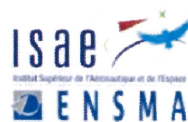


The 33rd International Conference on **Biomechanics in Sports**

Poitiers, France
29 June – 3 July 2015



P R O C E E D I N G S



CARRYING A BALL CAN INFLUENCE SIDESTEPPING MECHANICS IN RUGBY

Scott R Brown, Matt Brughelli and Patria A Hume

Sports Performance Research Institute New Zealand (SPRINZ) at AUT Millennium,
Auckland University of Technology, Auckland, New Zealand

Sidestepping mechanics have been implicated as a risk factor for knee injury in rugby. Carrying a ball is proposed to alter movement patterns. Therefore the purpose of the study was to examine the effects of sidestepping with a ball compared to sidestepping without a ball on lower-extremity biomechanics in male rugby athletes. Three-dimensional kinematics of 18 male rugby athletes were recorded during a maximal effort 45° sidestepping task without and with a ball. Sidestepping with a ball resulted in 15% greater knee adduction angle during weight acceptance and 18% greater hip adduction angle during peak push-off than without a ball. Future biomechanical evaluations of athletes require the inclusion of the ball specific to the sport to ensure accurate interpretation of movement patterns.

KEYWORDS: knee injury, anterior cruciate ligament, ACL, planned, cut, manoeuvre.

INTRODUCTION: Rugby union is the most played contact sport in the world with over seven million participants spanning 120 countries ("Year in Review 2014," 2014). Rugby includes an assortment of physically demanding activities including running, sprinting, kicking, passing, colliding, tackling and scoring; all are required during the course of an 80-minute match (Brown, Brughelli, Griffiths, & Cronin, 2014). Rugby athletes are often plagued with lower-extremity musculoskeletal injuries, specifically hamstring and anterior cruciate ligament (ACL) injury (Brown, Brughelli, & Hume, 2014). The majority of ACL injury rehabilitation claims are classified as non-contact and are seen frequently during sidestepping (Brown, Brughelli, & Hume, 2014). Previous research examining sidestepping has primarily focused on females, footballers or a combination of the two (Brown, Brughelli, & Hume, 2014). With 78% (4.5 million) of all rugby athletes being male ("Year in Review 2014," 2014), there is limited research that has examined male rugby athletes and accurately replicated the tasks seen in match play. While sidestepping has been examined in Australian Rules footballers, the velocities at which the task was performed may potentially be lower than match velocities (Brown, Brughelli, & Hume, 2014), calling into question the applicability of findings. Several authors have examined the influence of ball-handling (Chaudhari, Hearn, & Andriacchi, 2005), passing (Fedie, Carlstedt, Willson, & Kernozek, 2010) and dribbling (Chan, Huang, Chang, & Kernozek, 2009) during sidestepping and have discovered substantial alterations in lower-extremity mechanics. There is no published study that has examined the effects of carrying a ball during sidestepping in rugby; ball retention being a major component of success in rugby ("Year in Review 2014," 2014). The purpose of this research was to examine the effects of carrying a ball on lower-extremity biomechanics during sidestepping compared to sidestepping without a ball in male rugby athletes. It was proposed that sidestepping with a ball would alter knee kinematics relevant to ACL injury risk such as decreased knee flexion angle at initial contact and increased knee adduction angle during weight acceptance.

METHODS: Eighteen male academy (high performance development) rugby athletes (age 20 ± 3 y, body-height 1.9 ± 0.1 m, body-mass 100 ± 14 kg) performed maximal effort 45° sidestepping tasks without and with a rugby ball.

Data collection: The planned sidestepping task (Brown, Wang, Dickin, & Weiss, 2014) consisted of athletes accelerating with maximum effort for 10-m before performing an offensively-initiated evasive manoeuvre, using their preferred kicking leg, at a 45° angle and then reaccelerating out to complete the task. Following a warm-up, static calibration and range of motion trials were captured at 200 Hz with a nine-camera three-dimensional motion capture system (T10S, Vicon Motion System Ltd., Oxford, UK) and a synchronised embedded force platform (Type 9287C, Kistler Instrumente AG, Winterthur, CH) collected at 1000 Hz. Athletes completed a minimum of eight trials without and with a ball given in a random order. A

successful trial consisted of athletes reaching a velocity of ≥ 6 m/s, striking the force platform completely with the sidestepping leg and executing the task as quickly as possible to closely simulate the requirements of a match situation.

Data processing: Athlete-specific joint-centre locations were calculated from the range-of-motion trials using a custom-made MATLAB programme (R2014b, The MathWorks, Inc., Natick, MA, US). Three-dimensional motion and ground reaction force data were filtered with a fourth-order Butterworth low-pass filter using a cutoff frequency of 16 Hz in Visual 3D (4.91.0, C-Motion, Inc., Germantown, MD, US). Knee power data were normalised by body-mass (W/kg) and time data were normalised to stance phase (%; from initial contact to final contact) to facilitate comparison between all athletes. Knee angle and hip data were examined during initial contact, weight acceptance, peak push-off and final push-off phases while knee power and knee velocity were examined at peak braking and peak propulsive phases using another custom-made MATLAB programme (Brown, Wang, et al., 2014).

Data analysis: To describe the results in detail, two-tailed, paired Student's *t*-tests were established and magnitude-based inferences were used to assess the standardised effects (the difference between the means was divided by the standard deviation of the leg sidestepping without a ball; effect size [ES]) of sidestepping with a ball using previously established methods (Hopkins, Marshall, Batterham, & Hanin, 2009). If the confidence limits were within the levels of the negative, trivial or positive mechanistic scale, the outcome was noted as clear and the likelihood of the true effect observed was described. If the confidence limits spanned all three levels, the outcome was noted as unclear.

RESULTS: Performance variable effects of sidestepping with a ball compared to without a ball were: approach velocity (6.6 ± 0.7 m/s and 6.6 ± 0.4 m/s; ES = 0.13) was unclear, stance time (0.19 ± 0.02 ms and 0.19 ± 0.03 ms; ES = 0.013) was likely trivial, depart velocity (6.1 ± 0.4 m/s and 6.2 ± 0.5 m/s; ES = -0.20) was possibly trivial and the angle ($16 \pm 2^\circ$ and $16 \pm 3^\circ$; ES = 0.092) was likely trivial. Knee flexion angle showed a possibly trivial decrease (ES = -0.16) at initial contact, knee adduction angle showed a possibly trivial increase at initial contact, a likely small increase at weight acceptance, a possibly trivial increase at peak push-off (ES = 0.19, 0.38 and 0.17 respectively) and hip adduction angle showed a possibly small increase at peak push-off (ES = 0.27) when sidestepping with a ball compared to without a ball; all other variables showed unclear or trivial inferences (Table 1). Sidestepping with a ball showed peak knee power as unclear and peak knee velocity with a possibly trivial decrease (ES = 0.032 and ES = -0.14 respectively) during the braking phase and possibly trivial decreases (ES = -0.20 and -0.16 respectively) during the propulsive phase compared to without a ball (Figure 1).

DISCUSSION: Studies (Chan, et al., 2009; Chaudhari, et al., 2005; Fedie, et al., 2010) including a ball during sidestepping have noted kinematic increases in knee flexion, knee abduction and hip adduction angles; the current study can only partially support these findings. Knee flexion angle for example, while carrying a ball, was slightly smaller at initial contact and then remained consistent throughout the remaining phases of sidestepping. Knee adduction angle was slightly larger while carrying a ball at all phases of sidestepping; with an unclear inference at final push-off. Unlike Chan et al. (Chan, et al., 2009) who found that dribbling a ball increased knee abduction angle at weight acceptance in female basketball athletes, we found an increased knee adduction angle at initial contact, weight acceptance and peak push-off when sidestepping with a ball which is more in line with findings (Fedie, et al., 2010) while attending to a ball in male and female basketball athletes. Hip adduction angle was larger at all phases while carrying a ball in this study and showed a clear and possibly small increase during peak push-off, which is comparable to findings of larger hip adduction angles (Chan, et al., 2009; Fedie, et al., 2010). Our findings of larger knee and hip adduction angles may be the result of substantially faster velocities while entering (~ 6.6 m/s) and exiting (~ 6.2 m/s) the manoeuvre. In addition, male rugby athletes may present different (unique) sidestepping mechanics as the requirements of the sport differ considerably from those found in male and female basketball athletes.

Table 1. Mean \pm standard deviation of knee and hip joint kinematics during sidestepping without and with a ball and inferences for change of the means.

Joint angles: Sidestepping phase:	Without ball (°)	With ball (°)	With–without ball sidestepping		
			<i>p</i> -value	Mean change; 90% CL	ES: Qualitative inference
Knee flexion (+) / extension (–)					
Initial contact	27 ± 8	26 ± 7	0.091	-1.4; ±1.3	-0.16: Trivial* -ive
Weight acceptance	39 ± 7	39 ± 6	0.732	0.29; ±1.41	0.041: Trivial**
Peak push-off	52 ± 5	52 ± 6	0.919	-0.086; ±1.457	-0.016: Unclear
Final contact	22 ± 7	22 ± 6	0.877	-0.15; ±1.69	-0.023: Unclear
Knee adduction (+) / abduction (–)					
Initial contact	9 ± 5	10 ± 4	0.199	1.1; ±1.5	0.19: Trivial* +ive
Weight acceptance	13 ± 5	15 ± 4	0.023	2.2; ±1.5	0.38: Small** +ive
Peak push-off	18 ± 7	19 ± 6	0.207	1.3; ±1.7	0.17: Trivial* +ive
Final contact	11 ± 5	11 ± 4	0.821	0.16; ±1.24	0.039: Unclear
Hip adduction (+) / abduction (–)					
Initial contact	5 ± 8	6 ± 6	0.179	1.04; ±1.28	0.13: Trivial**
Weight acceptance	6 ± 8	7 ± 7	0.191	0.94; ±1.20	0.12: Trivial**
Peak push-off	10 ± 8	12 ± 7	0.031	2.2; ±1.6	0.27: Small* +ive
Final contact	11 ± 7	11 ± 5	0.561	0.33; ±0.97	0.055: Trivial***

Values are means \pm standard deviation; mean change; \pm confidence limits (CL) (90%); ES, effect size; (+) and (–) , positive and negative values associated with the corresponding angle; +ive and -ive, substantial positive and negative change with ball relative to without ball sidestepping; trivial and small inference: 25-74%, possibly (*); 75-94%, likely (**).

The results for knee power and knee flexion velocities were unclear or trivial mechanistically and are most likely due to large confidence limits. While further work is needed in this area to clarify our findings, it is interesting that smaller peaks were observed in knee joint power while the knee velocity peaks were similar when sidestepping with a ball during the braking and propulsive phases when compared without a ball. During these phases, the ACL and other soft tissue structures in the lower-extremity have the potential to experience a greater amount of loading over a longer period as a result of increased tension development (Brown, Wang, et al., 2014). If sidestepping without a ball elicits greater energy absorption and production peaks, the ACL may experience greater tensile loading; results of which may present incorrect or misleading information that are unrepresentative of those found during match play. Furthermore, when compared to female footballers performing sidestepping on the preferred leg without a ball, the male rugby athletes in this study elicited substantially larger power absorption (-34 vs -23 W/kg; 33%), power production (20 vs 12 W/kg; 42%), knee flexion velocity (-708 vs -499 deg/s; 30%) and knee extension velocity (587 vs 530 deg/s; 10%) (Brown, Wang, et al., 2014). Based on this simple observation, it would seem essential that male and female athletes should not be placed into the same data pool for lower-extremity analyses.

While purely speculative at this time, the altered mechanics of sidestepping with a ball compared to without a ball as observed in this study may be the due, in part, to the athletes' ingrained protection of the ball to maintain possession. In order to acquire a similar centre-of-mass position without the use of the arms (e.g. while carrying a ball) and obtain the same performance objective, an athlete may be required to reorient the trunk and/or the lower-extremities. As this topic was not the focus of the current study, further investigation is required to accept or reject this contention.

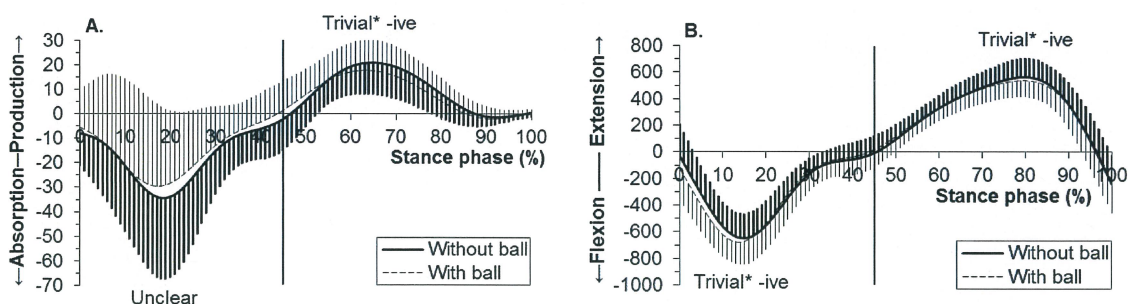


Figure 1: Graphical representations of (A.) knee power (W/kg) and (B.) knee velocity (deg/s) without and with a ball during the stance phase of sidestepping; error bars, equivalent to one standard deviation; vertical line, indicates the division of the braking and propulsive phases; -ive, substantial negative change with ball relative to without ball sidestepping; trivial inference: 25-74%, possibly (*).

CONCLUSION: Sidestepping with a ball resulted in 15% greater knee adduction angle during weight acceptance and 18% greater hip adduction angle during peak push-off than without a ball; implicating that sidestepping with a ball alters lower-extremity mechanics relevant to ACL injury risk. It is suggested that future biomechanical evaluations of athletes require the inclusion of the implement/ball specific to the sport in order to ensure accurate interpretation of movement patterns.

REFERENCES:

- Brown, S.R., Brughelli, M., Griffiths, P.C., & Cronin, J.B. (2014). Lower-extremity isokinetic strength profiling in professional rugby league and rugby union. *International Journal of Sports Physiology and Performance*, 9(2), 358-361.
- Brown, S.R., Brughelli, M., & Hume, P.A. (2014). Knee mechanics during planned and unplanned sidestepping: A systematic review and meta-analysis. *Sports Medicine*, 44(11), 1573-1588.
- Brown, S.R., Wang, H., Dickin, D.C., & Weiss, K.J. (2014). The relationship between leg preference and knee mechanics during sidestepping in collegiate female footballers. *Sports Biomechanics*, 13(4), 351-361.
- Chan, M.S., Huang, C.F., Chang, J.H., & Kernozek, T.W. (2009). Kinematics and kinetics of knee and hip position of female basketball players during side-step cutting with and without dribbling. *Journal of Medical and Biological Engineering*, 29(4), 178-183.
- Chaudhari, A.M., Hearn, B.K., & Andriacchi, T.P. (2005). Sport-dependent variations in arm position during single-limb landing influence knee loading: Implications for anterior cruciate ligament injury. *The American Journal of Sports Medicine*, 33(6), 824-830.
- Fedie, R., Carlstedt, K., Willson, J.D., & Kernozek, T.W. (2010). Effect of attending to a ball during a side-cut maneuver on lower extremity biomechanics in male and female athletes. *Sports Biomechanics*, 9(3), 165-177.
- Hopkins, W.G., Marshall, S.W., Batterham, A.M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, 41(1), 3-12.
- Year in Review 2014. (2014). Retrieved 2015, from World Rugby at: <http://www.worldrugby.org/documents/annual-reports>

Acknowledgements

Scott R Brown was funded by the AUT Vice Chancellors PhD scholarship. The authors thank the athletes and staff of the Auckland Rugby Academy team for their participation; Thor F Besier for his contribution to the structure, organisation and support of the study; and Allan B Carman, Anna V Lorimer and Kaitlyn J Weiss for their assistance with data collection and processing.

THE EFFECT OF LIMB PREFERENCE ON KNEE MECHANICS DURING A FATIGUED UNANTICIPATED SIDESTEPPING MANOEUVRE

Kaitlyn J. Weiss & Scott R. Brown

Sport Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand

Fatigue may adversely affect knee kinetics and kinematics during the sidestepping manoeuvre. There is a lack of research examining the effect of limb preference on knee mechanics during fatigued unanticipated sidestepping. Twelve female collegiate soccer and field hockey players performed right and left unanticipated sidestepping prior to and following completion of a fatigue protocol. Magnitude based inferences were used to assess the impact of limb preference on knee mechanics during initial contact, weight acceptance, peak push-off, and final push-off of the sidestep. The preferred limb was more likely to experience increased coronal plane loading, whereas the non-preferred limb is more likely to experience increased transverse plane loading during fatigued, unanticipated sidestepping.

KEYWORDS: kinetics, kinematics, football, field hockey, females.

INTRODUCTION: The sidestepping manoeuvre is a dynamic sports task that allows the performer to change direction from standing, walking, or running. Poor mechanical execution of the sidestep manoeuvre can place the ligaments of the knee at the greatest risk of injury (Sanna & O'Connor, 2008). Given the majority of dynamic sidestepping tasks are not pre-planned during games, anticipated manoeuvres are likely not a true reflection of lower extremity mechanics.

The use of unanticipated dynamic tasks such as sidestepping is meant to mimic the nature of the task's performance in game situations (Cortes et al., 2011). Ilmanen and LaRue (2008) discovered that temporal constraints (self-initiated, anticipation-coincidence, and reaction condition) have a significant effect on anticipatory postural adjustments. These anticipatory postural adjustments are centrally produced as a feed-forward mechanism to offset the mechanical effects of predicted perturbations on stability in dynamic sports tasks. During an unanticipated task an individual's ability to adjust to the environmental perturbations commonly experienced during a game or practice may be restricted, making them more susceptible to potential injury.

The majority of reported anterior cruciate ligament (ACL) injuries in team sports occur towards the end of the game, indicating that fatigue may enhance non-contact ACL injury risk (Hawkins & Fuller, 1998). Fatigue can influence the muscular mechanisms of the lower extremities, resulting in kinetic and kinematic changes when compared to non-fatigue conditions (Dierks, Davis, Hamill, 2010). In an evaluation of fatigue on single limb landing, increases in knee valgus angles were reported when landing direction was unanticipated, and may have been due to the effect of fatigue on coordination and timing. These results suggest that ACL injury risk may increase when both fatigue and decision-making conditions are present (Santamaria & Webster, 2010).

Previous research has assessed lower-limb preference related to the risk of ACL injury and athletic performance (Matava, Freehill, Grutzner, & Shannon, 2002; Negrete, Schick, & Cooper, 2007). Though significance between limbs in terms of injury risk has not been consistently observed, limb asymmetries may still pre-dispose athletes to injury (Matava et al., 2002; Negrete et al., 2007). More recently, a study comparing limb preference and ACL injury risk found that the majority of males injured their preferred limb, whereas the majority of females injured their non-preferred limb (Brophy, Silvers, Gonzales, & Mandelbaum, 2010). Research by Brown et al. (Brown, Wang, Dickin, & Weiss, 2014) identified differences between limbs during planned sidestepping in female footballers that indicated the non-preferred limb may be at an increased risk of ACL injury during weight acceptance, while the preferred limb may be at an increased risk of injury in the peak push-off phase of sidestepping. Though both soccer and field hockey don't impart a huge demand on one limb versus the other, it is still

probable that a disparity will exist between limbs.

Though several studies have looked at the effect of fatigue and anticipation on knee mechanics during dynamic sports tasks, none have observed the impact of limb preference in these instances. Since unanticipated sidestepping towards the end of a game is likely accompanied by increased risk of injury, it is important to investigate how limb preference impacts knee mechanics in these instances.

The primary purpose of this study was to investigate magnitude of difference in knee mechanics due to the effect of limb preference during a fatigued unanticipated sidestep task.

METHODS: Twelve college-aged National Collegiate Athletic Association Division I female football and field hockey players volunteered for this study (mean age = 20.31 ± 1.84 years; height = 1.68 ± 0.05 m; mass = 61.99 ± 6.45 kg).

Players came to the laboratory for a single testing session. Using a modified plug-in-gait model, markers were placed on anatomical landmarks of both the upper and lower body that included 4-marker clusters on each thigh and shank. The preferred limb (PL) was defined as the leg used to kick a ball, and the opposite limb was defined as the non-preferred limb (NL) (Matava et al., 2002). All players identified their PL as the right limb. Players performed a self-selected dynamic warm-up for ten minutes, followed by three vertical jumps to determine maximum jump height. Players practiced at least three of each sidestepping task (i.e., sidestep left, sidestep right and stop) or more trials until they felt comfortable. Timing gates were set up 3 m from the centre of the force plates so that as participants ran through the timing gates, custom built computer software randomly generated an instruction (i.e., direction arrows or a stop sign) for the dynamic task for projection onto a screen in front of the player. After completing the warm-up and practice trials, players performed the Yo-Yo Intermittent Recovery Test (YYIRT) (Krustrup & Bangsbo, 2001). This protocol consisted of repeated high intensity 20 meter shuttle runs starting at 10 km/h and increasing on successive trials by 0.5 km/h with 10 seconds of recovery after each trial (20m x 2), and was repeated until the player was unable to successfully complete two 20m sprints in the allotted time. Players then ran for two minutes on a treadmill in the testing area at their estimated $\text{VO}_{2\text{max}}$ speed as calculated by the YYIRT, followed by vertical jumps until they were unable to reach 80% of their maximum vertical jump height for three successive jumps. Finally, players performed the post-fatigue randomized dynamic tasks trials, without a rest period between each trial. The post-fatigue trials were considered complete once four good right and left sidesteps had been performed.

The raw marker trajectory data were reconstructed in Nexus (VICON, Oxford Metric Ltd., Oxford, UK) and processed in Visual3D (C-Motion, Germantown, MD, USA) with the use of standard segment and joint definitions. External net joint moments were calculated using standard inverse dynamics equations. Three-dimensional knee angles were calculated using a joint coordinate system approach. Knee moments were normalized to body mass and height and were displayed as Nm/kgm. The time data for all variables were normalized with respect to stance phase time (distinguished as the point from initial contact to toe-off of the stance limb, as established by the force platforms' 10N threshold readings) to allow for comparisons to be made between players. The variables were divided into several phases within stance consistent with previously determined definitions (Besier, Lloyd, Cochrane, & Ackland, 2001) and were detected using a custom Matlab (The MathWorks, Inc., Natick, MA, USA) program for initial contact, weight acceptance, peak push-off, and final push-off.

Statistical analyses included: a two-tailed, paired Student's t-test assessing the preferred versus the non-preferred limbs at a significance level of 0.05 calculated in SPSS (Version 19.0 for Windows, SPSS Inc., Chicago, IL, USA); the standard error of the measurement, 90% confidence limits, and differences between the means (the non-preferred limb minus the preferred limb) calculated using the post-only crossover Excel spreadsheets from Sportsci.org. Standardisation was used to evaluate the magnitude of the difference (i.e. the difference between the means divided by the standard deviation for the preferred limb). To evaluate the magnitude of the standardized effects threshold values of 0.0 (trivial), 0.2 (small), 0.6 (moderate), 1.2 (large), 2.0 (very large), and 4.0 (extremely large) were used to represent differences (Hopkins, Marshall, Batterham, & Hanin, 2009). The uncertainty in the estimates

of effects on limb preference was extracted at 90% confidence limits and additionally as probabilities that the true effect value was either substantially positive or negative.

RESULTS and DISCUSSION: Dependent t-tests across all sidestepping trials confirmed there were no significant differences in sidestepping speed or contact time between limbs. In comparison to the preferred limb, the non-preferred limb showed small increases in knee internal rotation moment at initial contact (ES = 0.53, -89%); small decreases in knee abduction moment at weight acceptance (ES = -0.48, -63%); small decreases in knee abduction moment (ES = -0.56, 81%) and small increases in internal rotation moment (ES = 0.55, -60%) at peak push-off; small decreases in knee abductor moment (ES = -0.57, -87%) and small increases in internal rotation moment (ES = 0.26, -15%) at final push-off. All other kinematic and kinetic differences between limbs were unclear.

The preferred limb was more likely to experience increased coronal plane loading, whereas the non-preferred limb was more likely to experience increased transverse plane loading during fatigued, unanticipated sidestepping. Both limbs had similar knee flexion angles during the stance phase, ranging from 23-49°. Given the relatively small knee flexion angles, it is likely that both coronal and transverse plane loading coupled with shallow knee flexion will place the ligaments at an increased risk of injury.

According to previous studies, the ACL experiences greater tension when knee flexion angles fall within 0° to 40° during sidestepping (Besier, Lloyd, Ackland, & Cochrane, 2001; Markolf et al., 1995). Our results suggest the ACL may have experienced high levels of tension in both the preferred and non-preferred limbs given during the initial contact of sidestepping, the average knee flexion angle was approximately 24° and increased to an average of 48° during peak push-off. It is possible the ACL was experiencing high tension across all four phases of sidestepping. In the preferred limb, knee abduction moment was greater from initial contact through peak-push-off, likely increasing the amount of tension experienced by the ACL. The combination of shallow knee flexion angles of <30° at initial contact and final push-off and greater internal rotation moments make the ACL of the non-preferred limb also likely to experience greater loading. This same trend appeared with respect to abduction moments, which would have increased the risk of injury to both the ACL and the medial collateral ligament (MCL). The MCL is primary in resisting internal rotation and abduction loads at approximately 30° of knee flexion, as experienced by both limbs in our study (Garrett & Yu, 2007). Focusing on both increasing stability in the coronal plane and transverse plane, as well as focusing on correct mechanical execution of sidestepping on both limbs under fatigued conditions may help to offset the risk of ACL injury. Training including single limb multi-planer dynamic loading may increase the ability of the knee joint to attenuate these loads during these tasks.

CONCLUSION: The purpose of this study was to investigate magnitude of differences in knee mechanics due to the effect of limb preference during a fatigued unanticipated sidestep task. The preferred limb displayed greater coronal plane loading, indicating the need for training and conditioning focused on increasing coronal plane stability, whereas the non-preferred limb displayed greater transverse plane loading, and thus potentially requires greater stability in the transverse plane.

REFERENCES:

- Besier, T. F., Lloyd, D. G., Ackland, T. R., & Cochrane, J. L. (2001). Anticipatory effects on knee joint loading during running and cutting maneuvers. *Medicine and Science in Sports Exercise*, 33(7), 1176-1181.
- Besier, T. F., Lloyd, D. G., Cochrane, J. L., & Ackland, T. R. (2001). External loading of the knee joint during running and cutting maneuvers. *Medicine and Science in Sports Exercise*, 33(7), 1168-1175.

- Brophy, R., Silvers, H. J., Gonzales, T., & Mandelbaum, B. R. (2010). Gender influences: the role of leg dominance in ACL injury among soccer players. *British Journal of Sports Medicine*, 44(10), 694-697.
- Brown, S. R., Wang, H., Dickin, D. C., & Weiss, K. J. (2014). The relationship between leg preference and knee mechanics during sidestepping in collegiate female footballers. *Sports Biomechanics*, 13(4), 351-361.
- Garrett, W. E., & Yu, B. (2007). Anterior cruciate ligament injury mechanisms and risk factors. *The Journal of Orthopaedic and Sports Physical Therapy*, 37(2), A10-11.
- Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports Exercise*, 41(1), 3-13.
- Markolf, K. L., Burchfield, D. I., Shapiro, M. M., Shepard, M. E., Finerman, G. A. M., & Slauterbeck, J. L. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. *Journal of Orthopaedic Research*, 13(6), 930-935.
- Matava, M. J., Freehill, A. K., Grutzner, S., & Shannon, W. (2002). Limb dominance as a potential etiologic factor in noncontact anterior cruciate ligament tears. *Journal of Knee Surgery*, 15, 11-16.
- Negrete, R. J., Schick, E. A., & Cooper, J. P. (2007). Lower-limb dominance as a possible etiologic factor in noncontact anterior cruciate ligament tears. *Journal of Strength and Conditioning Research*, 21(1), 270-273.