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Anticipatory effects on side-step cutting biomechanics in Women's Australian Football League players

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ABSTRACT

Objectives Reactive side-step cutting manoeuvres are linked to anterior cruciate ligament (ACL) injuries in Women's Australian Football League (AFLW) matches. We explored knee joint moments and ground reaction forces (GRFs) in AFLW players when performing anticipated and unanticipated side-stepping.

Methods Sixteen AFLW players (age=25.3±4.2 years; height=1.71±0.06 m; mass=68.4±4.7 kg) completed anticipated and unanticipated side-stepping trials during which full-body three-dimensional kinematics and kinetics were recorded. One-dimensional statistical parametric mapping paired t-tests were used to compare three-dimensional knee moments during weight acceptance and GRFs during the stance phase between anticipated and unanticipated conditions.

Results Unanticipated side-stepping incurred lower knee flexion (18%–39% of stance, p<0.01) and abduction (11%–24% of stance, p<0.01) moments. Braking and propulsive GRFs were lower and higher, respectively, across the majority of stance phase (6%–90% of stance, p<0.01) in unanticipated side-stepping. Vertical GRFs were lower in unanticipated side-stepping in the early stance phase (14%–29% of stance, p<0.01).

Conclusion Contrary to existing literature, AFLW players exhibited knee joint moments associated with reduced ACL loading when performing unanticipated side-stepping. Players appeared to adopt a 'cautious' approach to the unanticipated side-step (ie, decelerating at the change of direction), by reducing braking and vertical GRFs in the early stance phase of cutting. This approach may be implausible to employ or detrimental to performance during matches. AFLW ACL injury prevention programmes may be enhanced with greater exposure to scenarios that replicate reactive match-play demands when aiming to improve side-stepping biomechanics.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Women's Australian Football League (AFLW) players are up to nine times more likely to suffer an anterior cruciate ligament (ACL) injury compared with men's AFL players. Reactive side-stepping is a common movement task associated with AFLW ACL injuries. Knee loads associated with increased ACL loading and strain are typically elevated when performing unanticipated versus anticipated changes of direction, yet this comparison is yet to be examined with AFLW players.

WHAT THIS STUDY ADDS

⇒ AFLW players minimise hazardous knee loads when performing an unanticipated versus anticipated side-step in a laboratory setting. We hypothesise that AFLW players are employing a 'cautious' approach to reactive side-steps in the laboratory setting, which may not be achievable in match-play scenarios where physical and cognitive demands are increased.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ AFLW ACL injury prevention programmes may be enhanced with greater exposure to match-play demands when performing reactive change of direction movements.

INTRODUCTION

Anterior cruciate ligament (ACL) injuries occur when the force applied to the ligament exceeds that in which it can withstand.[1] Short-term consequences of ACL injuries include a lengthy rehabilitation period, difficulty returning to preinjury sport and an increased risk of secondary ACL injury.[2–4] Long-term consequences include prolonged knee pain, reduced quality of life and increased risk of early-onset osteoarthritis.[5–7] Women appear to have an increased severity of these consequences, reporting worse knee pain and quality of life following an ACL injury.[8] Alarmingly high rates of ACL injuries occur in the Women's Australian football league (AFLW).[9–12] Compared with male Australian Football League (AFL) players, AFLW players are 3–9 times more likely to suffer an ACL injury (8.83 vs 0.95 and 3.22 vs 0.97 per 1000 player hours in 2020 and 2021, respectively).[9–12] Considering the significant short-term and long-term consequences of ACL injuries, it is important to understand why these injuries are happening in the

AFLW, and what modifiable factors may be addressed to help reduce the high AFLW ACL injury rate.

A pivotal step in addressing the AFLW 'knee crisis' is to understand the sport-specific injury characteristics of AFLW ACL injuries.[13–15] Our team's previous research identified the common characteristics and scenarios of AFLW ACL injuries.[16] Reactive side-stepping is a common movement task observed with AFLW ACL injuries, with 52% of all AFLW ACL injuries involving this movement characteristic.[16] This AFLW ACL injury scenario typically occurs when a defensive player performs a side-step cutting manoeuvre when reacting to an offensive opponents change of direction (COD).[17] We labelled this the 'Reactive Defending' scenario, which accounted for one-third of all AFLW ACL injuries analysed (ie, 33%).[17] Side-stepping manoeuvres require control of knee loading (ie, stress and strain on tissues within and surrounding the knee joint)[18] in all three planes of motion.[19] The term 'knee joint moments' is used frequently in most studies,[19–22] including the present, to infer the load placed on the knee joint. In the frontal and transverse planes, these loads (eg, valgus moments, internal/external rotation moments) were up to doubled when performing unanticipated compared with anticipated side-step cutting manoeuvres in amateur soccer players.[20] Aspects of AFLW match play (eg, applying defensive pressure) may elicit an increased demand for unanticipated, compared with anticipated COD movements to be executed and subsequently contribute to players being exposed to more high-risk match scenarios associated with ACL injury.[17]

Previous literature has explored factors associated with increased ACL loading and strain during reactive side-step cutting.[23 24] Specifically, a rearfoot footfall increased knee valgus and abduction moments during unanticipated side-stepping tasks.[20 25–28] These potentially hazardous lower limb postures (ie, rearfoot footfall, knee valgus) and loads (ie, abduction moments) were observed during video analysis of reactive side-step cutting AFLW ACL injuries.[17] Previous literature has explored biomechanical differences between unanticipated and anticipated side-stepping manoeuvres in other field/court-based team sports,[23 24] however, this type of investigation is yet to be performed in AFLW players. Considering the prevalence of ACL injuries that occur in the AFLW when performing reactive side-stepping manoeuvres, gaining a biomechanical understanding of how AFLW players perform this movement task is warranted. This information will provide greater insight into how reactive scenarios may contribute to increased ACL loading and strain in AFLW players, thus providing a greater understanding of the prevalence of the 'Reactive Defending' AFLW ACL injury scenario. The purpose of this research is to understand the knee joint moments and ground reaction forces (GRFs) experienced by AFLW players when performing unanticipated versus anticipated side-step cuts. We hypothesise that during unanticipated side-step cutting trials knee joint moments and GRFs associated with increased ACL loading and strain will be observed.

METHODS

A convenience sample of 16 elite (ie, players competing at the highest level of AFLW players (mean±SD, age=25.3±4.2 years; height=1.71±0.06 m; mass=68.4±4.7 kg) from a single club was recruited to participate in this study. Participants were: (1) free of current lower limb injury; (2) had not suffered an injury to the lower limb in the past 6 weeks and (3) were free of any neuromuscular or musculoskeletal disorders that affected the lower limb. One participant with a history of ACL injury was included as the injury occurred on the right knee (ie, not the push of leg used in this study).

Participants completed both anticipated and unanticipated side-step cutting tasks. The anticipated condition involved a cut performed on the left leg initiating a 35°–55° COD to the right, with no reactive stimuli present. The unanticipated condition involved participants responding to a visual stimulus directing them to perform one of three common Australian football movements. The three movements were: (1) a side-step cut performed on the left leg initiating a 35°–55° COD to the right (ie, replicating the anticipated task); (2) a straight run and (3) a stop jump. A 10-metre run-up was implemented. The three movements were randomised (ie, via simple randomisation using the timing gate system) to stimulate the unanticipated nature of the task. Approach speed was recorded and monitored by two photoelectric timing gates (Swift Performance, Wacol, Queensland, Australia), placed 2 m apart, and positioned 2 m prior to the cutting area. This four-gate set-up also ensured consistency of approach speed. Trials were accepted if the approach speed was between 3.5 m/s and 5.5 m/s. In the unanticipated condition, a light stimulus on timing gates indicated the required task. A timing gate positioned 2 m prior to the cutting area triggered the specific light stimulus for each task. This distance ensured that participants had adequate time to react, but the tasks remained unanticipated.[22] A trial was deemed successful when the side-step cut was performed on the left leg, with the entire foot landing within the boundaries of the force-plate. Approximately 60 s rest between each trial was provided to minimise fatigue. Ten successful trials of the anticipated side-step task and five successful trials of the unanticipated side-step task were completed. To minimise participant fatigue and familiarity across unanticipated trials, a reduced number of the unanticipated tasks were performed.

Three-dimensional kinematics of the torso and lower limbs were measured using a nine-camera Vicon MX motion analysis system (Vicon, Oxford Metrics Limited) sampling at 250 Hz. Forty 14 mm retro reflective markers were attached to palpable landmarks. Twenty-four were individual markers, with rigid clusters with four markers used to track the thigh and shank. Calibration markers were located on the greater trochanters, medial knees and medial malleolus. Markers were located on the C5, medial right clavicle, acromion processes, posterior superior iliac spines, anterior superior iliac spines, lateral knees, lateral malleolus and bilaterally on the head of the first and fifth metatarsal. Four rigid clusters with four markers per cluster were located bilaterally at the lateral thigh and the lateral shank. GRFs were recorded using a single 600×900 mm in-ground AMTI force-plate (Advanced Mechanical Technology Incorporated, Watertown, Massachusetts, USA) sampling at 1500 Hz. Vertical GRF data exceeding a 20 N threshold were used to identify initial contact and the end of the stance phase during the cutting movement—with this time period extracted for subsequent analyses.

Prior to completing movement trials, a static calibration trial with participants standing in a neutral position was used to scale a generic musculoskeletal model[29] of the torso and lower limbs based on the relative distances between experimental and model markers. The musculoskeletal model provided by Lai *et al*[29] was modified to include three degrees of freedom at the knee joints, whereby internal/external rotation and abduction/adduction of the tibia relative to the femur were allowed. Torque-driven simulations of the side-stepping trials were generated in OpenSim 4.3.[30] Prior to analyses, experimental marker and force data were filtered using a low-pass fourth order Butterworth filter with a cut-off frequency of 18 Hz. The choice of cut-off frequency was based on existing work examining similar side-stepping movements,[25] and a matched cut-off frequency between marker and force data was selected to avoid impact artefacts in joint moment data.[31] The individually scaled musculoskeletal models were combined with experimental marker data from the side-stepping trials within inverse kinematics analyses to calculate torso and lower limb joint angles. OpenSim's residual reduction algorithm (RRA) was then implemented to produce joint angles more dynamically consistent with the GRF data and generate torque-driven simulations of the side-stepping trials. Three-dimensional knee joint moments were extracted from the RRA output and compared between the anticipated and unanticipated conditions using one-dimensional statistical parametric mapping (SPM1D)[32] paired t-tests. A region of interest (ROI)[33] approach was used to compare knee joint moments over the weight acceptance (WA) phase of the cutting movement. We found the traditional method for identifying WA (ie, initial foot-ground contact to the first trough in vertical GRF)[25] was unsuccessful in certain trials (particularly in anticipated conditions), due to the lack of an early impact peak and subsequent trough in the filtered vertical GRF data. Therefore, the first 40% of the stance phase was used as the ROI for WA as this captured the traditional characteristics of the WA phase (ie, the early peaks observed in knee joint moments). SPM1D paired t-tests were also used to compare three-dimensional GRFs across the stance phase of the anticipated and unanticipated side-step conditions. A Sidak correction was applied to an alpha level of 0.05 to determine statistical significance.

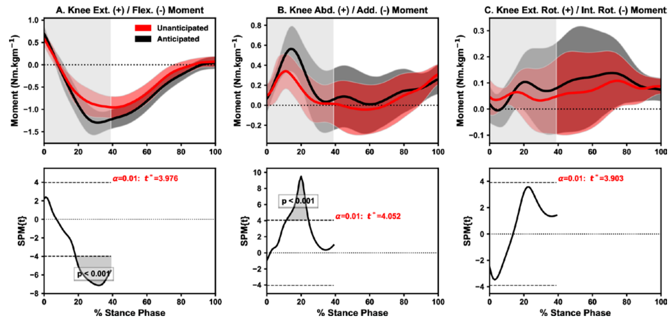

Figure 1 Subplot of unanticipated (red) and anticipated (black) knee joint moment data (top) and SPM1D paired t-tests (bottom). Knee flexion/extension moments (A), knee abduction/adduction moments (B) and knee internal/external rotation moments (C). The first 40% of the stance phase is shaded in the knee joint moment data as the region of interest for weight acceptance as this captured the traditional characteristics of the weight acceptance phase. The region shaded in the SPM1D graphs indicates statistically significant differences. SPM1D, one-dimensional statistical parametric mapping.

RESULTS

Players recorded an average approach speed of 5.37±0.24 and 5.07±0.28 m/s in the anticipated versus unanticipated conditions, respectively.

The mean±SD for stance times for the anticipated trials was faster 210±33 ms compared with the unanticipated trials 233±24 ms.

We observed lower knee flexion (18%–39% of stance phase, $p<0.01$) (figure 1A) and knee abduction moments (11%–24% of stance phase, $p<0.01$) (figure 1B) during the unanticipated versus anticipated conditions. No statistically significant difference was observed for knee internal/external rotation moments between anticipated and unanticipated conditions (figure 1C).

Braking (figure 2A) GRFs were lower and propulsive (figure 2A) GRFs were higher, across the majority of the stance phase (6%–90% of stance phase, $p<0.01$) in the unanticipated condition. We also observed lower vertical GRFs (figure 2B) in the early stance phase (14%–29% of stance phase, $p<0.01$) of the unanticipated condition. No statistically significant difference was observed in medial/lateral GRFs between the two conditions (figure 2C).

DISCUSSION

Reactive side-step cutting is a common movement task linked with AFLW ACL injuries.[16] The aim of this research was to identify the anticipatory effects on side-step cutting biomechanics in AFLW players. Players exhibited knee joint moments associated with reduced ACL loading and strain during unanticipated side-step cutting tasks. The lower braking and vertical GRFs in the early stance phase compared with the anticipated condition may be explained by greater deceleration occurring suggested by

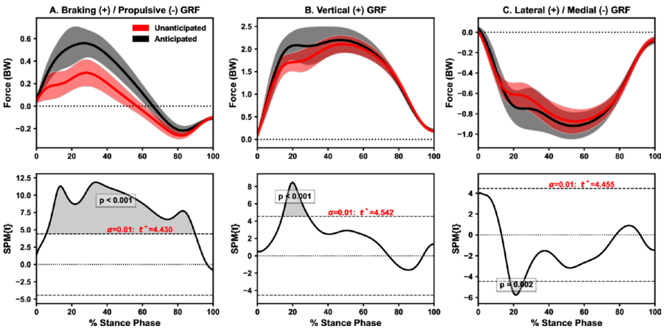

Figure 2 Subplot of unanticipated (red) and anticipated (black) GRFs (top) data from SPM1D paired t-tests (bottom). Braking/propulsive GRFs (A), vertical GRFs (B) and lateral/medial GRFs (C). 100% of stance phase was analysed for GRFs. The region shaded in the SPM1D graphs indicates statistically significant differences. GRF, ground reaction force; SPM1D, one-dimensional statistical parametric mapping.

the reduced approach speeds when performing unanticipated side-step cuts.

Unanticipated side-step cutting trials exhibited lower knee flexion and knee abduction moments across the early stance phase (ie, first 40%). No statistically significant difference between internal/external rotation knee moments was found between conditions. These findings suggest a reduced risk of potentially hazardous ACL loading and strain during unanticipated side-step cutting, which is contrary to our hypothesis and previous literature.[23 24] In previous studies, unanticipated side-stepping frequently elicits changes in knee joint moments associated with increased ACL loading and strain.[25–28] Specifically, increased knee abduction and internal rotation moments during unanticipated COD manoeuvres.[20 25 26] These increased knee joint moments are proposed to occur due to the reduced time available to prepare during unanticipated movement tasks.[20] Our results did not support this hypothesis, with AFLW players experiencing 'safer' lower limb loads when performing the unanticipated condition. A possible explanation is players slowed down (ie, as reflected by the slower approach speeds and increased stance phase time) prior to executing the unanticipated task to allow themselves additional time to safely prepare and execute the movement task. When cognitive demands of a task increase, body postures associated with elevated ACL injury risk are observed,[23 24] therefore we propose by players slowing down this may have counteracted the increased cognitive demand thereby reducing ACL loading.[23–28 34] Typically, during unanticipated conditions additional external cues are processed thereby limiting attention available to employ protective lower limb postures known to reduce ACL loading when executing reactive COD manoeuvres.[23–28 34] Reactive side-step cutting is a high-risk scenario for AFLW ACL injuries.[16] Therefore, the lower knee joint moment findings during unanticipated side-stepping trials are counterintuitive to previous research.

Lower braking and vertical GRFs along with elevated propulsive GRFs were found during unanticipated side-stepping trials. These findings similarly suggest that AFLW players were experiencing overall reduced loads during unanticipated side-step cutting. These findings reveal however, that a greater degree of deceleration may have occurred in the unanticipated trials, which is supported by previous research.[35] Greater knee loading is associated with increased running speeds during COD tasks.[36] At higher running speeds, peak posterior and medial GRFs increase significantly, which is associated with increased ACL loading and strain.[36] Therefore, a slower approach speed may explain the current results (ie, lower braking and medial GRFs). In our study, we controlled the approach speed to be between 3.5 m/s and 5.5 m/s at 2 m prior to the force plate, similar to previous work.[19 22 23 26] Players achieved these speeds, and on average recorded approach speeds of 5.37±0.24 and 5.07±0.28 m/s in the anticipated versus unanticipated conditions, respectively (ie, 5.7% slower in the unanticipated condition). In lieu of having timing gates at initial contact, we reviewed the velocity of the pelvic centre of mass from kinematic data to estimate approach speed at initial contact. We found average initial contact approach speeds of 1.04±0.09 and 0.92±0.11 m/s in the anticipated versus unanticipated conditions, respectively (ie, 11.0% slower in the unanticipated condition). These results of participants exhibiting a relatively larger difference in slower approach speeds in the final steps of the unanticipated condition helps to explain our findings. Considering previous research consistently identify knee loads and forces associated with increased ACL strain during unanticipated side-step cutting,[20 25 26] the slower approach speed and lower GRFs in the current study may explain why 'safer' biomechanics were observed in the unanticipated condition.

Our team's previous research identified unanticipated side-stepping as a high-risk movement task for AFLW ACL injuries.[16] The findings from our present study of reduced knee loads during unanticipated side-step cutting therefore contradict previous studies. We propose that the laboratory testing elicited a 'planned unplanned' (ie, participants were aware that a reactive decision was required, therefore to increase the likelihood to successfully execute the unanticipated task they slowed down their approach) side-step cut, which allowed for players to employ a 'cautious' approach as observed in the lower approach speed and GRFs. In matches, cognitive demand and speed at which movements are executed increases. Future investigations may benefit from the inclusion of a dual-task approach (ie, increases cognitive demand) with unanticipated side-stepping analysis in the laboratory to stimulate a more realistic match-like response.[37] Investigations into unanticipated side-step cutting biomechanics with the addition of a dual-task element (eg, passing a ball) found as task complexity increases, the athlete is more likely to fail at successfully completing the task.[37] It is hypothesised by Frendt and colleagues that during these failed task scenarios, athletes are at a higher-risk of injury.[37] Increased task demands experienced in matches may inhibit an AFLW player's ability to employ the 'cautious' approach observed in the laboratory. Hence, AFLW players may be vulnerable in match scenarios, potentially explaining the presence of hazardous body postures associated with increased ACL loading observed in matches.[16] AFLW ACL injury prevention strategies may therefore benefit from increasing player exposure to match demands (ie, speed and cognition) when targeting side-stepping biomechanics. Replicating match demands in training is of dual benefit to both side-step cutting performance and ACL injury prevention strategies. Encouraging AFLW players to perform the side-step cut at speed promotes acceleration throughout the cut rather than slowing down to execute the task. Players then performing the side-step cuts at match speed and under increased cognitive demands may be better equipped to tolerate full knee loads experienced in matches.

While our study had an injury risk focus, the findings are also relevant to side-stepping performance. The slower approach speed at initial contact when executing unanticipated tasks aligns with previous research.[20 25] Besier *et al*[20] reported consistent approach speeds across unanticipated and anticipated trials, however unanticipated cuts were on average performed ~0.15 m/s slower. This finding perhaps indicating that speed was lost during the performance of the cut.[20] Dempsey and colleagues,[22] observed a 7% decrease in speed of unplanned compared with planned side-stepping tasks.[22] Interestingly, although both papers observed participants having difficulty in performing the unanticipated tasks suggested by the slower speeds,[20 25] only Besier and colleagues[20] observed increased knee loading in the unanticipated task.[20] This may be due to the differences in timing of the stimulus delivery, with Besier and colleagues[20] delaying the delivery of the stimulus.[20] In the current study and Dempsey and colleagues[22] a slower approach speed may have allowed participants to appropriately prepare for the unanticipated tasks in employing desirable postural adjustments known to reduce ACL strain.[20] This provides a potentially protective outcome, but likely has negative performance implications (ie, slower cutting speed).[36] Speed plays a crucial role in the performance of COD manoeuvres,[27] and therefore reducing approach speed should not be considered as a feasible ACL injury prevention approach.[27] As an alternative, a greater emphasis on improving cognitive function (ie, reaction time, information processing speeds) in ACL injury prevention programmes may facilitate improved postural preparation during unanticipated side-stepping without negatively impacting performance.[35 38] This could be achieved through applying a dual-task approach to Australian football movement drills (eg, executing a COD manoeuvre while also hitting a handball target).[39] A dual-task approach increases the cognitive load to a movement task.[39] This recommendation is supported with high-performance athletes exhibiting both superior reactive side-step cutting biomechanics, and enhanced cognitive function (eg, reaction time, information processing speeds, accuracy) compared with non-elite populations.[35 38] If AFLW players can react and process external cues quicker, this may allow for greater attention available to employ safer lower limb postures during unanticipated side-step cutting – providing the dual benefit of enhancing performance while reducing ACL injury risk.

Limitations

First, only side-step cuts performed on the left leg were analysed. This was due to the position of the force plate within the laboratory environment, with insufficient space to allow for a side-step cut being performed on the right leg. Therefore, compared with previous research where the unanticipated condition was generated by randomising the direction of the COD task (ie, to the left or right side of the body), our study randomised three Australian football movement tasks. This may account for some of the differences in our findings compared with previous research. However, there are little biomechanical side-to-side differences found between lower limbs when performing side-step cutting manoeuvres,[40] therefore the impact of this limitation may not be significant. Second, monitoring approach speed across the entire run-up through to task execution across both conditions may have allowed for greater approach speed consistency across conditions. While the different deceleration profiles we observed revealed important factors related to COD technique in AFLW players—we recommend that future studies endeavour to better match approach speed across anticipated and unanticipated conditions for a potentially more accurate comparison. Thirdly, as kinematic factors (eg, trunk kinematics) were not investigated we are unable to understand the technique-related factors that may have contributed to the changes we observed. Therefore, investigation into the kinematics underpinning our findings is warranted for additional insight into the initial findings. Finally, investigation of muscle forces (ie, through the use of electromyography) in future research may provide an additional layer of understanding in this space as to how muscle coordination strategies may differ between the different conditions.

Clinical implications

We observed lower knee joint moments, and lower GRFs in AFLW players performing unanticipated versus anticipated side-step cuts. When coupled with our observation of slower approach speed at initial contact, these findings suggest a 'cautious' approach was employed during unanticipated side-step cutting. This provided a potentially protective outcome by lowering knee loads, but likely has negative performance implications (ie, slower cutting speed). An inability to consciously adopt this 'cautious' approach may explain why ACL injuries occur during these movements in AFLW matches. AFLW ACL injury prevention strategies may be enhanced with greater exposure to scenarios that replicate match cognitive demands and the speed of task execution when aiming to improve side-step cutting biomechanics.

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Patient consent for publication Not applicable.

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