completed 120 minutes of simulated soccer match-play with a 15-minute passive half-time rest period interceding at the 45-minute mark and another 5-minute rest period at the end of 90 minutes of simulated soccer match-play. At the beginning of the soccer match simulation (0 minutes), after the first half (45 minutes), immediately after half-time (60 minutes), at the end of the second half (105 minutes), at the beginning of the first half of extra time (110 minutes) in between the extra time halves (125 minutes) and at the soccer match simulation (140 minutes), participants' ankle kinematics were assessed with 5 trials of side cutting tasks using the dominant limb and the non-dominant limb. Limb dominance was determined by the participants' preferred limb to be used when kicking a ball and this was controlled (Raja Azidin et al., 2015) for all participants.

Participants' physiological responses were monitored using a heart rate monitor (Polar Heart Rate System, Electro, Finland) and the rate for perceived exertion (RPE, 20-point Borg Scale). During rest intervals such as half time and before extra time periods, the participants remained seated and were allowed to drink water. A report on the physiological responses during the simulation has been published elsewhere (Hamdan, Mohd Noh, et al., 2018).

Side cutting tasks

Side cutting tasks were used for this study because of its manoeuvres that reflect most reported kinematics and demands of the lower limb during ACL injury occurrence (Faunø & Wulff, 2006; Hawkins et al., 2001; McLean et al., 2004). Further reports on the reliability of side cutting kinematics have also been published elsewhere for both two-dimensional kinematics (Hamdan, Mohd Noh, et al., 2018) and three-dimensional kinematics (Sankey et al., 2015). Photocell timing gates (Swift Performance, USA) were set up 2 m apart and 2 m from the designated landing box for the side cutting tasks to control the side cutting approach speed which was set at 4 – 5 ms^{-1} as it was proposed as a safe entrance speed to perform a cutting manoeuvre with representative kinematic data for injury risk assessment (Vanrenterghem et al., 2012). Trials with approach speeds under or exceeding the set range were excluded from the analysis. The side cutting tasks utilized were anticipated in nature and required a 45˚ change of direction during exiting which were guided by markings on the floor and cones at 45˚ deviation from the runway. All participants performed 5 successful trials of side cutting for both dominant and non-dominant limbs at all time points during the simulation.

Soccer Match Simulation with Extra Time

The soccer match simulation used in this study was a similar protocol used by Hamdan, Mohd Noh, et al. (2018) which was an extension of the over-ground soccer match simulation by Raja Azidin et al. (2015). This soccer match simulation protocol has been proven to represent the demands in an actual soccer match-play in both the physical loading (Barreira et al., 2016) and the physiological loading aspects (Raja Azidin et al., 2015). The over-ground soccer match simulation protocol consists of a 15 m course that includes multidirectional utility movements. A 15- minute audio cue instructs the participants to perform different activities throughout the 15 m course and repeated to suit a full soccer match-play duration with two extra-time halves. Several obstacles (i.e. cones, poles) were incorporated throughout the 15 m course for participants to manoeuvre themselves through, in between, or around using movements as detailed in the Figure 1. A detailed elaboration of the simulated soccer match-play has been published elsewhere (Barreira et al., 2016; Raja Azidin et al., 2015).

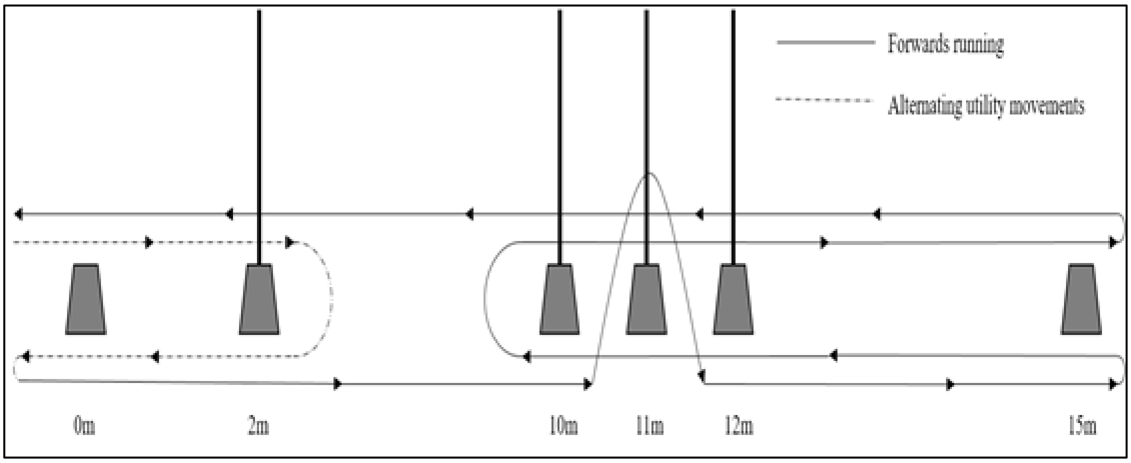

Figure 1 A schematic diagram of the overground soccer match simulation by Raja Azidin et al. (2015).

Data Collection

All side cutting tasks were performed inside a 0.30 × 0.30 m box marked on the ground with two high-speed cameras (Exilim ZR800, Casio, USA) set at 240 frames per second (fps) and a pixel resolution of 512 × 384 px placed at perpendiculars to both sides (sagittal plane) of the side cutting box. The height and distance of the cameras were set at 1.22m above the floor 3.45 m away from the landing region (Padua et al., 2009) but were adjusted accordingly if needed to fit the full model of the markers into the recorded display in order to ensure that the markers were all visible for processing. Video playback speed was calibrated to fit the sampling rate.

10 reflective markers were placed on both sides of the participants' selected body bony landmarks (acromion process, greater trochanter, lateral femoral epicondyle, lateral malleolus and fifth metatarsal) to enable visual access for the observer to process the recorded data.

The ankle angle was obtained from an angle formed by a straight line originating from the lateral femoral epicondyle to the lateral malleolus and from the lateral malleolus to the fifth metatarsal epicondyle. Sagittal plane landing strategies (i.e. rearfoot, midfoot, and forefoot) were also observed for each trial at each time point.

Data and Statistical Analysis

Initial contact (IC) was defined as the first instance (frame) where the participants' foot touches the ground. The definition and determination of the initial contact phase were practiced as close and consistent as possible across all trials for all participants. The markers on the lateral malleoli and the fifth metatarsals aided in determining IC.

Paired t-tests were used to compare the pre-test (time 0 min) ankle angles between dominant and non-dominant limbs to assess the baseline assumption of similar pre-test angles between the two limbs. A 2 (limb: dominant, non-dominant) × 7 (time: 0 min, 45 min, 60 min, 105 min, 110 min, 125 min, 140 min) mixed within-between analysis of variance was conducted for each dependent variable. All data were analysed using the Statistical Package for Social Sciences (SPSS v. 26, IBM, New York, USA). The equality of variances between limbs and time points were assessed using the Mauchly's test of sphericity. Sphericity violations are corrected accordingly to the Greenhouse – Geisser epsilon. An epsilon value of < 0.75 the Greenhouse – Geisser correction was applied and referred to while epsilon values of > 0.75 are corrected using the Huynh – Feldt correction as elaborated by Girden (1992). Since the similar outcome measures are analysed for each repeated measure, the Bonferroni post-hoc procedures were used to control Type 1 errors. In this study, limb dominance and time were treated as independent variables while the ankle angles were treated as dependent variables. Each successful five trials at every time point were computed for a mean reading. The alpha level was set at 0.05.

The occurrence probability for different landing strategies were also calculated using the following formula:

$$P(a) = \frac{n(a)}{n} \tag{1}$$

Where $P(a)$ denotes the probability of a determined landing strategy, $n(a)$ is the number of occurrences of the landing strategy, and n in the total number of landings for the time point.
The domains for (a) are rearfoot, midfoot and forefoot landings. $P(a)$ for dominant and nondominant limbs were calculated separately.

RESULTS AND DISCUSSION

Results

Two participants were unable to complete the full 120-minute protocol. All data presented are for the remaining sixteen participants.

Paired T-Tests

Paired samples test revealed that no difference was present between dominant and non-dominant ankle angles during IC of side-cutting (p = .485). Therefore, a baseline assumption of similar pre-test angles between the two limbs was met.

Mixed Within-Between Analysis of Variance

There was a significant main effect of time on the ankle angles ($F_{3.493, 104.803}$ =3.521, p = 0.013, partial η^2 = 0.105). This mean that notable changes could be observed in ankle angles during IC of side cutting regardless of the limb dominance. However, no significant interaction effect was observed ($F_{3.349, 104.803}$ = 0.419, p = 0.769, partial η^2 = 0.014), suggesting that limb dominance does not play a role in the changes occurring in the ankle angles over time. A notable difference could be observed in the dominant limb ankle at the end of extra-time (120min) in comparison to the end of a conventional soccer match (105min).

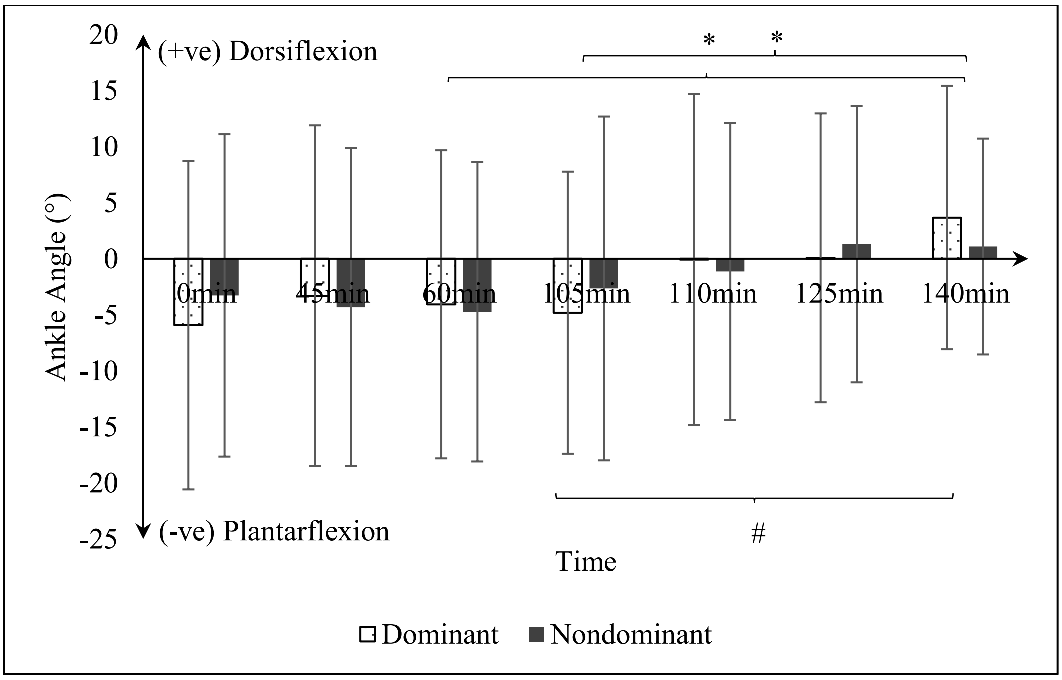

Figure 2 Ankle angle at initial contact during side-cutting overtime during soccer match simulation with extra time. *Represents significant difference between time points regargless of limb dominance. # Represents significant difference between time points for the dominant limb.

Probability Distribution of Landing Strategy Outcomes

The probability of rearfoot, midfoot and forefoot landings for both dominant and nondominant limbs revealed that overall, a rearfoot landing appears to be a more probable outcome in both dominant and nondominant limbs (dominant = 0.60, nondominant = 0.64). This was followed by forefoot landings (dominant = 0.22, nondominant = 0.27) and midfoot landings (dominant = 0.18, nondominant = 0.09). A further dissection of the outcome probabilities revealed that the probabilities for rearfoot landings appear to increase over time to over 0.75, whereas forefoot landing probabilities appear to drop to below 0.20 as described in Table 1 and visualised in Figure 3.

Table 1
Probability of landing strategies during soccer match simulation

	$P(a)$						
	0 min	**45 min**	**60 min**	**105 min**	**110 min**	**125 min**	**140 min**
Dominant Limb Forefoot Strike	0.44	0.19	0.23	0.23	0.23	0.15	0.09
Dominant Limb Midfoot Strike	0.16	0.25	0.19	0.20	0.18	0.18	0.13
Dominant Limb Rearfoot Strike	0.39	0.56	0.58	0.58	0.60	0.68	0.79
Nondominant Limb Forefoot Strike	0.31	0.32	0.33	0.28	0.27	0.20	0.21
Nondominant Limb Midfoot Strike	0.05	0.14	0.14	0.14	0.04	0.08	0.04
Nondominant Limb Rearfoot Strike	0.64	0.54	0.53	0.58	0.69	0.73	0.75

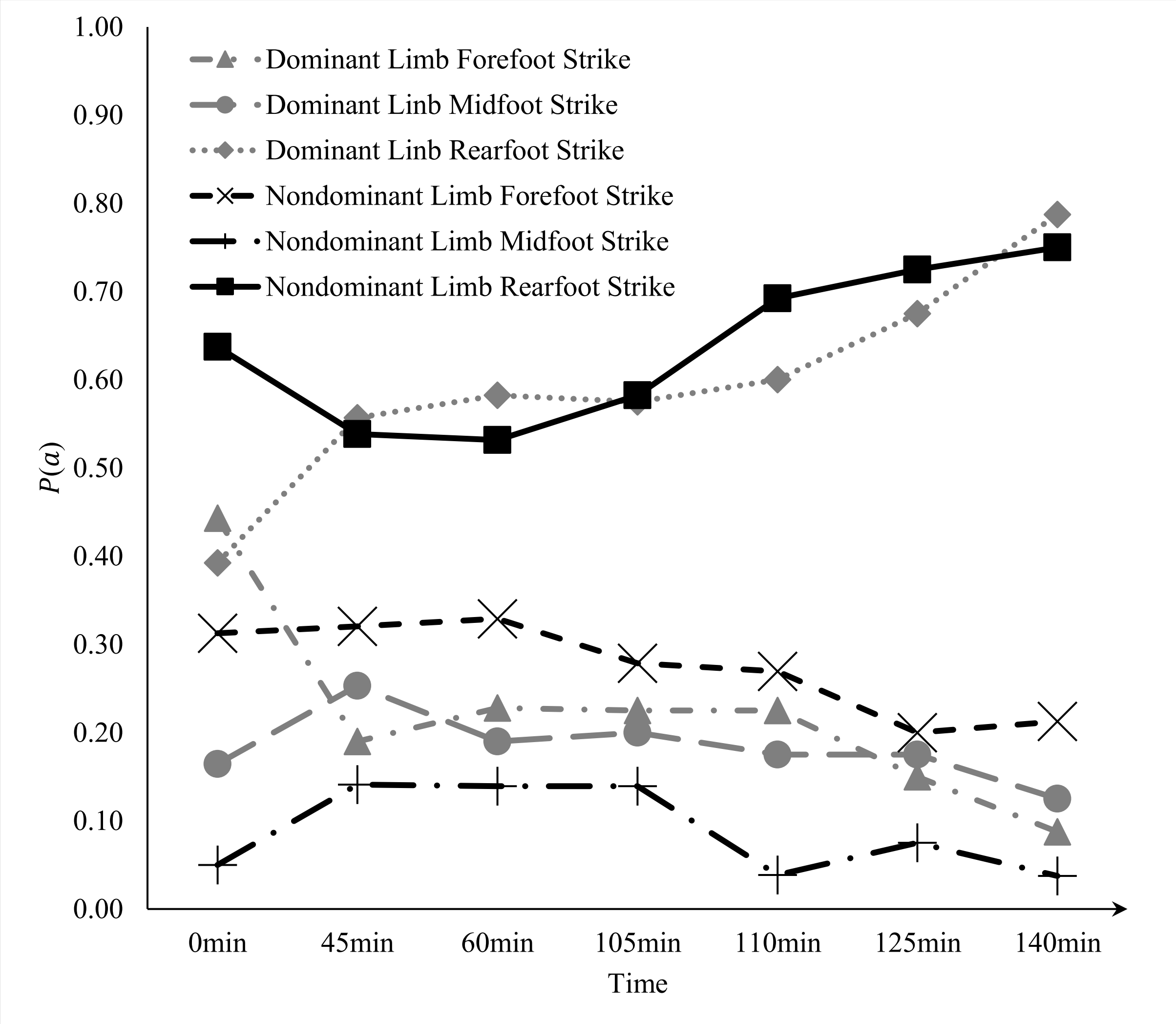

Figure 3 Probability changes of different landing strategy outcomes during side cutting throughout simulated soccer match-play with extra time.

Discussion

The effects of fatigue on ankle angles during side-cutting

The main purpose of this study was to investigate the effects of soccer specific exertions ankle kinematics during side-cutting tasks. The primary findings of the study reveal that there is a significant change in ankle angles as fatigue develops over time during the soccer match simulation. The changes over time do not appear to favor one etiological factor (i.e. dominant, nondominant) over the other. This suggests that the nondominant limb may be as equally at risk of injury as the dominant limb, which comes in line with previous studies (Hamdan, Ismail, et al., 2018; Hamdan, Mohd Noh, et al., 2018) that noted similarities in changes of the sagittal hip and knee angles across limb dominance with the onset of fatigue. A multicenter retrospective study by Negrete et al. (2007) also noted similarities between the dominant and nondominant limbs. This may be explained by the symmetrical indices found between dominant and nondominant limbs in over 95% of functional tasks and isokinetic tests conducted at different fatigue states by Petschnig et al. (1998). This finding, however, contradicts epidemiological observations in actual soccer match participations, noting that there seemed to be a greater tendency for a dominant limb injury among male players (Brophy et al., 2010; Ekstrand et al., 2011). It is worth noting that Ekstrand et al. (2011) remarked higher distribution of injury for the dominant limb only in the quadricep muscles (60% versus 33%), whereas other regions reported a closely similar injury distributions from 50% to 54%. Brophy et al. (2010) believes that greater peak knee extension torques and muscle activity in nondominant limbs during support phases in dynamic tasks contributes to better control in the nondominant limbs, thus reducing the risk of injury in the nondominant side. In contrast to previous studies, this study focused on the ankle angles and orientation during landing as opposed to hip and knee angles.

This study believes ankle angles and orientation at initial contact may reveal crucial information on ACL injury risk as the plantar flexors play a crucial role in absorbing ground reaction forces on landing as mentioned by Devita and Skelly (1992) and Schmitz et al. (2007). Furthermore, observing the ankle angles and orientation during initial contact of a landing task may enable clinicians and researchers to observe and estimate ankle displacement throughout the task. This was demonstrated by Fong et al. (2011) who studied how ankle dorsiflexion range of motion (ROM) is associated to knee and hip kinematics and kinetics in relation to the ACL risk of injury. The team found that a reduced dorsiflexion ROM during landing allows lesser knee flexion displacement and higher ground reaction forces, which are known to be regarded as risk factors for ACL injury (Griffin et al., 2006; Hewett et al., 2005; Yu et al., 2006). In this study, as represented in Figure 2, it was observed that the ankle angles shifted from a more plantar flexed orientation towards a more dorsiflexed position. These changes directly translate to a reduction of passive dorsiflexion ROM, thus progressively inhibiting the ability to absorb the ground reaction forces in the sagittal plane through ankle dorsiflexion, and hip and knee flexion, which is one of the proposed mechanism for loading the ACL to a point of injury (Blackburn & Padua, 2008; Devita & Skelly, 1992; Kovacs et al., 1999).

The effects of fatigue on landing strategies during side-cutting

An interesting finding in this study is how the landing strategies during side cutting changes over time. In Figure 3, this study believes two key points demand attention: a) the dominance of rearfoot landing strategies over midfoot and forefoot strikes, and b) the increasing probability of rearfoot landings in the later stages of the match-play simulation.

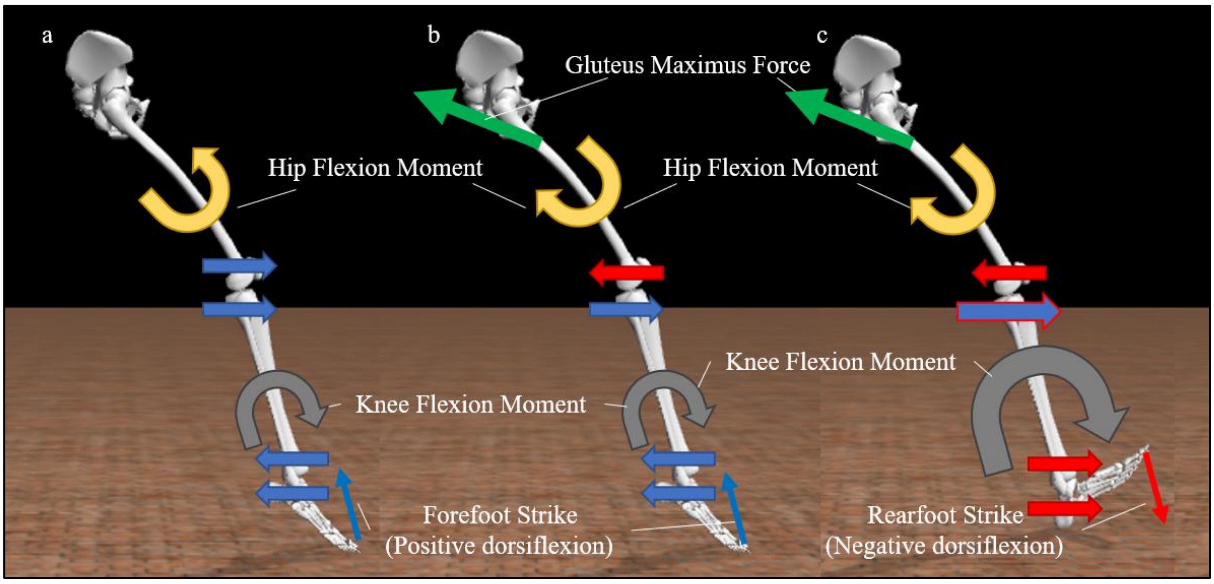

Figure 4 Hip-knee-ankle flexion coupling during landing. (a) An optimal landing at full extension, as proposed by Hashemi et al. (2011), coupled with a forefoot strike, neuromuscular control assumes that hip and knee flexion, and ankle dorsiflexion occurs in synchrony, (b) a forced hip extension during knee flexion with a forefoot strike, and (c) a forced hip extension during knee flexion with a rearfoot strike. (Not a free body diagram).

As discussed in the previous subsection, a rearfoot landing requires the ankle to be actively dorsiflexed prior to landing, thus reducing the available passive dorsiflexion ROM that ensues following foot strike, thus potentially reducing the force absorption. In the perspective of ACL injury mechanism, a rearfoot landing may enable multiple mechanisms to the loading of the ligament to rupture. In an optimal landing, Hashemi et al. (2011) described a hip and knee co-flexion harmony during landing tasks to be a protective mechanism against ACL injury. When coupled with a forefoot landing (Figure 4a), the passive dorsiflexion motion throughout the weight acceptance phase facilitates the tibial motion into knee flexion in synchrony with the hip flexion motion, thus may provide a rationale to a reduced ground reaction force and an increased knee flexion displacement reported by Fong et al. (2011).

When the hip and knee co-flexion mechanism is impaired, the hip flexes more slowly compared to the knee or in complete dysynchrony, thus leading to tibial anterior translation, and directly loading the ACL (Hashemi et al., 2011). This may occur due to the inability of the hip flexors and the hamstrings to counteract the gluteus maximus (Figure 4b) and quadriceps forces in hip and knee extension motions respectively, possibly due to deceleration movements as cutting manoeuvres (Hashemi et al., 2011) or reductions in the flexors' eccentric strengths due to fatigue (Greig, 2019; Hamdan et al., 2020; Raja Azidin et al., 2015). In both cases, the passive dorsiflexion provided by a forefoot landing could still provide a protective mechanism to the ACL by promoting knee flexion displacement.

In this study, a rearfoot strike during a cutting manoeuvre appears to be a favoured strategy, with increasing probability of its employment over time as fatigue develops. This study believes that this may play a crucial role in rationalizing the increased rate of injuries in later stages of match play (Hawkins et al., 2001) as well as increases in knee and hip extension angles during cutting tasks (Greig, 2009; Hamdan, Ismail, et al., 2018; Hamdan, Mohd Noh, et al., 2018; Raja Azidin et al., 2015). The math to the hypothesis becomes rather simple, the more a player recruits a rearfoot landing strategy, the higher chance he faces in inflicting damage to his ACL.

In a rearfoot landing, dorsiflexion may be limited, restricted, or even in the negative (i.e. passive plantarflexion). Fong et al. (2011) and Ota et al. (2014) demonstrated how a reduced or restricted passive dorsiflexion may implicate major risk factors of ACL injury in the frontal plane and the sagittal plane by increasing the ground reaction forces and knee flexion moments. In addition to increased knee laxity (Shultz et al., 2015) and erect landing postures (Hamdan, Ismail, et al., 2018; Hamdan, Mohd Noh, et al., 2018; Raja Azidin et al., 2015) from soccer specific exertions, a rearfoot landing could render the ACL brutally compromised. A passive plantarflexion instead of the desired dorsiflexion could firstly disrupt the hip and knee co-flexion synchrony by impairing the balance of the knee flexion displacement motion by delaying the eccentric co-contraction of the gastrocnemii into the late stance phase, whereas the hip flexors and hamstrings struggle to counteract the gluteus maximus and quadriceps forces (Figure 4c), therefore leaving the knee to be vulnerable to a hyperextended position. Hamdan (2017) demonstrated how this hyperextended position of the knee may jeopardize the ACL in a myriad of concurrent mechanisms: a) an increased ACL elevation and deviation angle (Li et al., 2005; Yu & Garrett, 2007), b) an increased intrinsic tension in the ACL due to the increase in the ligament's length (Li et al., 2005; Neumann, 2015), c) an increased quadriceps force due to the increase in patella tendon insertion angle in reference to the longitudinal axis of the tibia, and d) a decreased hamstring contraction force due to the decrease of hamstrings insertion angle with respect to the tibia (Blackburn & Padua, 2008; Zheng et al., 1998). To absorb the increased ground reaction forces, rearfoot landings often result in foot pronation, leading to an internally rotated tibia (Chan & Rudins, 1994), promoting a valgus orientation in the knee, a risk factor known to brutally challenge the ACL (Hewett et al., 2005). This rotation caused by the oblique hinge axis of the subtalar joint (Chan & Rudins, 1994) may explain the convergence of multiplanar factors leading up to the compromise of the integrity of the ACL.

Practical implications

This study has demonstrated how landing strategies and ankle kinematics may be altered as a function of increasing fatigue from match-play exertions. Perhaps players and practitioners could reap benefits by attempting to offset these effects such as by warming up with specific, targeted exercises that has been highlighted to reduce injury risk as recommended by Padua et al. (2018) and including additional focus on landing strategies as a feedback component (Ter Stege et al., 2014) as it is commonly used to alter motor control strategies to perform dynamic tasks as jump-landings and changes of direction during sporting activities (Dai et al., 2012).

Additionally, such training could perhaps be implemented as a re-warmup protocol (Rahnama et al., 2002) or during a fatigued state (i.e. after small-sided games or at the end of a training session) to improve the players' tolerance to fatigue at a neuromuscular level as suggested by Greig and Siegler (2009) and Small et al. (2010).

Limitations

This study believes that the increased probability of rearfoot landings strategies' employment may provide rationale for understanding and inform future research endeavours designed to study the biomechanical risk factors of ACL injury in a more holistic approach. However, several limitations should be considered when synthesizing its outcomes. First of all, the overground soccer match simulation in this study involved multidirectional overground running. However, in soccer, various other tasks may also compromise the integrity of neuromuscular control in the lower limbs, especially in the ankles. Perhaps a more comprehensive match simulation that incorporates ball-handling tasks (i.e., kicking, dribbling and passing) as well as jump landing tasks (i.e., heading) such as the ball-oriented soccer simulation by (Hamdan & Raja Azidin, 2022; Hamdan et al., 2023) or the technical soccer aerobic field test (da Silva & Lovell, 2020) may reveal more definitive findings with regard to kinematic landing strategies employed during landings in bouts of fatigue.

Additionally, this study only observed sagittal plane ankle angles and orientations at initial contact of a side cutting task. Further exploration of the hip, knee and ankle flexion motions, ROMs and multiplanar kinematics and kinetics are still warranted to explore and understand the roles of each joint and muscle in the development of ACL injury prevention programs. Furthermore, more advanced, analysis methods such as computer-modelled simulations and time-series analyses (Pataky, 2012) of joint kinematics, ground reaction forces and muscular activities could reveal a more in-depth understanding of how the ankles could contribute to the protection of the ACL and the level of influence they pose on the loading of the ACL in comparison to the hip and knee joints.

CONCLUSION

The findings of this study suggested that there appears to be a trend towards increasing ankle dorsiflexion at initial contact and an increased occurrence of rearfoot landings during side-cutting tasks as fatigue develops from prolonged exertions. This pattern could introduce multiplanar challenges to the ACL, aligning the structure awkwardly and increasing the forces acting on the ligament. Researchers and practitioners may consider exploring the efficacy of targeted interventions to offset the effects of fatigue on landing strategies and kinematics among soccer players.

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CONFLICT OF INTREST

No conflict of interest is declared by any of the authors.

AUTHORS CONTRIBUTIONS

MH conducted the data collection, data analysis and writeup of the manuscript. RMFRA supervised and guided the theoretical framework and research design.

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