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An individualised approach to assess the sidestep manoeuvre in rugby union athletes

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Abstract

The appropriateness by which anterior cruciate ligament injury risk information is commonly interpreted from, using group/team data, is fundamentally questionable when compared to the importance of individual differences and their impact on injury risk. This study compared external knee abduction moments during sidestepping on each leg and to qualitatively assess the differences between group means and individual athletes. A descriptive cross-sectional study involving sixteen male academy-level rugby union athletes (age, 20 ± 3 years; body-height 1.9 ± 0.1 metres; body-mass 99 ± 14 kilograms). Athletes performed three maximal effort sidesteps (> 6.0 $m \cdot s^{-1}$) each on the preferred and non-preferred leg using marker-based three-dimensional motion analysis techniques. Quantitative comparisons were made between the legs while qualitative comparisons were made been the group means and the individual athletes. When sidestepping on the non-preferred leg, athletes produced 25% greater knee abduction moments (ES=0.43) and presented modified postural adjustments associated with injury risk (extended knee [ES=-0.26; -8%], more trunk lateral flexion [ES=42; 17%] and more distance between the centre-of-mass and ankle-joint-centre of the stance leg [ES=0.97; 11%]) compared to the preferred leg. Individually, only 9 out of 16 athletes presented a higher abduction moment in their non-preferred leg with individual asymmetries ranging between 2.2 and 47%. Nearly half of our athletes showed the potential to "slip under the radar" of traditional group mean assessments. When assessing athletes "at risk" for ACL injury, individual data must be examined in conjunction with group means for a holistic view of the problem.

Keywords: knee injury, anterior cruciate ligament, biomechanics, screening.

INTRODUCTION

Anterior cruciate ligament (ACL) injuries occur frequently in sport (8). There is a high frequency of ACL injury rates reported for male athletes (18) wherein the sidestep is the most common manoeuvre associated with non-contact ACL injury (12). During the stance phase of a sidestep the knee experiences applied flexion, abduction and internal rotation moments (1), which are combined loads that increase ACL strain (24). Ligament injury occurs when the external forces exceed the mechanical properties of the tissue; which is believed to occur within the first 30% of stance phase (12, 21). Therefore, assessment and potential interventions to reduce ACL injury have focused on reducing these key kinetic variables, particularly the applied knee abduction moment (11, 13, 15). Kinematic variables that can contribute to increasing external knee abduction moments include smaller knee flexion angle, larger trunk lateral flexion angle, larger distance between the centre-of-mass of the body (COM) and the ankle-joint-centre (AJC) and increased speed and angle of the sidestep (14). Continual sidestepping on a single leg, in addition to the positional requirements of rugby, may then develop or further augment a neuromuscular asymmetry between the legs; potentially affecting lower-extremity injury risk (6, 8).

During the sidestep, there is evidence to suggest that that female footballers (soccer) are more likely to injure their non-preferred kicking leg; supporting the hypothesis that leg preference contributes to the aetiology of non-contact ACL injuries (3). To our knowledge, there are only two (9, 26) biomechanical studies that have attempted to examine joint moments with respect to leg preference during sidestepping; providing limited support to the retrospective evidence. Brown and colleagues (9) also found that female footballers experienced greater external abduction moments in the non-preferred leg while sidestepping, however in contrast, Marshall and colleagues (26) found that male rugby athletes experienced greater internal varus (external abduction) moments in the preferred leg. While the differences in knee abduction moment between legs of both studies were only small (ES = ~0.2), the information regarding differences between the legs aligns with the retrospective evidence seen by Brophy et al. (3). However as both studies incorporated different athletes, methods and analyses, any meaningful inference of the combined data is difficult at this time; yet the idea remains promising.

Following traditional data collection procedures of the sidestep, information is typically reported as group means and standard deviations (8). By using means, researchers are able to group athletes together to make meaningful inferences based on the data; *i.e.* difference between the means, spread of the data, etc. While this is an important structure to have when comparing 40-m sprint performance for example, group means also have the potential to miss individual variability within and between athletes. Individual responses have previously been observed in footwear comfort perception, leading authors (29) to comment on the importance of evaluating individual results when making decisions that may ultimately affect the group. When evaluating variables that are associated with injury risk (*i.e.* external knee abduction moment during sidestepping), missing individuals that may need further attention is counterintuitive to the very purpose of injury risk assessments (4). While few authors (1, 28) have mentioned the ability for unique knee mechanics to be present while sidestepping, a full inclusion and subsequent dissemination of individual knee abduction moments while sidestepping among a similar athlete cohort has yet to be performed.

The main purpose of this research was two-fold: firstly, we wanted to assess the sidestep manoeuvre at velocities and angles similar to what might be performed in rugby union match-play and then examine the differences in external knee abduction moment at weight acceptance between the preferred and non-preferred legs; secondly, we wanted to qualitatively compare the differences between group means and individual means of external knee abduction moment during weight acceptance. Falling in line with similar sidestepping research (9, 14, 15), we theorised that the non-preferred leg would present greater "at risk" mechanics (*i.e.* larger abduction moments during weight acceptance along with less knee flexion, greater distance between the COM and AJC and more lateral trunk flexion during initial contact) compared to the preferred leg. We also speculated that the athletes would present a substantial range of individual differences in knee abduction moments between the legs during sidestepping. This final venture was proposed based on similar rugby codes research showing a substantial range of differences between the legs in other biomechanical measures like strength and sprint mechanics (5, 6).

METHODS

Experimental Approach to the Problem

A cross-sectional design was used to compare external knee abduction moments between legs during a maximal effort sidestep (> 6.0m·s^{-1}) and assess the qualitative differences between group mean and individual data. Testing occurred during the athletes' off-season after ~24 h of rest. At the time of this study all athletes were free from injury in the previous six months, either chronic or acute, that may have inhibited them from performing the required sidestepping task. All athletes were cleared by the team's medical staff for full competitive play.

Athletes

Sixteen male academy (high-performance development) rugby athletes (mean ± SD; age 20 ± 3 yr, body-height 1.9 ± 0.1 m, body-mass 99 ± 14 kg, body-mass index 29 ± 4 kg·m^{-2}) participated in this research. Athletes consisted of forwards (*n* = 12) and backs (*n* = 4) from European and Pacific Island descent and had an average playing experience of 11 ± 4 yr, encompassing >151 matches played per athlete. Fifteen athletes indicated their right leg as their preferred kicking leg while one forward specified the left leg; denoted as the leg at which they preferred to kick the ball with or which they could kick the furthest with.

The *Sample-size estimation* Excel spreadsheet for use with magnitude based inferences (found at sportsci.org) identified a minimum of 16 athletes were necessary to show a clear effect with the smallest worthwhile difference of 0.20 when using a kinetic effect size of 0.42 from similar research (9) and concurrent analysis of the collected kinetic data of the present study (19). Constraints from many of the athletes' professional contracts resulted in only 16 "healthy and cleared-to-play" athletes available for testing. All procedures used in this study were approved by the Auckland University of Technology Ethics Committee (#13/378) and all athletes provided their informed verbal and written consent prior to data collection.

Procedures

All athletes were fitted with identical, size appropriate compression clothing (Nike Pro Compression, Nike, Inc., Beaverton, OR, USA) and wore the same cross-training shoes (GEL-KUROW, ASICS Ltd., Kobe, JPN). Athletes performed a general self-selected lower-extremity dynamic warm-up, identical to the team's weight training, practice and game warm-up procedures. All athletes in this study preformed a planned sidestepping manoeuvre in each direction (9).

The sidestepping task was performed on an indoor track surface (Sportflex Super X, Mondo U.S.A. Inc., Conshohocken, PA, USA) using the athlete's preferred and non-preferred leg (n = 15 right, n = 1 left). Athletes were given a 10-m runway in which to maximally accelerate before performing a sidestep into a channel located at 45° from the centre of the force platform and then maximally reaccelerating out to complete the task. Specifically, an athlete would step with their right foot when sidestepping to the left and vice versa. Athletes were verbally and visually instructed on how to perform the sidestepping task and were allowed adequate familiarisation of the protocol. Testing began only when they felt comfortable with performing the movement at a maximal effort. When ready, athletes completed a minimum of three trials in each direction given in a random order. A successful trial consisted of athletes reaching an approach velocity of ≥ 6.0 m·s^{-1}, striking the force platform completely with the sidestepping foot and executing the task as quickly as possible to closely simulate the requirements of a match situation. Sidestepping velocity was determined in real-time by a Stalker Acceleration Testing System (ATS) II radar device (Model: Stalker ATS II, Applied Concepts, Dallas, TX, USA) secured to a tripod positioned 3-m behind the starting line at a height of 1-m above the ground, approximately in-line with the athlete's COM. Tape lines the same width of the force platform (600-mm) were provided to direct athletes through the initial runway and the 45° exit paths (**Figure 1**).

INSERT FIGURE 1 HERE

At the beginning of the collection, a laboratory calibration were completed to establish the capture volume (collection area) and position of the nine-cameras (T10S, Vicon Motion System Ltd., Oxford, GBR) relative to each other and the laboratory origin (front right corner of the force platform [Type 9287C, Kistler Instrumente AG, Winterthur, CHE]). To create a three-dimensional model for analysis, the University of Western Australia full-body marker set (2, 14, 23) was modified to include additional spherical retro-reflective markers (10-mm width) to improve redundancy through the dynamic sidestepping manoeuvre (78 total). All markers were placed on specific anatomical locations by a highly trained, Level-3 certified ISAK anthropometrist. The upper-body model (32 markers) consisted of eight single markers placed on the left/right superior border of the acromion process, superior border of the manubrium (sternal notch), inferior boarder of the xiphoid process, spinous process of the seventh cervical and tenth thoracic vertebrae and left/right inferior angle of the scapulae to create the 'thorax' segment and eight single markers placed on the medial/lateral epicondyles of the humerus and on the styloid processes of the ulna and radius of both arms to create the 'upper-arm' and 'lower-arm' segments. The lower-body model (46 markers) consisted of six single markers placed on the left/right iliac crest and left/right posterior/anterior superior iliac spines to create the 'pelvis' segment, ten single markers placed on the left/right greater trochanters, medial/lateral femoral condyles and medial/lateral malleoli of both legs to create the 'upper-leg' and 'lower-leg' segments and fourteen single markers placed on the superior/inferior posterior calcaneus, navicular tuberosity, cuboid and head of the first, third and fifth metatarsals of both feet to create the 'foot' segment. Additionally, four-marker cluster sets attached to thermo-moulded plastic shells were added to the upper- and lower- arm and leg segments to increase redundancy about the joints (**Figure 2**).

INSERT FIGURE 2 HERE

Static and range-of-motion calibration trails were performed on the individual athletes using Vicon Nexus software. Elbow, wrist, knee and ankle medial markers were removed after the calibration trials were complete to allow for the dynamic movement of the testing protocol. Athlete-specific helical-axis joint centre locations for the hips and knees were calculated from the range of motion trials (hip star and squats respectively) using a custom-made MATLAB programme (R2014b, The MathWork, Inc., Natick, MA, USA) (2, 31). Synchronised three-dimensional motion (100 Hz) and ground reaction force (1000 Hz) data were filtered with the same low-pass fourth-order zero-lag Butterworth filter using a cutoff frequency of 16 Hz in Visual 3D (4.91.0, C-Motion, Inc., Germantown, MD, USA) based on residual analysis and visual inspection of the kinematic and kinetic data (22).

Sidestepping performance variables (*i.e.* velocity, angle and stance time of the sidestep) were calculated in Visual 3D to allow comparison between the preferred and non-preferred leg. Sidestep velocity ($m \cdot s^{-1}$) was calculated via tracking the athlete's COM before (approach) and after (depart) the stance phase. Stance time (s) was calculated from the instant vertical force rose above 10 N (initial contact) to the time vertical force dropped below 10 N (final contact). Sidestep angle (θ) was calculated using the x- and y-coordinates of the stance foot AJC at initial contact (x_1 and y_1) and the coordinates of the contralateral AJC at final contact (x_2 and y_2) using Equation 1 (**Figure 3**):

1. Sidestep angle $(\theta) = tan^{-1}(\frac{a}{b})$;

where

$$a = |x_2 - x_1| \text{ and } b = |y_2 - y_1|.$$

Sidestepping mechanical variables (*i.e.* knee flexion angle, trunk lateral flexion and COM to AJC distance) were also calculated in Visual 3D during initial contact. Knee flexion angle (θ) was defined as the angle between the thigh and shank segments, where full knee extension represented 0º of knee flexion. Trunk lateral flexion angle was defined as the angle between the thorax (trunk) and the ground; where a straight posture represented 0º of trunk lateral flexion. The COM to AJC distance (m) is was calculated using the x-coordinates of the COM (x_3) and the AJC (x_1) using Equation 2 (**Figure 3**):

2. Distance from the centre-of-mass to the ankle-joint-centre (m) $= |x_3 - x_1|$.

INSERT FIGURE 3 HERE

Finally, knee abduction moments were calculated using standard inverse dynamics equations and were defined as those externally applied to the segment's distal end. Moments were normalised to body-mass and body-height ($Nm \cdot kg^{-1} \cdot m^{-1}$) and time data were normalised to stance phase (%; from initial contact to final contact) to facilitate comparison between all athletes. Moment data were analysed during weight acceptance (the average between initial contact and the first trough in the unfiltered vertical ground reaction data [**Figure 4a**]) (8). Initial contact and weight acceptance phases were calculated using a custom-made MATLAB programme (9). Individual asymmetries were calculated using a non-dimensional modified symmetry angle equation (37) to report the absolute difference of external knee abduction moments between the legs (preferred leg versus the non-preferred leg) described in Equation 3 (**Figure 4b**). This equation was chosen as it does not require an arbitrary reference leg, is unaffected by artificial inflation by near-zero numbers and is useful in determining clinically relevant information in sports science (16, 17, 37). In-line with previous research (37), we decided to implement an initial 15% threshold as a means for separating the data into “acceptable” ranges of symmetry (< 15%) and asymmetry (≥ 15%) such that the interpretation of the data would change between the two groups.

3. Absolute symmetry angle $(ABS\theta_{SYM}) = \dfrac{\left|45 - \left(tan^{-1}\left[\frac{preferred}{non\text{-}preferred}\right]\right)\right|}{90} \times 100;$

but if

$$\left|45 - \left(tan^{-1}\left[\frac{preferred}{non\text{-}preferred}\right]\right)\right| > 90,$$

then

$$(ABS\theta_{SYM}) = \frac{\left|45 - \left(tan^{-1}\left[\frac{Preferred}{Non\text{-}preferred}\right] - 180\right)\right|}{90} \times 100.$$

Statistical Analyses

The *Post-only crossover* Excel spreadsheet employing magnitude-based inferences (found at sportsci.org) was used to describe the standardised effects of leg preference on knee mechanics (20). The preferred leg was chosen as the reference in this study as it is commonly chosen for analysis purposes (9). Uncertainty in the estimates of effects on leg preference was expressed at 90% confidence limits and as probabilities that the true value of the effect was substantially negative (-ive) and positive (+ive). Qualitative probabilistic inferences regarding the true effect were then made (20). If the probabilities of the true effect being substantially positive and negative were both >5%, the effect was expressed as unclear; otherwise the effect was clear and expressed as the non-clinical (mechanistic) magnitude of standardised effects with threshold values of <0.2, 0.2, 0.6, 1.2 for trivial, small, moderate and large differences respectively (20). The scale for interpreting the probabilities was: 25-75%, possibly (*); 75-95%, likely (**); 95-99.5%, very likely (***); and >99.5%, most (or extremely) likely (****).

RESULTS

Performance variables executed on the preferred and non-preferred leg are presented in Table 1. All athletes displayed similar approach velocity (ES = 0.045), depart velocity (ES = -0.057) and sidestep angle (ES = -0.19) when comparing sidestepping off the preferred and non-preferred legs. There was a clear but small difference in absolute stance time (ES = -0.23) between the legs; further justifying the normalisation of the kinematic and kinetic data to stance time. All mechanical variables showed clear differences between the preferred and non-preferred legs as presented in Table 1. The non-preferred leg demonstrated 8% smaller knee flexion angles (ES = -0.26), 17% larger trunk lateral flexion angles (ES = 0.42) and 11% larger COM to AJC distance (ES = 0.97) during initial contact of the sidestep.

INSERT TABLE 1 HERE

Figure 4a illustrates (in grey) the small but clear difference between the group average for knee external abduction moments during weight acceptance for the preferred leg compared to the non-preferred leg (0.61 ± 0.32 and 0.76 ± 0.44 $Nm\cdot kg^{-1}\cdot m^{-1}$, respectively; ES = 0.43; 25%). Individual athlete averages for knee abduction moments, presented in Figure 4b, shows seven athletes have a -ive slope (44%; larger average external knee abduction moment in the preferred leg) while nine have a +ive slope (56%; larger average external knee abduction moment in the non-preferred leg). Also within this cohort, just over half of the athletes (56%) presented "acceptable" symmetry angle scores (< 15%; range: 2.2 – 14), whereas the remaining 44% presented asymmetrical scores (≥ 15%; range: 15 – 47).

INSERT FIGURE 4 HERE

DISCUSSION

The sidestep manoeuvre is a very unique movement which is associated with high ACL injury risk. The continued examination of sidestepping has greatly increased our knowledge of non-contact ACL epidemiology in sport and has aided in the creation of helpful injury prevention training programmes. To enhance ecological validity, the sidestepping task has become more sport-specific to replicate the typical demands the athlete would experience at the time of injury by increasing the velocity, including a ball, and affecting reaction time, decision-making and complexity to name a few. A primary component of the current study was to replicate the faster velocity of the sidestep to closely resemble those experienced in male rugby union athletes; as such, approach velocity was constrained to $\geq 6.0\ m \cdot s^{-1}$. Our two-fold purpose was to examine non-contact ACL injury risk via knee abduction moment at weight acceptance in the preferred and non-preferred legs: (1) using standard quantitative techniques of obtaining group means; and (2) using a qualitative method to investigate individual variability within/between the athletes. While both methods showed clear results, they provide different views into injury risk status and unique insight into subsequent injury prevention strategies.

To our knowledge, this is the first sidestepping study where the athletes were required to produce an approach velocity of $\geq 6.0\ m \cdot s^{-1}$ with a subsequent maximal acceleration out of the sidestep. Rapid entry and exit from the sidestep replicates the goals of the manoeuvre during match play (34). While the exit angle was controlled, the actual sidestep angle was calculated and reported in order to present the true angle based off foot placement. We found that the increased velocities of the task resulted in a decreased sidestep angle (~24°) from the initial 45° pathways used to direct the athletes exit strategy. Previous literature (8) has also observed higher velocities associated with greater differences between the actual and attempted sidestep angle. The sidestepping angle was considered a secondary performance variable compared to the overall velocity of the movement, therefore angle was not a constraint in the study design; rather, an informative addition. As a purpose of this study was to replicate the sidestep in a match like manner, exit velocity was monitored and quantified to assess and comment on the athletes' ability to reaccelerate following the change-of-direction; a common performance variable (30, 36). The athletes' ability to reaccelerate after the stance phase of the sidestep was affected only marginally (6.1 m·s^{-1}; 6.9% decrease from the approach velocity), highlighting the athletes' skill at effective energy transfer during the stance phase (10).

The average group external abduction moments at the knee during weight acceptance showed a small and clear difference between the legs. Brown et al. (9) previously reported a 19% greater external abduction moment during the weight acceptance phase of the sidestep in the non-preferred leg compared to the preferred leg in National Collegiate Athletic Association Division I female footballers. Similarly, our results show a 25% greater abduction moment for the non-preferred leg compared to the preferred leg. Brown et al. (9) surmised that the mechanical differences found between the legs may have resulted in greater knee flexion velocity and greater power absorption during the braking phase (weight acceptance) coupled with a larger internal rotation angle, thus potentially increasing the tension of the ACL in the non-preferred leg. The absolute magnitude of the abduction moment produced by the male rugby athletes in the current study is up to 4x greater than that produced by female footballers (9) and 2.5x greater than that of similar male athletes (8); even when normalised to body-mass and body-height. It is proposed that the greater velocity of the side step approach and exit contributed to the increased moments.

While sidestepping on the non-preferred leg we observed a decreased knee flexion angle (a more extended stance leg), an increased trunk lateral flexion angle (leaning more towards the stance leg side) and an increased distance between the COM and AJC (the stance leg is further away from the body) compared to the preferred leg. Landing with the leg in a more extended position can increase the resultant strain at the ACL (24, 25). Additionally, while sidestepping off of the non-preferred leg, athletes showed greater trunk lateral flexion angles and a further distance between the COM and AJC compared to sidestepping on the preferred leg; both of which have been shown to increase knee abduction moments (14). Our results were slightly larger compared to previous research (13, 14) that reported lateral trunk flexion angles between 7–8° (compared to our 14–17°) and COM to AJC distances between 34–37cm (compared to our 36–40cm). The greater kinematic differences found in our study may also be explained by the larger body-mass (80 vs 99kg) and/or faster velocity (5.7 vs 6.5m·s^{-1}) in this rugby union cohort. Additionally, as the location of the AJC gets further away from the body, the trunk needs to laterally flex more to ensure the COM stays close to the base-of-support to maintain balance during the sidestep, explaining the increase in both variables.

Group means and standard deviations are frequently used in sports science research when describing a certain attribute of a cohort. However, an individual and detailed look at each athlete should be performed to benefit all athletes. Said beautifully by Mündermann and colleagues (29), "…subgroups of individuals exist and that the evaluation of individual results can reveal important information that may not be obtained by the analysis of group means." The current study reinforces the idea that individual differences have great potential to be masked by group means, as seen in our results. Another purpose of this research was to qualitatively compare the group means to the individual data when assessing abduction moments at weight acceptance as a surrogate for injury risk. Figure 4b shows all sixteen athletes' individual and mean abduction moment values produced by both legs and compared to the group mean (discussed previously).

Presenting the data individually allows for three important observations: (1) variability within each athletes' leg (the vertical spread of the Xs and Os); (2) each athletes' deviation from the group mean (the vertical distance between the solid back squares and the grey lines); and (3) symmetry within each athlete (the positive/negative slope of the black lines). As seen in the results, each of these observations were unique to the athlete. A somewhat balanced distribution was apparent between the number of athletes that produced larger abduction moments on their preferred leg versus those that produced larger abduction moments on their non-preferred leg (9/7 respectively). Interestingly, the athletes that were furthest outside the group mean (#8 and 15) or showed the largest asymmetry (#16) did so by producing larger abduction moments on their non-preferred leg. The larger moments experienced could have been a result of the larger kinematic alterations while sidestepping off of the non-preferred leg, or perhaps the result of a greater hip abduction and/or internal rotation moments which have been found to increase knee abduction moments during sidestepping (27). Lower-extremity strength could also play a role in the results, as hip strength (the ability to stabilise the hip/pelvis of the stance leg while decelerating) has been shown to be an important factor of body position during sidestepping (32, 33). The influence of hip strength on sidestepping mechanics warrants further investigation as rugby union athletes have been shown to possess strength asymmetries at the hip across multiple levels of experience (6, 7).

The current study illuminated several interesting findings with regards to the sidestep manoeuvre in male rugby athletes. From a task acquisition stand-point, all athletes performed the task to a similar level of efficiency and completed the sidestep manoeuvre within the provided 45º paths at the required velocity of $\geq 6.0\ m \cdot s^{-1}$. Upon closed look however, the athletes presented unique postural techniques while sidestepping potentially increasing knee abduction moment in the non-preferred leg. While these unique postures have been proposed to increase ACL injury risk (14), to our knowledge there has been only one attempt where authors (9) suggested a clear distinction in knee mechanics between the preferred and non-preferred legs. Similarly, our findings suggest that the non-preferred leg may experience a greater risk of injury while sidestepping by an inability to establish an appropriate posture; thus placing the body in an “at risk” position and directing more of the external force towards the knee and challenging its structural integrity to resist an abducted (valgus) position.

We feel it is important to acknowledge limitations in the current study to give context to the interpretations of our findings. First, while we attempted to improve the ecological validity of the sidestep as it pertains to male rugby union athletes, our study was still conducted in a laboratory-based setting. As such, the interpretation of the results should account for additional environmental factors such as surface, footwear and climate that may potentially affect sidestepping mechanics (35). Second, unplanned sidestepping more accurately represents the task demands of match play (8) however, we were not ethically permitted to perform such a modification on the professionally contracted athletes in the current study due to the potential for increasing injury risk. Future authors whom are not confined with such limitations should examine a similar experimental process with the inclusion of unplanned sidestepping to gain greater insight into the importance of the neuromuscular system (22). Third, while our sample size was sufficient enough to detect a small worthwhile change (an effect size of at least

0.20) between the legs, a larger sample may show a smaller, equal or greater variation of individual responses of knee abduction moments during the sidestep compared to the data in the current study. Fourth, we expressed the probability levels of ACL injury risk based on scaled differences in knee mechanics between the two legs. During which, the knee mechanics of the preferred leg served as the reference leg. Thus, results from this study are only comparable with ACL injury risk studies of similar statistical analyses at this time (9).

While our observations that the non-preferred leg of the *group* of athletes is at an increased risk of injury risk are correct, the interpretations can show a substantially different picture when accounting for the *individual* athlete. For example, if the group results from this study where interpreted as: 'increase lower-extremity strength, postural stability and sidestepping technique in the non-preferred leg to decrease external knee abduction moments and injury risk', nearly half (44%) of the athletes may have missed out on any beneficial training effect. However if the individual results from this study were interpreted as: 'each athlete presents a unique injury risk profile while sidestepping and must therefore be given an individualised training programme to decrease external knee abduction moments and injury risk', the potential for a greater percentage of the group benefitting from a training effect would theoretically increase. Unfortunately these final statements are purely speculative at this time as there is little to no research investigating the effects of individualised injury prevention training to decrease external knee abduction moments while sidestepping among a group of male rugby athletes; accounting for each leg as a unique structure with unique attributes.

Moving forward, we suggest the continuation of examining "at risk" scenarios (*i.e.* sidestepping) in athletes but with the inclusion of individual results to show the true spread of the data and to highlight athletes requiring special attention outside of the traditional team training prescription. Whether this information is presented within the academic journal article itself or via appendices, supplemental material or other online source (ResearchGate.net 'Dataset') is solely up to the discretion of the authors and/or journal editors. Further, while the inclusion of both legs in any injury risk assessment seems paramount to the complete picture of an athlete's status to subsequently base injury prevention recommendations, research is greatly lacking in this area. Although symmetrical athletes are thought to exist (and perhaps even seen on occasion), realistically the majority of athletes (especially male rugby athletes [as seen in the current study]) will have some sort of unique asymmetry as a result of genetics, sport, previous injury or other. When assessing injury risk, our job as sports scientists or clinicians is to find the asymmetry and provide direction to strength and conditioning practitioners.

PERSPECTIVE

- Interpreting group mean data in isolation has the potential to mask the athletes whom may be "at risk" for ACL injury and whom might benefit the greatest from a targeted intervention;
- Healthy male rugby athletes show a somewhat equal distribution of injury risk (large external knee abduction moment) on each leg while sidestepping at a maximal velocity;
- Injury risk assessments should be examined on an individual and group basis to illuminate athletes whom (1) are outside of normal / expected group limits; (2) have high levels of variability within the movement; and / or (3) show large asymmetries.

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REFERENCES

1. Besier TF, Lloyd DG, Cochrane JL, and Ackland TR. External loading of the knee joint during running and cutting maneuvers. *Med Sci Sports Exerc* 33: 1168-1175, 2001.

2. Besier TF, Sturnieks DL, Alderson JA, and Lloyd DG. Repeatability of gait data using a functional hip joint centre and a mean helical knee axis. *J Biomech* 36: 1159-1168, 2003.

3. Brophy RH, Silvers HJ, Gonzales T, and Mandelbaum BR. Gender influences: The role of leg dominance in ACL injury among soccer players. *Br J Sports Med* 44: 694-697, 2010.

4. Brown SR and Brughelli M. Assessment strategies for individualised injury prevention in sport. *N Z J Sports Med* 41: 78-79, 2014.

5. Brown SR and Brughelli M. Determining return-to-sport status with a multi-component assessment strategy: A case study in rugby. *Phys Ther Sport* 15: 211-215, 2014.

6. Brown SR, Brughelli M, and Bridgeman LA. Profiling isokinetic strength by leg preference and position in rugby union athletes. *Int J Sports Physiol Perform*: in press, 2015.

7. Brown SR, Brughelli M, Griffiths PC, and Cronin JB. Lower-extremity isokinetic strength profiling in professional rugby league and rugby union. *Int J Sports Physiol Perform* 9: 358-361, 2014.

8. Brown SR, Brughelli M, and Hume PA. Knee mechanics during planned and unplanned sidestepping: A systematic review and meta-analysis. *Sports Med* 44: 1573-1588, 2014.

9. Brown SR, Wang H, Dickin DC, and Weiss KJ. The relationship between leg preference and knee mechanics during sidestepping in collegiate female footballers. *Sports Biomech* 13: 351-361, 2014.

10. Brughelli M, Cronin J, Levin G, and Chaouachi A. Understanding change of direction ability in sport: A review of resistance training studies. *Sports Med* 38: 1045-1063, 2008.

11. Cochrane JL, Lloyd DG, Besier TF, Elliott BC, Doyle TLA, and Ackland TR. Training affects knee kinematics and kinetics in cutting maneuvers in sport. *Med Sci Sports Exerc* 42: 1535-1544, 2010.

12. Cochrane JL, Lloyd DG, Buttfield A, Seward H, and McGivern J. Characteristics of anterior cruciate ligament injuries in Australian football. *J Sci Med Sport* 10: 96-104, 2007.

13. Dempsey AR, Lloyd DG, Elliott BC, Steele JR, and Munro BJ. Changing sidestep cutting technique reduces knee valgus loading. *Am J Sports Med* 37: 2194-2200, 2009.

14. Dempsey AR, Lloyd DG, Elliott BC, Steele JR, Munro BJ, and Russo KA. The effect of technique change on knee loads during sidestep cutting. *Med Sci Sports Exerc* 39: 1765-1773, 2007.

15. Donnelly CJ, Elliott BC, Doyle TLA, Finch CF, Dempsey AR, and Lloyd DG. Changes in knee joint biomechanics following balance and technique training and a season of Australian football. *Br J Sports Med* 46: 917-922, 2012.

16. Exell TA, Gittoes MJR, Irwin G, and Kerwin DG. Gait asymmetry: Composite scores for mechanical analyses of sprint running. *J Biomech* 45: 1108-1111, 2012.

17. Exell TA, Irwin G, Gittoes MJR, and Kerwin DG. Implications of intra-limb variability on asymmetry analyses. *J Sports Sci* 30: 403-409, 2012.

18. Gianotti SM, Marshall SW, Hume PA, and Bunt L. Incidence of anterior cruciate ligament injury and other knee ligament injuries: A national population-based study. *J Sci Med Sport* 12: 622-627, 2009.

19. Hopkins WG. Estimating sample size for magnitude-based inferences. *Sportscience* 10: 63-70, 2006.

20. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-12, 2009.

21. Krosshaug T, Nakamae A, Boden BP, Engebretsen L, Smith G, Slauterbeck JR, Hewett TE, and Bahr R. Mechanisms of anterior cruciate ligament injury in basketball: Video analysis of 39 cases. *Am J Sports Med* 35: 359-367, 2007.

22. Lee MJC, Lloyd DG, Lay BS, Bourke PD, and Alderson JA. Effects of different visual stimuli on postures and knee moments during sidestepping. *Med Sci Sports Exerc* 45: 1740-1748, 2013.

23. Lloyd DG, Alderson J, and Elliott BC. An upper limb kinematic model for the examination of cricket bowling: A case study of Mutiah Muralitharan. *J Sports Sci* 18: 975-982, 2000.

24. Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GA, and Slauterbeck JL. Combined knee loading states that generate high anterior cruciate ligament forces. *J Orthop Res* 13: 930-935, 1995.

25. Markolf KL, Wascher DC, and Finerman GA. Direct in vitro measurement of forces in the cruciate ligaments. Part II: The effect of section of the posterolateral structures. *J Bone Joint Surg Am* 75: 387-394, 1993.

26. Marshall B, Franklyn-Miller A, Moran K, King E, Richter C, Gore S, Strike S, and Falvey É. Biomechanical symmetry in elite rugby union players during dynamic tasks: An investigation using discrete and continuous data analysis techniques. *BMC Sports Sci Med Rehabil* 7: 1-13, 2015.

476 27. McLean SG, Huang X, and van den Bogert AJ. Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: Implications for ACL injury. *Clin Biomech* 20: 863-870, 2005.

479 28. McLean SG, Neal RJ, Myers PT, and Walters MR. Knee joint kinematics during the sidestep cutting maneuver: Potential for injury in women. *Med Sci Sports Exerc* 31: 959-968, 1999.

482 29. Mündermann A, Stefanyshyn DJ, and Nigg BM. Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Med Sci Sports Exerc* 33: 1939-1945, 2001.

485 30. Nimphius S, McGuigan MR, and Newton RU. Relationship between strength, power, speed and change of direction performance of female softball players. *J Strength Cond Res* 24: 885-985, 2010.

488 31. Piazza SJ, Okita N, and Cavanagh PR. Accuracy of the functional method of hip joint center location: Effects of limited motion and varied implementation. *J Biomech* 34: 967-973, 2001.

491 32. Pollard CD, Davis IM, and Hamill J. Influence of gender on hip and knee mechanics during a randomly cued cutting maneuver. *Clin Biomech* 19: 1022-1031, 2004.

493 33. Pollard CD, Sigward SM, and Powers CM. Gender differences in hip joint kinematics and kinetics during side-step cutting maneuver. *Clin J Sport Med* 17: 38-42, 2007.

495 34. Sayers MGL and Washington-King J. Characteristics of effective ball carries in Super 12 rugby. *Int J Perform Anal Sport* 5: 92-106, 2005.

497 35. Shultz SJ, Schmitz RJ, Benjaminse A, Chaudhari AM, Collins M, and Padua DA. ACL Research Retreat Vl: An update on ACL injury risk and prevention, March 22-24, 2012, Greensboro, NC. *J Athl Train* 47: 591-603, 2012.

36. Spiteri T, Cochrane JL, Hart NH, Haff GG, and Nimphius S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci* 13: 646-652, 2013.

37. Zifchock RA, Davis I, Higginson J, and Royer T. The symmetry angle: A novel, robust method of quantifying asymmetry. *Gait Posture* 27: 622-627, 2008.

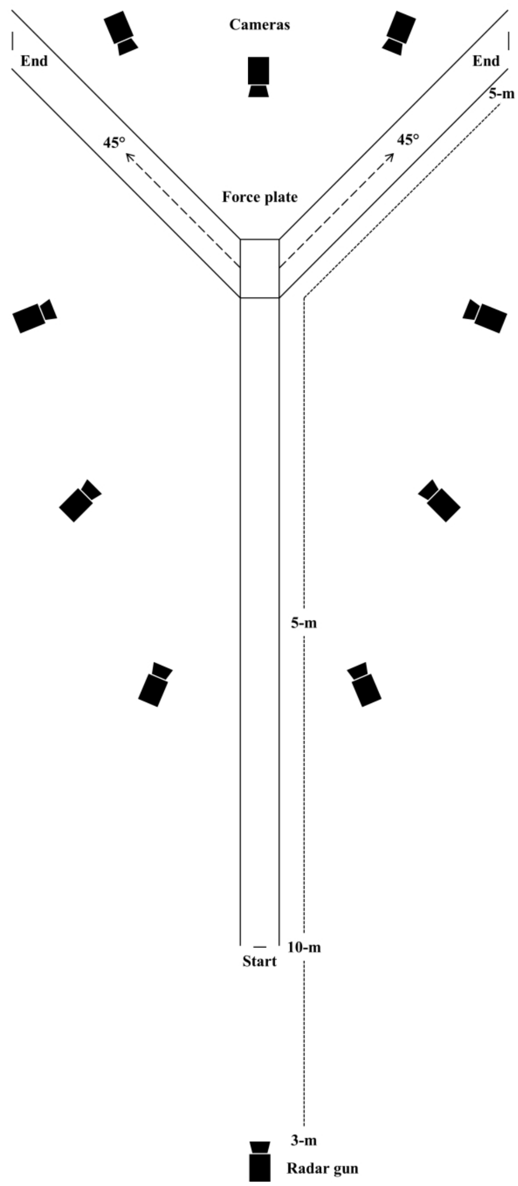
FIGURE LEGEND

Figure 1. Experimental setup.

Figure 2. The Auckland University of Technology (AUT) full-body marker set.

Figure 3. Sidestepping variable configuration. a, opposite side length; b, adjacent side length; d, distance; θ, theta or 'angle'; AJC, ankle-joint-centre; COM, centre-of-mass; (x, y), coordinates.

Figure 4. (a) Group mean unfiltered vertical ground reaction force (Newton per kilogram of body-mass [$N \cdot kg^{-1}$]) during sidestepping for the preferred (solid black line) and non-preferred (dashed black line) leg. Group mean external knee abduction moments (Newton-metre per kilogram of body-mass per metre of body-height [$N \cdot kg^{-1} \cdot m^{-1}$]) during sidestepping for the preferred (solid grey line) and non-preferred (dashed grey line) leg. Small inference; **likely, 75–94%. +ive; substantial positive change of the non-preferred leg relative to the preferred. **(b)** Individual peak external knee abduction moments (Newton-metre per kilogram of body-mass per metre of body-height [$N \cdot kg^{-1} \cdot m^{-1}$]) during weight acceptance of sidestepping for sixteen individual male rugby athletes. Data shown (Xs and Os) are each trial of the sidestep manoeuvre performed on the preferred and non-preferred leg respectively. Solid black squares represent the average of the three trials on each leg. Solid and dashed grey bars represent group mean data for the preferred and non-preferred legs respectively. Data are presented in ascending order based on 1.) the negative (-ive) and positive (+ive) slope of the solid line connecting the average moment data of each leg [a negative slope signifies the preferred leg experienced a larger external knee abduction moment whereas a positive slop signifies the non-preferred leg experienced a larger moment]; and 2.) the absolute symmetry angle score shown in brackets beneath the athlete's number.



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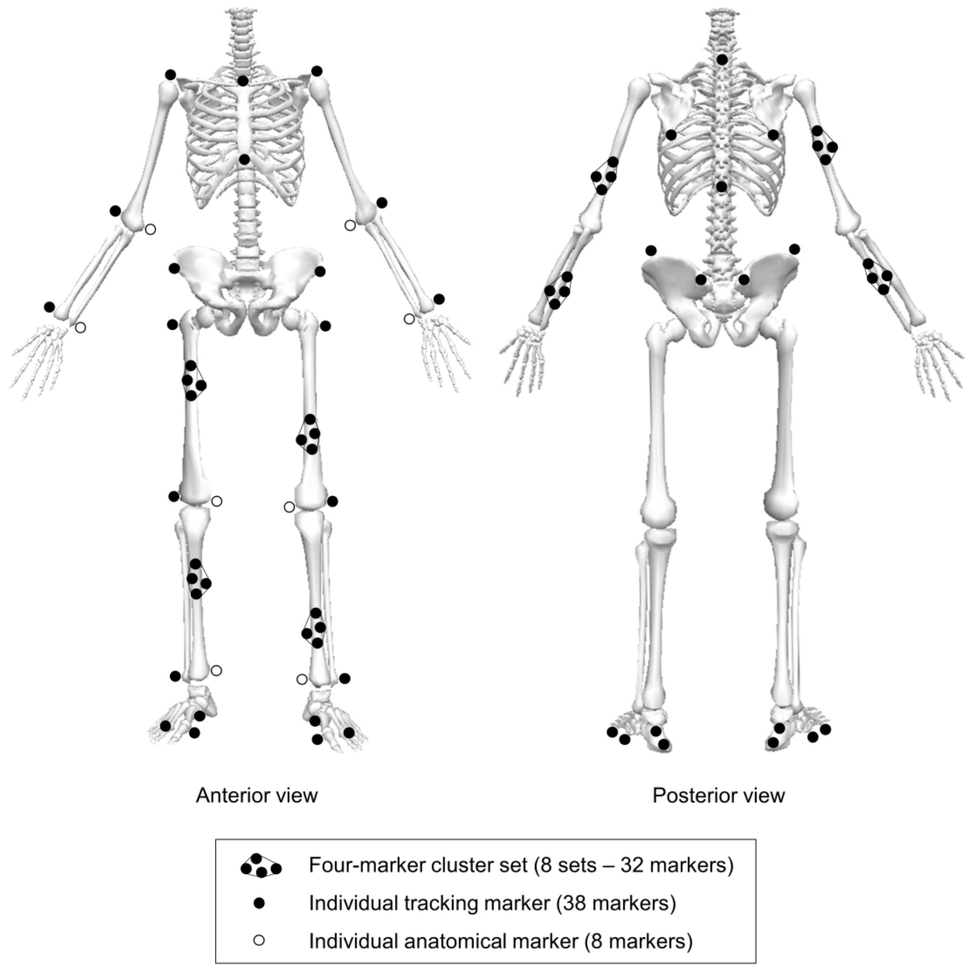

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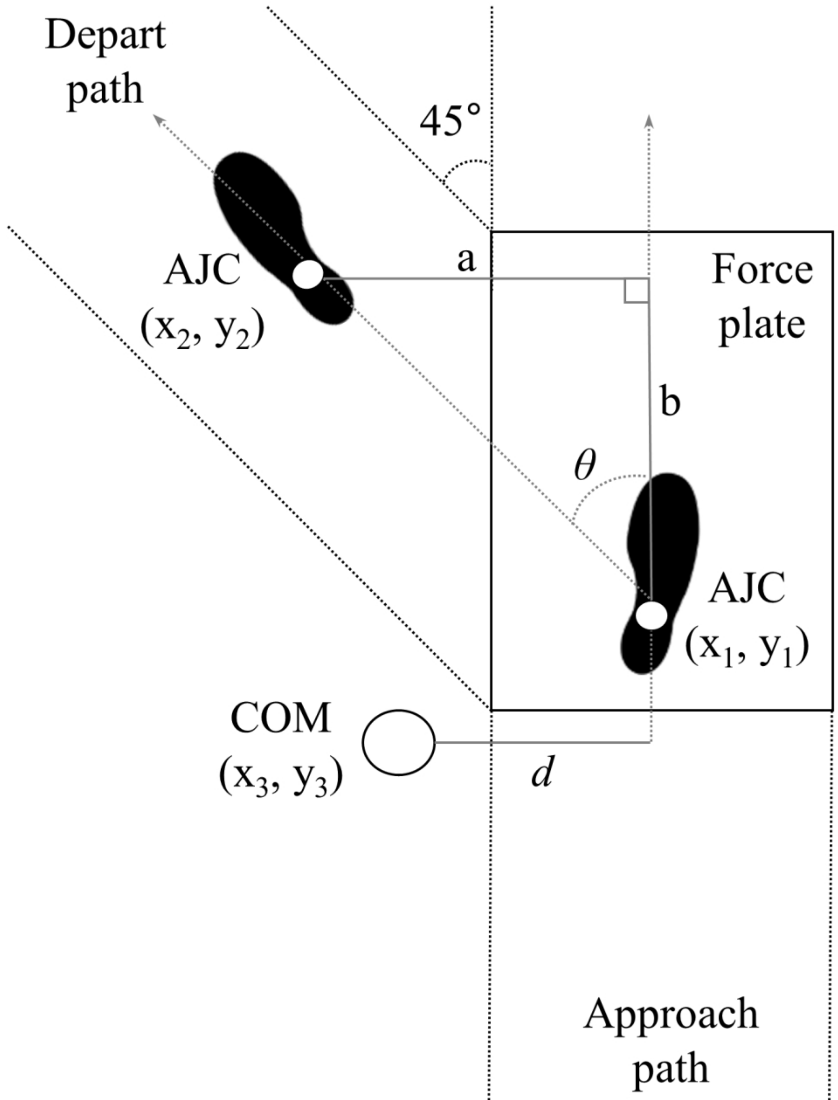

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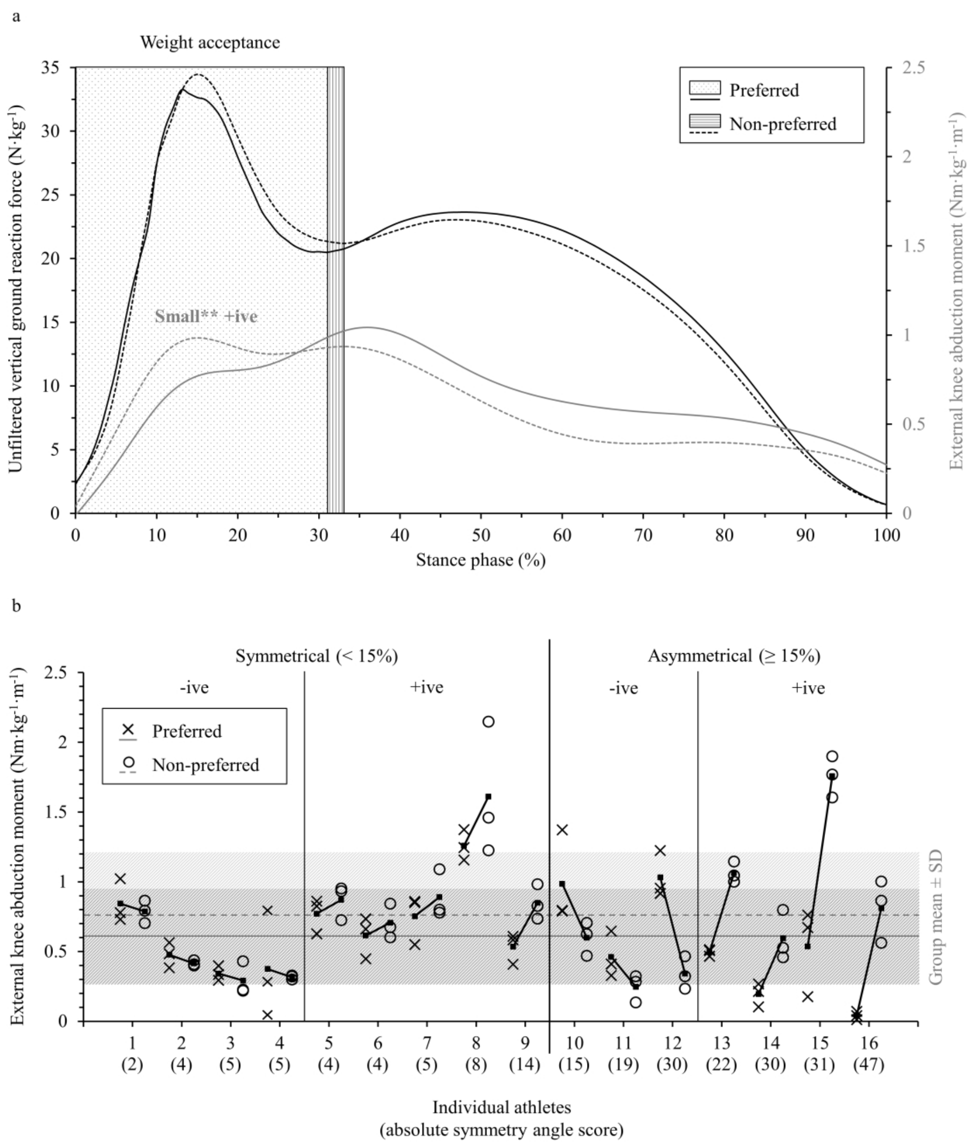

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Table 1

Performance and mechanical sidestepping variables. Performance variables occurred throughout the sidestep whereas mechanical variables occurred at initial contact (the instant vertical force rose above 10 N) of the sidestep.

			Non-preferred – preferred	
	Preferred	Non-preferred	Mean change; ±90% CL	Qualitative inference
Performance variables				
Approach velocity ($m \cdot s^{-1}$)	6.5 ± 0.5	6.5 ± 0.4	0.045; ±0.083	Trivial** +ive
Stance time (s)	0.18 ± 0.03	0.18 ± 0.02	-0.0061; ±0.0046	Small* -ive
Depart velocity ($m \cdot s^{-1}$)	6.1 ± 0.5	6.1 ± 0.4	-0.027; ±0.084	Trivial** -ive
Sidestep angle (Deg)	25 ± 4	24 ± 3	-0.73; ±0.99	Trivial***
Mechanical variables at initial contact				
Knee flexion angle (Deg)	27 ± 8	25 ± 6	-2.2; ±1.5	Small* -ive
Trunk lateral flexion angle[a] (Deg)	14 ± 6	17 ± 6	2.5; ±1.32	Small** +ive
COM to AJC distance (m)	0.36 ± 0.04	0.40 ± 0.04	0.039; ±0.013	Moderate*** +ive

Abbreviations: CL, confidence limits; m, metre; s, second; deg, degree, [a] contralateral to the sidestepping direction, -ive; COM, centre-of-mass; AJC, ankle-joint-centre. Values are means ± standard deviation and mean change; ±90% confidence limits. Trivial, small and moderate inference: *possibly, 25–74%; **likely, 75–94%; ***very likely, 95-99.5%. -ive and +ive = substantial negative and positive change of the non-preferred leg relative to the preferred.

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