LOWER EXTREMITY COORDINATION VARIABILITY DURING ANTICIPATED AND UNANTICIPATED SIDESTEPPING: IMPLICATIONS FOR ACL INJURY PREVENTION

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Non-contact anterior cruciate ligament (ACL) injuries commonly occur during sidestepping, particularly under time constraints. This study investigated the differences in lower limb coordination variability (CV) of five male team sport athletes during anticipated and unanticipated sidestepping. Intra-limb couplings associated with ACL injury mechanisms were investigated. Athletes demonstrated 21% greater thigh rot/leg rot CV; 31% greater thigh abd-add/leg abd-add CV; 22% greater knee flex-ext/hip rot CV and 14% greater hip rot/knee abd-add CV during unanticipated sidestepping. These results suggest that CV increases as a function of task complexity. Consequently, injury prevention programs must incorporate perceptual components in order to optimise planning time and coordinate appropriate postural adjustments to counter external loads.

KEY WORDS: Kinematics, training, perception.

INTRODUCTION: A significant body of research has been dedicated toward understanding the underlying mechanisms of non-contact anterior cruciate ligament (ACL) injuries. In-vivo, in-vitro and in-silico research have identified elevated combined peak knee extension, valgus and internal rotation moments while the knee is in an extended posture (i.e. <20º) to elevate ACL strain and subsequently place an athlete at risk of injury (Besier, Lloyd, Ackland, & Cochrane, 2001; Markolf et al., 1995; McLean, Huang, Su, & Van Den Bogert, 2004). These injuries typically occur during sidestepping and single leg landing; tasks which are characterized by sudden redirections of whole-body centre of mass concurrent with rapid accelerations and decelerations of the body (Cochrane, Lloyd, Buttfield, Seward, & McGivern, 2007). Team based sports often require athletes to perform these tasks in response to external stimuli (i.e. a ball, team member, opponent). These external stimuli require rapid and precise reactions. Time constraints associated with these dynamic movements may cause unplanned anticipatory adjustments and, as a consequence, lead to altered joint biomechanics (Besier et al., 2001; Mornieux, Gehring, Fuesrst, & Gollhofer, 2014). Laboratory research comparing anticipated and unanticipated sidestepping has shown peak knee valgus and internal rotation moments to be up to twice as high in unanticipated conditions (Besier et al., 2001). Additionally, total muscle activation of muscles crossing the knee was found to increase by only 10%, which is unlikely sufficient to counter the elevated external forces applied to the joint (Besier, Lloyd, & Ackland, 2003).

Understanding the anticipatory postural adjustments is important to further the body of knowledge toward how performance and safety can be enhanced during unanticipated sporting tasks. Patla et al. (1999) identified two on-line steering strategies that participants utilize to initiate change of direction; 1) foot placement which is used when planning can be performed early and, 2) a trunk strategy where the trunk moves away from the intended direction of travel in the frontal and transverse planes to generate momentum to swing back toward the intended direction of travel. From a kinematic perspective, unanticipated sidestepping is characterized by increases in knee extension, abduction and internal rotation angles (Brown, Brughelli, & Hume, 2014). McLean et al. (1997) found that inexperienced athletes produced greater inter-trial variability for knee joint angles in all three planes compared with experienced athletes. In-silico research has found a general strategy to reduce peak knee valgus moments is to move the whole body centre of mass toward the desired direction of travel. Different combinations of nine kinematic techniques contributed to this generalized strategy, suggesting that stability and flexibility in task performance is obtained by local compensation of available degrees of freedom (Van Emmerik, Hamill, & McDermott, 2005). The majority of research associated with lower limb biomechanics and ACL injury have reported on the kinematics of lower extremity joints in isolation, rather than addressing the interaction between them. With this in mind, the purpose of this study was to determine if differences in coordination variability (CV) exist when time constraints occur in sporting tasks. It was hypothesized that there would be increased variability in intra-limb couplings during the weight acceptance (WA) phase of unanticipated sidestepping tasks as compared to their anticipated counterparts.

METHODS: Five male (25.4±4.2 years, 1.77±0.05 m, 72.7±6.4 kg) recreational team sport athletes were asked to complete a previously published sidestepping protocol (Besier et al., 2001; Dempsey, Lloyd, Elliott, Steele, & Munro, 2009; Donnelly et al., 2012) involving unanticipated and anticipated conditions. Marker trajectories were recorded using a 11 camera Qualisys motion capture system (Qualysis, Inc., Gothenburg, Sweden) sampling at 240Hz and ground reaction forces at 1200Hz (AMTI, Watertown, MA). Vertical ground reaction force was used to identify the stance and weight acceptance phases (Dempsey et al., 2007). All participants wore standardized footwear provided by the laboratory. To calculate lower limb kinematics, retro-reflective marker clusters were placed on the pelvis, thigh, shank and foot. Static anatomical markers and functional joint centres were used to define segment coordinate systems and joint centres for the pelvis, thigh, shank and foot.

Data processing was performed using Visual 3D software (C-motion, Inc., Rockville.MD). Marker data were low pass filtered at 14Hz. Segment CV was calculated using a modified vector coding technique (Chang, Van Emmerik, & Hamill, 2008) for each participant and each sidestepping condition (i.e. anticipated and unanticipated). Angle-angle plots were created for motion between adjacent segments and joints (thigh, tibia, hip, knee) over stance. CV was calculated as the standard deviation of the vector connecting corresponding consecutive time points of the angle-angle plots across trials using circular statistics (Hafer & Boyer, 2017). Based on the ACL loading mechanisms identified in the literature (Markolf et al., 1995), the following intra-limb couplings from the stance limb were examined: thigh rotation/leg rotation, thigh abduction-adduction/leg abduction-adduction, knee flexion-extension/knee rotation, knee flexion-extension/hip rotation and hip rotation/knee abduction-adduction. To investigate the differences in CV in anticipated and unanticipated sidestepping, CV for each coupling of interest was calculated during the stance phase of 7 trials in each side-stepping condition. Mean CV during WA was also measured as this corresponds to where peak knee joint loading occurs (Dempsey et al., 2007). CV in anticipated and unanticipated side-stepping were compared using paired t-tests. All statistical analyses were conducted in SPSS (IBM SPSS Statistics 22, SPSS Inc., Chicago, IL) with an $\alpha = 0.05$. Cohen's d effect sizes were calculated and defined as small (0.2), moderate (0.5) and large (0.8) (Cohen, 1988).

RESULTS: No statistically significant differences were observed between the unanticipated and anticipated conditions. However, during WA, large effect sizes were observed indicating greater variability in unanticipated versus anticipated sidestepping (Table 1). Athletes demonstrated 21% greater thigh rotation/leg rotation CV, 31% greater thigh abduction-adduction/leg abduction-adduction CV, 22% greater knee flexion-extension/hip rotation CV and 14% greater hip rotation/knee abduction-adduction CV. A small effect size of 9% was observed indicating greater knee flexion-extension/knee rotation CV. Figure 1 presents mean coordination variability for all five couplings across the stance phase for unanticipated and anticipated sidestepping.

Table 1. Mean (SD) coordination variability (⁰) during the weight acceptance phase of stance for anticipated and unanticipated sidestepping tasks.

	Anticipated	Unanticipated	P value	Effect size
Thigh rotation/Leg rotation (^{0})	26.7 (7.3)	34.2 (8.2)	0.107	1.0
Thigh ab-ad/Leg ab-ad (^{0})	22.0 (11.7)	32.3 (13.4)	0.251	0.8
Knee flex-ext/Knee rotation (^{0})	18.8 (6.3)	20.5 (9.1)	0.529	0.2
Knee flex-ext/Hip rotation (^{0})	17.7 (3.4)	22.6 (9.1)	0.155	0.7
Hip rotation/Knee ab-ad (^{0})	30.7 (5.5)	35.8 (6.2)	0.054	0.9

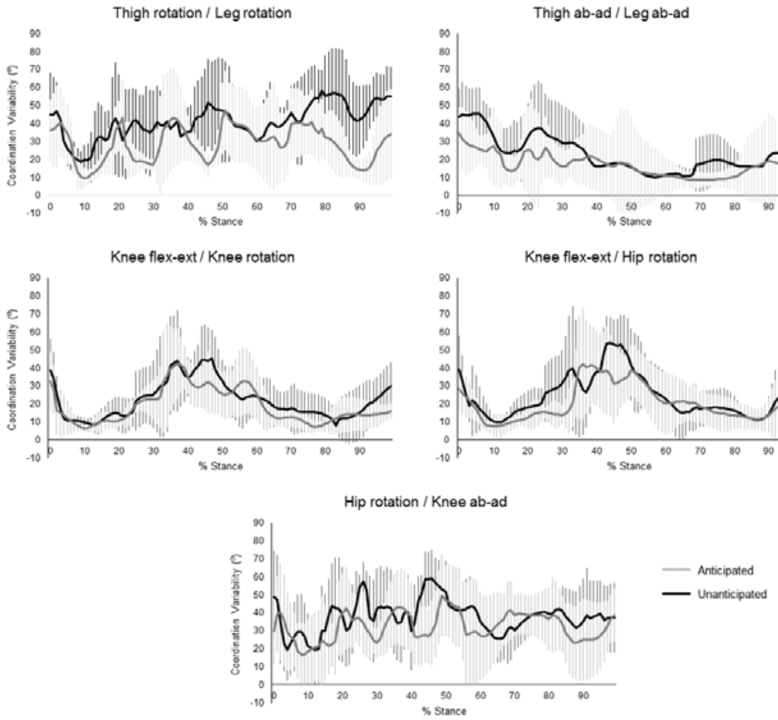

Figure 1. Mean (SD) coordination variability of five couplings across the stance phase of anticipated and unanticipated sidestepping.

DISCUSSION: The findings from this preliminary study support the hypothesis that during unanticipated sporting manoeuvres, athletes display elevated lower limb coordination variability. More specifically, this occurs at initial contact and weight acceptance. These results support previous research describing inherent differences in kinetic (i.e. elevated peak knee moments) (Besier et al., 2001), kinematic (i.e. greater knee abduction angle) (Brown et al., 2014) and muscular activation strategies (i.e. increased total muscle activation and generalised co-contraction) (Besier et al., 2003) during unanticipated as compared to anticipated sidestepping. Sidestepping is a complex task that requires multiple, complex coordination patterns to achieve successful change of direction performance. Consequently, there must be a large kinematic solution space. As task complexity increased in this study (i.e. reduced time to plan the movement in unanticipated scenarios), coordination variability increased. During planned sidestepping, the WA phase occurs prior to initiation of change of direction in order to control the centre of mass toward the intended direction of travel while the knee is adducting (Sigward, Pollard, Havens, & Powers, 2012). During this task, multiple kinematic solutions and high CV is likely unnecessary as athletes have the ability to plan the movement. This pattern is altered in unplanned sidestepping where change of direction initiation occurs at or near initial contact when the knee is abducted and the centre of mass is accelerating away from the desired direction of travel. This altered strategy is likely a function of the inability of the CNS to generate anticipatory postural adjustments appropriate to perform the task successfully from a performance and loading perspective. While this study aids in understanding the movement coordination variability characteristics during unanticipated sidestepping, it is important to note that currently conclusions can only be drawn based on associated literature and the limited sample size. The next phase of this study will be to define the relationship between coordination variability, peak knee joint moments and muscle activation patterns in a heterogeneous athletic sample.

CONCLUSION: Athletes display increased lower limb coordination variability during the weight acceptance phase of unanticipated sidestepping. This increase in CV may have functional implications during this task relative to its anticipated counterpart because of the unknown, temporal uncertainty as to where to cut. These findings highlight the importance of perceptual training in combination with the traditional strength, balance and plyometric injury prevention training regimes in order to improve reaction time and better interpret visual cues to enable athletes to increase the time available to pre-plan a movement.

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