DIFFERENCES IN PREPARATORY KINEMATICS OF PLANNED AND UNPLANNED SIDESTEPPING

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This study aimed to characterise the preparatory kinematics of sidestepping (SS) and investigate kinematic differences between planned and unplanned SS tasks. Thirty five male Australian rules football players completed an established SS movement assessment. Trunk, pelvis, knee and ankle kinematics were recorded for straight running and planned and unplanned SS tasks. At toe-off of the penultimate step the stance foot was placed across the midline of the centre of mass in planned SS (-12.5 ± 6.42 cm) and significantly further away from the centre of mass ($p<0.01$) than in unplanned SS (4.4 ± 4.33 cm). This study highlights differences in body reorientation strategies in SS manoeuvres and further supports the rationale for the inclusion of unplanned tasks in the development of prophylactic training programmes and injury screening.

KEYWORDS: cutting, online-steering, preparation, technique.

INTRODUCTION: Anterior cruciate ligament (ACL) injuries are one of the most common and debilitating injuries in team sport, suffered by amateur and elite players alike. From both cadaveric (Markolf et al., 1995) and in vivo research (Brown, Brughelli, & Hume, 2014), it is generally accepted that ACL injury risk can be characterised by increased peak knee valgus (PKVM) and internal rotation moments. Match analysis also has been used to classify postures involving increased “dynamic knee valgus” as corresponding with the event of ACL injury during SS (Johnston et al., 2018). Furthermore, 50-80% of all non-contact ACL injuries occur during sidestepping (SS) manoeuvres (Cochrane, Lloyd, Buttfield, Seward, & McGivern, 2007; Johnston et al., 2018). Subsequently, PKVM is often used as a surrogate measure of ACL injury risk and occurs during the first 20-30% of stance, the weight acceptance (WA) phase of landing and SS (Besier, Lloyd, Cochrane, & Ackland, 2001). Research therefore often focuses on classifying tri-planar trunk, hip, knee and foot kinematics within this phase to assess associations with PKVM during SS.
In addition to kinematics, there is a clear association between planning time and PKVM in SS, with unplanned manoeuvres regularly producing greater PKVM (Brown et al., 2014). Despite an apparent link between planning time and PKVM, the movement patterns responsible for initiating a dynamic change of direction (CoD), prior to WA, are not clearly understood. Patla, Adkin, and Ballard (1999) characterised specific body reorientation strategies associated with planned and unplanned CoD while walking. Two reorientation or “online-steering” strategies were found to be used to influence the orientation of the centre of mass (COM) when turning and were implemented during the penultimate step, prior to the CoD step (Patla et al., 1999). The first strategy involved a modified foot placement distinguished by placing the stance foot across the midline of the body in the penultimate step. The second used a combination of trunk rotation (towards the new direction) and lateral flexion (opposite the desired direction), beginning towards the end of the penultimate step and continuing throughout the CoD step. Importantly the first strategy was only observed in the planned condition and the second occurring in both. These findings suggest that different strategies are used depending on the temporal constraints of the task, though it is unknown if they carry over to faster CoD actions such as SS.
The aims of this study were to: *1)* characterise preparatory kinematics associated with SS and, *2)* identify differences in trunk, pelvis and foot kinematics at toe-off (TO) of the penultimate step, between planned and unplanned SS. It is hypothesised that a narrower mediolateral foot placement at TO will be specific to planned SS. Secondly it is proposed

that trunk rotation will be towards the new direction of travel (DoT) and lateral flexion will be away from the DoT in both planned and unplanned SS at TO.

METHODS: 35 male Australian rules football athletes (23 ± 5.4 yrs, 1.84 ± 0.06 m, 81.7 ± 9.54 kg) completed a series of planned and unplanned RUN, crossover-cut and SS running tasks off their self-selected preferred stance limb. All subjects preferred performing the tasks off their right limb. Both CoD tasks were completed at an angle of 45° and only considered successful if approach velocity was between 4.5 ms^{-1} and 5.5 ms^{-1}. Participants were required to complete three successful trials of each task before testing was completed. For the current analysis only RUN, planned and unplanned SS tasks were analysed.

A 12 camera Vicon MX system (Oxford Metrics, UK) recording at 250 Hz synchronized with an AMTI force platform (AMTI, Massachusetts, USA) capturing at 2,000 Hz, captured three-dimensional marker trajectories and ground reaction force data respectively. Using a custom lower body kinematic model, kinematic data were used to calculate trunk, pelvis and ankle joint kinematics (Donnelly et al., 2012). Positive trunk lateral flexion was defined as leaning away from the DoT. Positive rotation reflected transverse plane rotation of the trunk towards the DoT. Mediolateral foot placement (FP_{ML}) was defined as the mediolateral displacement of the stance foot ankle-joint centre to the COM and measured relative to the transverse orientation of the pelvis (Byrne, Weir, Alderson, Lay, & Donnelly, 2017). Negative FP_{ML} indicated the foot had crossed the COM to the contralateral side of the stance leg. Ground reaction force data was used to define the WA phase of stance (Besier et al., 2001).

Tri-planar trunk and pelvis kinematics and FP_{ML} were calculated as a mean of three trials at TO of the penultimate step for all three tasks. This is thought to be the latest point any preparatory adjustments to the body’s kinematics could be observed prior to WA in a successful SS (Patla et al., 1999). Peak knee moments were measured during the WA phase of the CoD step for each task. All variables were reported as means ± standard deviation. To determine differences ($\alpha < 0.05$) between tasks at TO, main effects of task condition were analysed (SPSS Inc, IBM, Chicago, Illinois) for each variable using a repeated measures ANOVA. A Tukey’s post-hoc analysis was used to assess for significant differences between tasks. The same analysis was used to compare peak knee moments during WA.

RESULTS: Mean and standard deviations of joint kinematics measured at TO in all three tasks are presented in Table 1. During unplanned SS mean trunk lateral flexion away from the DoT was greater ($p < 0.01$) at TO of the penultimate step compared with planned SS but not with RUN. At TO mean trunk flexion was significantly less than RUN for both planned ($p < 0.01$) and unplanned ($p = 0.02$) SS. Trunk to pelvis lateral separation and pelvis lateral tilt were both greater ($p < 0.01$) in planned SS compared with both unplanned SS and RUN. FP_{ML} was significantly lower ($p < 0.01$) in planned SS compared to both unplanned SS and RUN, to the point of crossing the midline of the COM to the contralateral side of the body to the stance leg.

Knee kinematics and kinetics associated with increased ACL injury risk during WA fell within previously reported values (Brown et al., 2014). Both peak knee flexion and internal rotation moments were larger ($p < 0.01$) in SS tasks compared to RUN but not different to each other. The largest ($p < 0.01$) PKVM was observed in unplanned SS (-0.92 ± 0.48 $Nm.kg^{-1}.m^{-1}$) followed by planned SS (-0.60 ± 0.37 $Nm.kg^{-1}.m^{-1}$) and finally RUN (-0.10 ± 0.13 $Nm.kg^{-1}.m^{-1}$).

DISCUSSION:

The primary finding of this study was that preparatory phase kinematics of SS are dependent on the time available to complete the task. In support of our first hypothesis, in planned SS participants placed their stance foot across the midline of the COM to the contralateral side of the body by approximately 13cm, a 17cm difference to unplanned SS and RUN conditions. In contrast to the second hypothesis however, trunk and pelvis rotation were not found to be different between either SS task or to RUN. Moreover, trunk lateral flexion was towards the DoT in planned SS. Interestingly, during unplanned SS trunk flexion was the only variable found to be significantly different to RUN.

Table 1: Comparisons of Mean (SD) joint kinematics at TO of the penultimate step for RUN, planned and unplanned SS

Variable	RUN	Planned SS	Unplanned SS
Trunk angle (°)			
Flexion (+)	9(4.1)	5(3.9)*	6(3.9)*
Lateral flexion: away from direction of travel (+)	-1(1.6)	-4(3.1)*	1(2.5) ^
Rotation: towards the direction of travel (+)	-9(4.5)	-8(4.6)	-9(5.2)
Trunk to pelvis separation angle (°)			
Flexion: trunk forward of the pelvis (+)	-13(5.0)	-13(5.1)	-11(4.6)
Lateral flexion: trunk leaning to right of the pelvis (+)	6(2.8)	10(4.2)*	6(3.5) ^
Rotation: separation of the trunk to the right of the pelvis (+)	-16(4.6)	-15(4.4)	-14(3.8)
Pelvis angle (°)			
Tilt: anterior tilt (+)	21(5.5)	17(5.1)*	17(5.0)
Lateral tilt: higher on the right (-)	-8(3.3)	-15(5.1)*	-7(4.3) ^
Rotation: towards the direction of travel (+)	4(3.2)	4(4.3)	4(3.9)
Mediolateral Foot Placement (cm)			
COM to AJC: AJC on ipsilateral side of COM to stance leg (+)	4.7(2.17)	-12.5(6.42)*	4.4(4.33) ^

* significant difference to RUN condition ($p<0.05$)
^ significant difference between planned and unplanned SS conditions ($p<0.05$)
COM = centre of mass, AJC = ankle joint centre, TO = toe-off, RUN = straight-line run, SS = sidestep

The narrow foot placement observed in planned SS appears to be a clear preparatory reorientation strategy being used to change direction. Placing the foot on the contralateral side of the COM during the penultimate step would likely affect the lateral acceleration of the COM. During single support the difference between the centre of pressure and COM dictates the direction and acceleration of the COM (Winter, 1995). When the participant has enough time to plan they make use of this mechanism early to help initiate the desired shift of the COM towards their new DoT. During unplanned SS the participant may not have sufficient time to respond to the stimulus, resulting in a FP_{ML} similar to a RUN.

A second proposed reorientation strategy was the use of trunk and hip musculature to facilitate a shift of the COM towards the desired DoT (Patla et al., 1999). This can be characterised by a piking action between the upper body and lower body about the pelvis. A similar exaggerated posture occurs during the CoD step of a SS (Dempsey et al., 2007; Houck, Duncan, & De Haven, 2006) and are typified by either increased trunk lateral flexion away from the DoT, increased hip abduction and a wide foot placement, or both. In contrast to our second hypothesis however, trunk lateral flexion at TO was more towards the DoT in planned SS. Interestingly, while there was less global trunk flexion away from the DoT in planned SS there was however a greater separation angle between the pelvis and the trunk compared to both unplanned SS and RUN. This may suggest that in planned SS participants rely less on their trunk and more on the action of the pelvis to create the necessary piking action between the trunk and the hips. In both SS conditions participants will use their trunk and hip musculature to perform a CoD (Houck et al., 2006). However, the inability to rely on favourable preparatory foot placement in the unplanned SS may mean directing the COM becomes more dependent on the activation and control of trunk musculature.

This study found greater pelvic lateral tilt in planned SS compared to the other tasks. The reason for this could be explained by looking again at the piking reorientation strategy (Patla et al., 1999). The CoD step of a SS typically involves a wide lateral foot placement to push off in the new DoT. By increasing the lateral tilt of the pelvis, to be higher on the right hip, this may allow for a reduction in the amount of hip abduction required to achieve the desired wide foot placement. Meyers, Greenleaf, and Saad (2005) suggested that neuromuscular control of the pelvis is important during high-speed multidirectional sports, as it provides an anchor between the upper body and lower limbs to facilitate dynamic locomotion. This may indicate that in planned SS participants have increased control over the forces being transferred between their upper and lower bodies and use their pelvis to help control and stabilise the actions of the trunk. Keeping the trunk more upright and pelvis neutral in unplanned SS may be a necessary strategy to ensure the participant can react to either direction whilst minimising the amount of strain on the surrounding musculature, within the given time limits. Reliance on a reorientation strategy involving greater trunk lateral flexion with no support from lower limb adjustments, combined with insufficient planning time to appropriately activate the surrounding musculature, may help explain the larger PKVM seen in unplanned SS.

CONCLUSION: A more medial foot placement and greater pelvic lateral tilt in the penultimate step were shown to be clear preparatory kinematics specific to planned SS. Even though execution may appear to be similar, these differences highlight the impact of planning time on the way athletes prepare for SS tasks in the time prior to WA. The clear differences in preparatory reorientation strategies support the assertion that planned and unplanned SS are separate skills. It also gives further support to the rationale for the inclusion of unplanned SS in the development of prophylactic training programmes and anterior cruciate ligament injury screening. While our findings give some insight into the reorientation strategies implemented in SS under two extreme time constraints, it is vital to understand whether these postures translate to game like scenarios where players are exposed varying stimuli and can rely on environmental factors and knowledge of past situations to assist in decision making.

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