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Introduction

In many team sports ACL injuries are unfortunately common, with the vast majority requiring reconstructive surgery and extensive rehabilitation, prior to athletes returning to pre-injury activities [11]. Even with surgery, sufferers of an ACL injury are at increased risk of developing osteoarthritis later in life, a disease with its own significant associated cost, both financially and in terms of quality of life [28]. In team sport settings 50-80% of ACL injuries occur in non-contact situations [1, 6, 9]. From an injury prevention perspective this is beneficial, as it indicates that modifying the characteristics of an individual may be sufficient to reduce the risk of ACL injury.

The first step in developing a prevention protocol is to identify the etiology of injury. Numerous anatomical studies [30, 31, 43] have shown that, although the ACL's primary function is to prevent anterior tibial translation, it is also loaded by both valgus and internal rotation moments. Modeling work by McLean et al. [34] found that, during landing and sidestep cutting tasks, anterior drawer loads in isolation were not sufficient to rupture the ACL and that valgus and internal rotation loads were essential. Therefore, *in vivo* loading in one plane may not be sufficient to rupture the ACL and rather an interaction and/or combination of loading from more than one plane increases the likelihood of injury, although there is still debate within the field in regards to this view [33, 42].

The effects of all three knee loading directions on ACL load have been shown to be altered by knee angle. In general terms, as knee flexion angle increases there is a reduction in the resultant strain on the ACL [15, 30]. However, when compared to anterior drawer in isolation, the application of both an anterior drawer and internal rotation load to the knee below 20° of knee flexion causes an increase in the resultant strain on the ACL [30]. The same is seen with a combination of valgus and anterior drawer from 15° to 50° of knee flexion [30].

In a sport setting non-contact ACL injuries often occur during sidestep cutting tasks [9], which have increased valgus and internal rotation moments at the knee compared with straight line running [2, 3]. Furthermore, ACL injuries often occur during an unplanned or "spur of the moment" sidestep cut, which has been shown to produce higher knee loads than those that occur during a planned maneuver [2]. In a prospective study, Hewett et al. [20] found that female athletes, who went on to suffer an ACL injury, recorded higher valgus loads when performing a jump landing in the laboratory. Analysis of ACL injuries occurring during sports such as team handball and Australian Rules Football have also shown that at the point of injury, the knee tends to collapse into valgus [6, 9, 37].

Video analysis has provided further clues to the mechanisms of ACL injury where athletes have exhibited similar body postures during sidestep cutting tasks that resulted in ACL injury. Specifically, at initial contact, these postures have been an abducted hip, extended knee joint, externally rotated foot and laterally flexed and rotated torso [6, 9, 22, 24, 37]. Our previous work imposed sidestep cut techniques on athletes in a laboratory setting and found that postures reflecting an abducted hip, laterally flexed torso and rotated torso resulted in increased valgus and/or internal rotation moments [12]. However, a more extended knee joint in isolation did not result in significantly increased moments. Studies linking body posture with knee loading during sidestep cutting tasks have also reported similar results [35, 40]. With this knowledge the question then arises; can we use technique modification to reduce non-contact ACL injuries?

Two previous studies have attempted to modify technique in an endeavor to reduce the risk of ACL injury. Ettlinger and colleagues [13] used videos of injuries in association with key technique points to teach ski instructors to recognize dangerous postures, and avoid these postures. Although the study was successful in reducing ACL injury rates it cannot be readily adopted in the team sport setting as skiing has a vastly different injury mechanism to team sports that involve sidestep cutting tasks [5]. There is not sufficient time after initial foot contact for an athlete to modify their technique prior to the injury occurring. Henning [17] taught team sports athletes to avoid using sidestep cuts and sharp decelerations, instead using cross over cuts, which have since been shown to produce knee moments that unload the ACL when compared to sidestep cuts [2, 3], and multistep decelerations. Although this study was also successful in reducing ACL injury rates, Henning's protocol requires substantial changes to the 'standard' technique usually seen in change of direction tasks during match play and may not therefore be readily accepted by the sports community.

The aim of this study was to examine whether changes to sidestep cutting technique could reduce knee loading. The chosen technique was based upon our previous work [12], where athletes performing a sidestep cut were trained to bring the stance foot closer to the midline of the body and position the torso, such that it was upright and facing in the general direction of travel. It was hypothesized that during sidestep cutting participants would display significant changes in the selected technique variables with accompanied reductions in the three-dimensional knee moments from pre- to post-training.

Methods

Twelve male non-elite team sport (5 Australian football, 5 rugby union, and 1 soccer) athletes (height 184.3 ± 5.4 cm, mass 80.2 ± 12.5 kg) who were experienced in performing a sidestep cut and who had no history of major lower limb injury or disease were recruited as participants. Nine participants completed the study with the three withdrawals caused by participants external time constraints. Participants were recruited through contact with sporting clubs and from the university. A power analysis conducted on our previous work [2] that revealed significant differences between planned and unplanned sidesteps indicated that for 80% power with the alpha set at $p=0.05$, 7 subjects were required. Ethics approval was obtained from The University of Western Australia Human Research Ethics committee and written, informed consent was obtained from all participants prior to data collection.

Experimental Design

Participants were tested twice, immediately prior to and following 6 weeks of technique modification training, which progressed from closed to more open skills practice. This progression required participants to move from performing the skill in a predictable environment at a time of the participant's choosing (closed skill) to performing the skill in an unpredictable environment where the execution of the skill was cued by external factors (open skill) [29]. This has been shown to produce better outcomes than only practicing a skill in an open environment[16]. Training was performed in small groups (1-2 participants), twice a week with each session lasting 15 minutes. Each week, designated technique training goals determined the structure of the drill set for that week (Appendix 1). All participants successfully achieved each weekly goal through the prescribed drills. During training, which was performed by the one instructor, participants were given both oral and visual feedback for the designated technique goal. The visual feedback used TimeWARP (SilconCOACH, Dunedin, NZ) to provide immediate feedback on their sidestep cut technique together with reference videos of athletes performing cuts using the desired technique. Participants aimed to gradually bring the stance foot closer to the midline of the body, ensure the stance foot was neither turned in nor turned out, and to maintain an upright torso, with the torso facing in the direction of travel (Figure 1). To guide participants in bringing their foot closer to the midline, markings were painted on the ground to indicate the outer limits of acceptable foot placement.

During testing all trials were performed on a 20 m x 15 m runway and recorded using a 12 camera VICON MX motion analysis system sampling at 250 Hz (VICON Peak, Oxford, UK). Ground reaction forces were synchronously recorded at 2000 Hz from a 1.2 m x 1.2 m force plate (Advanced Mechanical Technology Inc., Watertown, USA). Before commencing trials, participants selected the preferred foot with which they would perform the sidestep cut.

The testing protocol was similar to that used previously by our group [2, 3, 12]. After adequate warm up and task familiarization, the participants were required to perform at least four successful trials of three maneuvers; a straight run, a sidestep cut and a cross over cut, under two different conditions; planned and unplanned. The sidestep cut, which along with the cross over cut, were to 45° ± 5°, was selected to permit comparisons with the literature [20, 35, 40]. For this study only the sidestep cut trials were analyzed, with the other trials retained to avoid anticipation of this maneuver during the unplanned tasks. Using a target board with three high intensity light emitting diodes, participants were given cues for one of the three tasks in both the planned and unplanned conditions. For the planned trials participants received the cue prior to the trial commencing. During unplanned trials participants were cued approximately 400 ms prior to reaching the force plate, the actual cue time was based upon their approach speed, the latter being monitored using infrared timing gates linked to custom software.

A trial was considered successful if the subject performed the required sidestep cut at 5.2 ± 0.5 $m.s^{-1}$ and achieved a cut angle of 45° ± 5, based on marks on the floor, with the foot of the leg of interest landing centrally on the force plate. Participants were aware of the location of the force plate but, to avoid targeting, they were instructed to look ahead. To assist in this a marker was placed at the start of the approach and moved to adjust the approach distance to ensure the desired foot contacted the force plate. Trials were also rejected if the subject clearly targeted the plate. This was identified by either a “stutter step” during approach or “reaching” towards the force plate with the last stride.

Data Collection and Analysis

Participants were fitted with retro-reflective markers as per the UWA Full Body Model [12], a combination of the UWA Upper [26] and Lower Body Models [4] (Figure 2). Kinematic and inverse dynamic calculations were performed in VICON Workstation (VICON Peak, Oxford, UK) using, the UWA Model, which employs custom code written in MATLAB (Mathworks, Natick, MA, USA) and VICON BodyBuilder (VICON Peak, Oxford, UK). This code uses data collected from functional methods to identify knee axes and hip joint centers and is described in more detail by Besier et al [4]. External moments were calculated with inverse dynamics [4, 23] using the body segment parameter values based on de Leva [10]. Prior to modeling, both the ground reaction force and position data were filtered using a 4th order 18 Hz zero-lag low-pass Butterworth filter, the filter frequency was selected by performing a residual analysis and visual inspection of the data.

Using the UWA Full Body Model reduces many of the errors introduced by poor marker placement as both the knee axis and hip joint center are located utilizing functional methods. This has been shown to produce more reliable kinetic and kinematic data than utilizing markers placed on anatomical landmarks[4]. However, as the model does have some markers placed on anatomical landmarks and intra-tester reliability is higher than inter-tester reliability, the same experience researcher undertook marker placement in both pre- and post-testing sessions [32].

A custom MATLAB program was used to identify the weight acceptance phase in stance, which was defined as from initial foot-ground contact to the first trough in the ground reaction force trace during the sidestep cutting task. Peak valgus and peak internal rotation moments were identified at the knee because these peaks are well defined in weight acceptance [12]. Mean flexion/extension moments were also determined in this phase, the mean being used because there is no peak in the flexion/extension moment in weight acceptance [12].

The moments were normalized to each subject's height (m) multiplied by their mass (kg) [8, 12, 20]. To identify technique changes as a result of technique modification training, the following joint posture data were determined at initial foot-ground contact: lateral torso flexion, torso rotation and foot distance from mid pelvis. Knee flexion angle at initial foot-ground contact and mean knee flexion angle across the weight acceptance phase was also calculated to allow a better understanding of the effects of knee moments on ACL load. Mean velocity across the task and cut angle were calculated for the pelvic center to assess the performance characteristics of each sidestep cut. Cut angle was calculated as:

$$CutAngle = \tan^{-1}\left(\frac{y_i - y_{i-10}}{x_i - x_{i-10}}\right) \text{ where } i = \text{mid-swing following heel strike}$$

As we *a priori* specified which way the pre- to post-training changes would occur, we used a one-tailed repeated measures two-way ANOVA design with two within factors to identify any significant ($p < 0.05$) main effects of testing session (pre- versus post-training) or condition (planned verses unplanned) on knee loading and sidestep cutting technique. When there were significant interaction effects within each ANOVA, a *post hoc* test was performed using a Sidak correction. All statistical procedures were performed using SPSS 15.0 (SPSS Inc., Chicago, IL). In order to link changes in knee load with changes in specific technique modifications a correlation was performed between moments reporting a significant difference between pre- and post-training and those postural variables reporting similar changes.

Results

After 6 weeks of technique modification training there was no significant change in the mean flexion moment or the peak internal rotation moment (Table 1). However, there was a significant 36% reduction in the peak valgus moment ($p = 0.034$) after training (Table

1). There were no significant planned or unplanned condition effects or any interaction effects between condition and testing session for any of the knee moments.

Neither knee flexion at initial foot-ground contact nor mean knee flexion angle across weight acceptance was significantly different between pre- and post-training (Table 2). There were also no significant main effects of condition for knee flexion at initial foot contact. However, there was increased mean knee flexion across weight acceptance for the unplanned sidestep cuts compared to the planned maneuvers (p = 0.038). Neither measure of knee flexion returned any significant interaction effects.

Participants significantly reduced (p = 0.039) foot distance from mid pelvis from pre- to post-training (Table 2). However, there were no significant main effects of condition or any interactions for foot distance from mid pelvis. There was a significant reduction in torso lateral flexion from pre- to post-training (p = 0.005, Table 2). Planned sidestep cuts were performed with less torso lateral flexion than unplanned sidestep cuts (p = 0.003), however there were no interaction effects (Table 2). There were no main or interaction effects for torso rotation.

As there was a significant difference in the peak valgus moment and foot distance from mid pelvis, a correlation was performed on the two variables, revealing a significant between-variable correlation of r = -0.468 (p = 0.025). The same procedure was followed for the differences in peak valgus moment and torso lateral flexion resulting in a non-significant correlation of r = -0.377 (p = 0.135).

There were no pre- to post-training effects or interaction effects for cut angle. However, during the unplanned sidestep cuts there was a lower cut angle compared to the planned events (p = 0.006, Table 2). Unplanned sidestep cuts were also performed more slowly than the planned sidestep cuts (p = 0.001). There was no difference in approach speed between pre- and post-testing and no interaction effects.

Discussion

Following technique modification training, the participants displayed a significant change in their sidestep cutting technique at initial foot-ground contact, specifically in foot placement distance from the pelvis and torso lateral flexion. Both of these technique variables changed in the desired manner as these technique modifications were the focus of the training program. Importantly, these technique changes were accompanied by a 36% reduction in peak valgus moment during the weight acceptance phase of the sidestep cut. In addition, there were correlations with pre- to post-training reduction in foot distance from the pelvis and torso lateral flexion with the reduction in peak valgus moment.

When using external knee moments as a surrogate measure of non-contact ACL injury risk, it should be highlighted that the moments are not equivalent to joint loads or ACL load. Initially, some of the measured external moments are supported by the musculature crossing the joint, subsequently the moment directly applied to "muscle-less" joint maybe different[27]. Secondly, some of the loading not absorbed by the muscles will be absorbed by other structures in the knee. However, externally applied moments are a good surrogate measure of non-contact ACL risk and have be used commonly in the literature[3, 35, 40].

The knee flexion angle at initial foot-ground contact and during weight acceptance is important in terms of valgus loading and its reduction post-training. Markolf et al. [30] showed that when compared with anterior tibial draw alone, ACL loading was increased when valgus moments were applied with 15° to 50° of knee flexion. With knee angles in this range the probability of suffering an ACL injury would certainly be increased if an athlete experiences high valgus loading, when in combination with anterior draw from quadriceps extension and/or internal rotation moments. Therefore, when assessing the non-contact ACL injury risk, both knee angle and knee loading are important. The present technique modification training resulted in a reduction in the valgus loading but no modification to the knee angle, either at initial foot-ground contact or during weight acceptance. Therefore, the lowering of the valgus moments due to the technique modifications would likely reduce the ACL loading, and therefore injury risk.

Results from this study support the incorporation of whole body technique modification to reduce knee valgus loading and, in turn, ACL injury prevention. However, despite reducing torso lateral flexion, the component of the training program encouraging participants to face the direction of travel, was unsuccessful. This lack of change in torso rotation may have been due to the participants being experienced team sports athletes or alternatively, the required postural technique changes may have represented minor modifications to participants who have well established sidestep cut technique. Therefore, a longer, more intense or more focused training program may be required to elicit changes in torso rotation. Applying the training program to younger, less experienced athletes may also be more appropriate to elicit the desired changes in technique. The failure to modify the peak internal rotation moment may also be due to the lack of change in torso rotation. Our previous work found that there was an increased peak internal rotation moment when sidestep cuts were performed with extreme torso rotation and wide foot placement[12]. It may be the case that, to cause any changes in the peak internal rotation moments would need the athletes to reflect these postures. This was not the case for the current cohort.

Unplanned sidestep cuts are often associated with non-contact ACL injuries[9, 37]. It was possible that training would only be effective in altering sidestep cutting technique in the planned condition, where the player had time to “setup” their body posture prior to the maneuver. However, the results showed that participants were also able to change their sidestep cutting technique in the unplanned condition, where they had very little time to adjust their body posture prior to performing the sidestep cut. As most injuries appear to occur when a subject is off balance or unprepared for the task, this is an extremely important finding [37].

The one previous study to report differences between the performance of planned and unplanned tasks in running activities found that unplanned sidestep cuts elicited higher valgus moments during weight acceptance when compared to planned sidestep cut tasks [2]. During the current study, although we found technique and performance differences, we found no differences in knee loading between planned and unplanned sidestep cuts. This discrepancy may be due to differences between the studies in selecting the cue time between participants receiving the light stimulus and performing the sidestep cut. In the Besier et al. [2] study, the delay was adjusted for each subject, and set to the point where the participant could only just perform the task, while one set time period was used in the current study for all participants. It may have been that for some individuals the delay was insufficient to produce a true unplanned sidestep cut. Nevertheless, the unplanned condition in the current study was a very difficult task as the participants performed the unplanned sidesteps 7% slower with a 9% smaller cut angle than in the planned maneuvers , similar to that seen in Besier et al. [2]. Another study which examined the performance of unplanned sidestep cuts while walking observed varus moments compared to a valgus moment for planned sidesteps in early stance, suggesting movement speed may be an important factor influencing knee loading[21]. There was a speed difference of approximately 2 $m.s^{-1}$ between the two studies, which may account for the between-study discrepancy. The current study's high running speeds may be expected to produce larger loading differences than those in the Besier et al.[2] study, although it could be at higher running speeds unplanned versus planned differences are reduced. Further investigation is warranted to investigate this discrepancy in results and impact of technique modification training on knee loads in unplanned sidestep cuts where a difference in load is observed between conditions.

In the current study the basic performance characteristics of the sidestep cuts were maintained from pre- to post-training. That is, the participants undertook the sidestep cut with the same running speed and cut angle in both testing sessions. This indicates that loading changes were not due to changes in overall sidestep cut performance characteristics. The apparent failure of participants to achieve the cut angle required (see Table 2) is due to this value not measuring the same factors as during the testing session. During testing, participants were required to place their foot within a 10° range, and were all successful in achieving this. Conversely, the angle reported is that of the pelvic centre over the 10 frames prior to mid-swing post heel strike. Interestingly, there is only one series of published papers which have examined differences in cut angle [2, 3] and no published studies have investigated the impact of speed in running sidestep cuts. As there was no change in the sidestep cut performance characteristics post-training, it appears that the technique modifications do not adversely affect performance, an important feature if the technique is to be accepted by the wider sporting community. However, there is a need for further analyses to examine the effectiveness of the modified sidestep cut technique in actual game conditions.

This study attempted to ascertain whether sidestep cutting technique could be modified over a period of time, and whether these technique modifications were successful in reducing knee loads during sidestep cutting. Now that it is established that we can modify sidestep cutting technique and reduce the accompanying knee loads, further research is recommended to compare the technique modification training to other non-contact ACL injury prevention protocols which have been shown to be successful in the laboratory, such as balance training (Cochrane et al., unpublished data, 2007), or as suggested by the literature, increasing knee flexion angle [9, 22, 41]. Further investigation is also required into whether the modified technique is maintained post training period, both in the short term (e.g. remainder of a sporting season) and long term (e.g. subsequent sporting seasons). The technique modification program also needs to be trialed in a team setting to ensure that the effects are maintained when being applied to a large group.

The ability to alter sidestep cutting technique needs also to be considered in the game situation. Results from this study are laboratory based and, while they show that valgus loading was reduced, this does not necessarily lead to a reduction in ACL injuries in the field. It is therefore recommended that the technique modification program should be trialed in a competition setting utilizing a large subject cohort to ascertain whether this training type can reduce ACL injuries in competition and training. In order to ensure that the reduction in the incidence of ACL injury is due to factors controlled by the research design, laboratory testing should be included alongside the epidemiology testing, at least on a subset of the participants; a factor that has been ignored in most epidemiology studies [7, 18, 36, 38].

Previously it has been suggested that training programs for ACL injury prevention should include balance, plyometric and technique components [14, 25, 39]. In fact, most intervention studies that have reported a significant reduction in ACL injuries have used multiple components [19]. A training program that provides specific sidestep cutting technique training combined with landing, balance and plyometric training may be the most effective at lowering ACL injury and should be examined in a prospective study.

Summary

Whole body technique training that focused on foot placement close to the midline of the body and the torso being in a more upright posture was effective in reducing the peak valgus loading of the knee during sidestep cutting. This reduction in knee loading might, in turn, reduce risk of injury to the ACL. The technique modification training examined in this research now needs to be compared to other ACL injury prevention training protocols both in the laboratory and in the field to ensure intervention strategies to reduce ACL are effective.

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Figure Captions

Figure 1 The whole body technique. Note the close placement of the stance foot relative to the coronal plane midline of the pelvis, the neutral foot alignment, the upright torso posture and the torso facing the direction of travel.

Figure 2 The University of Western Australia (UWA) Full body marker set.

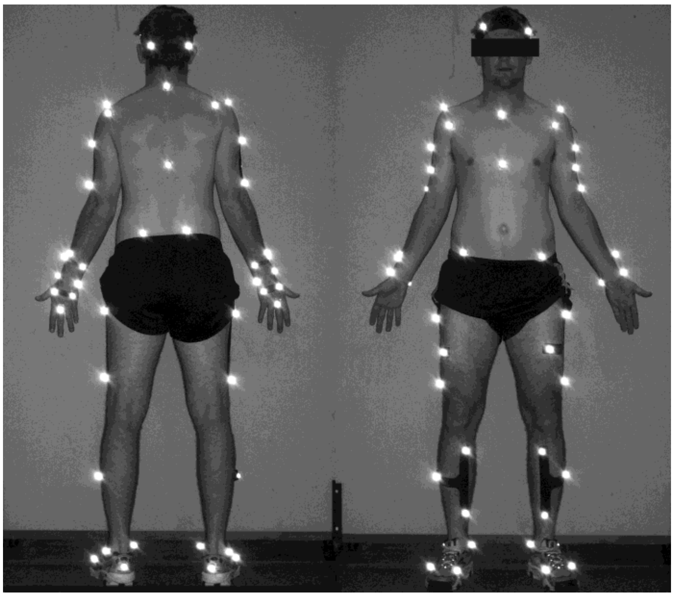

Table 1 Mean (SD) knee joint moment data ($Nm \cdot kg^{-1} \cdot m^{-1}$) during sidestep cutting.

	Whole Body			
	Pre		Post	
	Planned	Unplanned	Planned	Unplanned
Mean Flexion/Extension	0.97 (0.33)	0.91 (0.23)	0.85 (0.30)	0.87 (0.31)
Peak Valgus	-0.38 (0.26)	-0.40 (0.23)	-0.24 (0.22)*	-0.26 (0.11)*
Peak Internal Rotation	0.17 (0.07)	0.26 (0.18)	0.19 (0.07)	0.21 (0.13)

* indicates a difference from pre- to post-training.

Table 2 Mean (SD) of the different postures and performance variables. For the posture variables positive values indicate the following: knee angle – knee flexion; torso lateral flexion – leaning right; torso rotation – left shoulder back.

	Whole Body			
	Pre		Post	
	Planned	Unplanned	Planned	Unplanned
Knee Flexion (°) (IC)‡	14.0 (5.4)	15.4 (5.2)	12.0 (3.3)	15.1 (3.8)
Mean Knee Flexion (°) (WA)‡	29.7 (4.8)	32.1 (2.8)†	30.0 (5.5)	32.9 (4.4)†
Foot from Pelvis (cm)	36.9 (4.0)	36.6 (1.7)	34.6 (4.4)*	34.4 (5.1)*
Torso Lateral Flexion (°)	7.4 (3.2)	12.2 (4.9)†	3.9 (3.2)*	11.6 (3.5)†*
Torso Rotation (°)	-15.9 (6.0)	-11.8 (5.9)	-14.3 (5.7)	-14.4 (9.8)
Cut Angle (°)	32.1 (4.7)	29.8 (5.1)†	31.3 (4.3)	27.9 (4.4)†
Velocity ($m.s^{-1}$)	5.7 (0.4)	5.1 (0.3)†	5.4 (0.5)	5.2 (0.3)†

‡ IC = initial foot-ground contact; WA = weight acceptance,

* indicates a significant difference from pre- to post-training,

† indicates a significant difference between the planned and unplanned sidestep cuts.

Appendix 1 Weekly Training Goals and Drills

Week	Training Aims
1	Can attain all three individual postures (stance foot closer to midline of body, torso upright, and torso facing in direction of travel)
2	Can do the full task with the required technique
3	Can do the full task while carrying a ball
4	Can start to do the task with trainer directed unanticipated sidestep cut
5	Can start to do the task with an unanticipated defender
6	Can perform the task consistently both pre-planned planed and unanticipated

Week	Tasks
1	• Perform self selected sidestep cut at ½ pace • Receive feedback based upon required changes • Initially receive feedback on torso angle, second session during the week they will receive information on foot position • Repeat performance with modified sidestep cut • Continue to receive feedback and performing modified sidestep cut and slowly increase pace
2	• Perform required sidestep cut at ¾ pace • Receive feedback based upon required changes • Should be able to perform the sidestep cut correctly by the end of the second session
3	• Perform required sidestep cut at full pace working to: • Performing required sidestep cut with ball • Receive feedback based upon required changes
4	• Perform the required sidestep cut at ¾ to full pace • Trainer will indicate to subject if they are required to step left, right or run through using arm cues. Cues will start early and progressively get later across two training sessions • Receive feedback based upon required changes

5	• Continuation of trainer directed movement direction
	• Start of defender directed movement direction
	    • Defender to initially stand and then move left or right with attacker to move the other way working to:
	        o Defender moving towards attacker then changing direction with attacker to go the other way
	• Receive feedback based upon required changes

6	• Perform task successfully every time • Feedback for any required changes