IDENTIFYING THE RELATIONSHIP BETWEEN PREPARATORY MECHANICS AND AN ATHLETES RISK OF ACL INJURY: A PRELIMINARY ANALYSIS

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This study investigated whether an athlete's mechanics during the preparatory phase of unplanned sidestepping predicted peak valgus knee moments during weight acceptance. Nine female community level team sport athletes completed an established sidestepping movement assessment. Preparatory anterior-posterior trunk momentum and left-right lateral trunk momentum, alongside trunk flexion range of motion during weight acceptance combined to predict 57% of the variance in peak knee valgus moments. These preliminary results show that preparatory trunk mechanics are related to subsequent peak knee valgus moments and anterior cruciate ligament injury risk during unplanned sidestepping. A data set of 116 mixed characteristic athletes is currently being analysed to verify these findings.

KEYWORDS: Sports injury, injury mechanism, injury prevention, athletes

INTRODUCTION: Direct *in-vivo* measurements of anterior cruciate ligament (ACL) strain and forces are highly invasive (Cerulli, Benoit, Lamontagne, Caraffa, & Liti, 2003) and calculating them through musculoskeletal modelling during high velocity sporting tasks is computationally expensive. Peak knee valgus moments (PKVM) are accessible surrogate measures of ACL forces (Markolf et al., 1995) and several kinematic variables during weight acceptance (WA) of sidestepping movements have been associated with PKVM. These kinematic variables include knee flexion at foot contact (Koga et al., 2010), lateral foot to centre of mass (CoM) distance (Dempsey et al., 2007), peak trunk lateral flexion (Dempsey et al., 2007) and trunk flexion range of motion (RoM) (Weir, Smailes, Alderson, Elliott, & Donnelly, 2013). When considering these kinematic-PKVM associations, several possible solutions exist to change an athlete's movement; making it difficult for athletes and coaches to use as guidelines to reduce ACL injury risk. A simplified message is required if we are to develop effective guidelines for reducing an athlete's risk of sustaining an ACL injury.

In-silico simulations of unplanned sidestepping (UnSS), have identified repositioning the CoM towards the desired direction of travel as an effective generalised kinematic strategy to reduce PKVM (Donnelly, Lloyd, Elliott, & Reinbolt, 2012). The trunk is the heaviest body segment (De Leva, 1996), therefore repositioning of an individual's whole-body CoM would be most effectively achieved through trunk repositioning. Given an athlete's ACL injury risk is greatest during WA (Cerulli et al., 2003; Donnelly et al., 2012), there is a small window of opportunity for the neuromuscular system to illicit postural (i.e., trunk) changes during this phase. It is plausible that preparatory (before WA) trunk velocity and more specifically preparatory trunk momentum may influence subsequent trunk posture and PKVM during WA. To the best of our knowledge no previous research has investigated the role an athlete's preparatory mechanics (e.g., trunk momentum) play in ACL injury. Given trunk kinematics during WA are associated with ACL injury risk, a similar relationship may exist for preparatory trunk mechanics.

The purpose of this study was to perform an exploratory analysis to determine if an athlete's preparatory mechanics are related to PKVM during the WA phase of UnSS. This information will be used to inform future analyses within a larger sample of 116 mixed characteristic athletes. We hypothesise that mean anterior-posterior trunk momentum (AP-TM) and mean left-right lateral trunk momentum (LR-TM) during the preparatory phase would predict PKVM during the WA phase of UnSS, as measured by multiple regression analyses.

METHODS: A 3-D motion capture system was used to record the full body kinematics of nine female community level team sport athletes (19.10±2.42 yrs, 1.69±0.07 m, 60.73±7.39 kg) during unplanned sidestepping (Dempsey et al., 2007). Kinematics were recorded at 250 Hz (Oxford Metrics, Oxford, UK) and ground reaction forces were recorded at 2,000 Hz (AMTI, Watertown, MA). A reliable customised full-body model (Besier et al., 2003) was used to calculate knee, hip and trunk kinematics and knee joint kinetics via inverse dynamics (Dempsey et al., 2007).

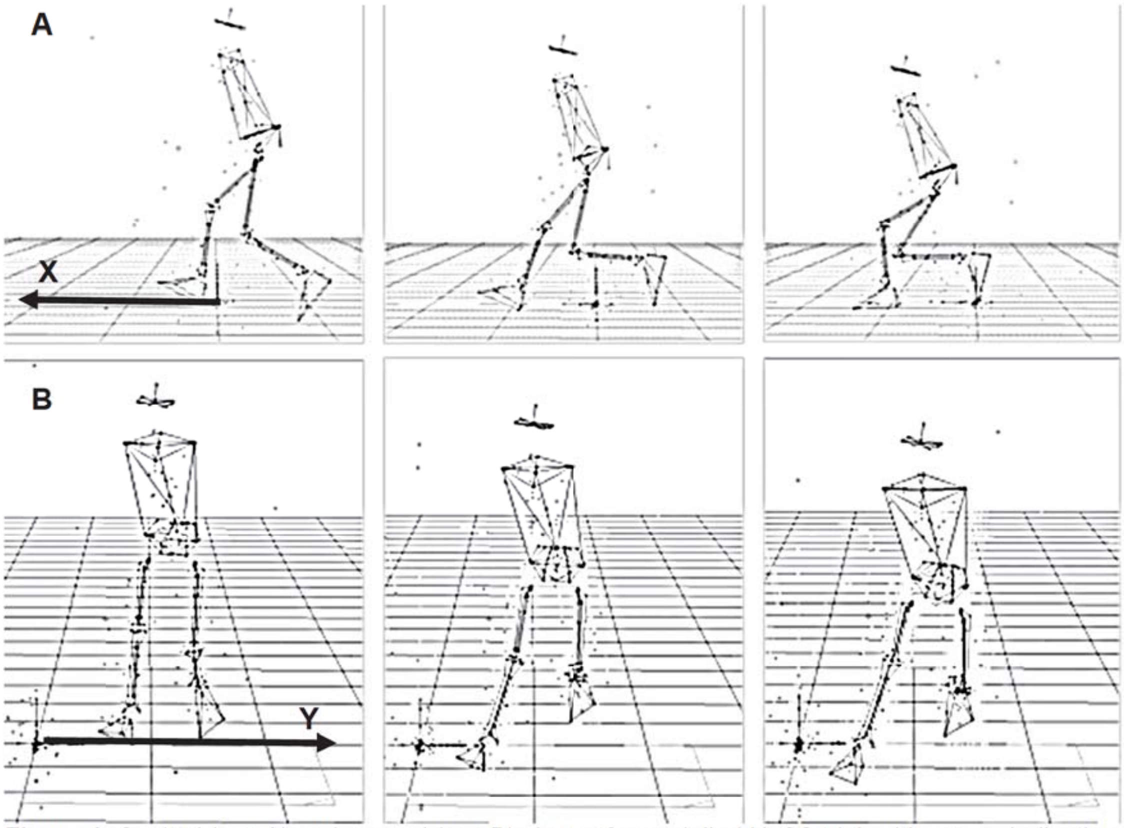

Figure 1: Sagittal (row A) and coronal (row B) views of a modelled UnSS trial, with arrows indicating the positive direction of X and Y axes in the global coordinate. From left to right: start of preparatory phase (toe-off), foot strike of sidestep and end of weight acceptance.

For each participant three to five UnSS trials were analysed. WA was defined as per Dempsey et al. (2007), with the preparatory phase defined as the flight phase prior to WA (toe-off to foot strike). Kinematic data was analysed during the preparatory and WA phases and included: trunk flexion RoM, trunk lateral flexion, AP-TM, LR-TM, and foot to CoM lateral distance. Trunk CoM velocity referenced to the global coordinate was used as an estimate of anterior-posterior and left-right lateral trunk CoM velocity. AP-TM and LR-TM were estimated by multiplying participant CoM velocity by trunk mass (De Leva, 1996). PKVM were analysed during WA, normalised to height and body weight (Ht*Bw) and expressed in scientific notation x10^{-1}.
Standard multiple regressions ($\alpha < 0.10$) were used to predict the dependant variable (PKVM). As this was an exploratory analysis an α of 0.10 was used to assist in identifying candidate predictors. First, three preparatory trunk variables were used as predictors in a multiple regression: mean AP-TM, mean LR-TM and initial trunk lateral flexion. In the second regression, three WA variables were used: peak trunk lateral flexion, trunk flexion RoM and peak foot to CoM position. Two-tailed ($p < 0.10$) bivariate correlations were performed to report the relationships between the independent variables and the dependant variable. The three variables with the strongest correlations with PKVM were selected as predictors of PKVM in a combined preparatory and WA multiple regression analysis. The variance inflation factor (VIF) was reported for each predictor variable within the three multiple regression analyses, with a value greater than five used as evidence of multicollinearity.

RESULTS: A mean PKVM measurement of 0.03±0.01 was recorded, with mean and standard deviation of the predictor variables presented in Table 1. Although not significant, the three preparatory variables in this exploratory analysis accounted for 33% of the variability in PKVM, $R^2 = .583$, adjusted $R^2 = .333$, $F = 2.329$, $p = .191$. The WA variables were also not significant predictors of PKVM, though when combined accounted for 12% of the variability, $R^2 = .451$, adjusted $R^2 = .122$, $F = 1.370$, $p = .353$. Trunk flexion RoM during WA, preparatory mean LR-TM and preparatory mean AP-TM were the three variables which most strongly correlated with PKVM. When used as predictors in a third multiple regression analysis, they accounted for 57% of PKVM variability within the regression model, $R^2 = .729$, adjusted $R^2 = .566$, $p = .070$. Unstandardised (*B*) and standardised (*β*) regression coefficients, as well as two-tailed bivariate Pearsons correlations (*r*) for each predictor in the three regression models are reported in Table 1. Multicollinearity was not a concern (VIF < 5) in any of the performed multiple regression analyses (Table 1).

Table 1. Multiple regression coefficients and Pearsons r correlations of weight acceptance, preparatory and combined variables as predictors of peak knee valgus moments.

Phase	Predictor	Mean	Std	*B*	*β*	*r*	VIF
Preparatory	Mean AP-TM (N.m)	100	16.4	< -.001	-.518	**.301***	2.48
	Mean LR -TM (N.m)	5	6.8	**.002***	**.926***	**.591***	1.84
	Initial trunk lateral flexion (°)	10	4.5	.002	.651	.294	1.82
Weight acceptance	Peak lateral trunk flexion (°)	15	2.5	< -.001	-.059	-.127	1.28
	Trunk flexion RoM (°)	10	7.7	-.001	-.692	**-.667****	1.18
	Foot to CoM position (cm)	290	30.9	-3.868^-5	-.088	.208	1.47
Combined	Trunk flexion RoM (°)	10	7.7	**-.001****	**-.619****	**-.667****	1.01
	Mean AP-TM (N.m)	100	16.4	1.695^-5	-.020	**.301***	1.01
	Mean LR-TM (N.m)	5	6.8	.001	.545	**.591***	1.01

*Note. N = 9. * = p < 0.10, ** p < 0.05. VIF = variance inflation factor, AP-TM = anterior-posterior trunk momentum, LR-TM = left-right lateral trunk momentum, RoM = range of motion and CoM = centre of mass. Positive values indicate: AP-TM, anterior momentum; LR-TM, left momentum; lateral trunk flexion, leaning right.*

Discussion: The hypothesis that mean AP-TM and mean LR-TM would be significant predictors of PKVM was supported. When used as predictors alongside initial trunk lateral flexion in a preparatory trunk mechanics analysis the model was not significant, although 33% of the variance in PKVM moments was explained – a practically large effect when considering the potential influence to an individual's risk of injury. However, in the combined preparatory and WA analysis, preparatory trunk momentum (AP-TM and LR-TM) and trunk flexion RoM during WA significantly predicted 57% of the variance in PKVM. This finding supports previous recommendations of improving dynamic trunk control to reduce PKVM during UnSS (Donnelly et al., 2012). However, the current study found that preparatory trunk mechanics has the potential to influence an athlete's ACL injury risk. There is a clear scientific rationale for performing future analysis of this research question with a larger data set. Based on the preparatory regression model F value (F = 2.329, effect size = 0.5), it is recommended that future analyses comprise a sample of at least 40 participants (from G*Power v3.1).

Athletes with high LR-TM towards the change of direction also displayed high PKVM ($p < 0.10$). The directionality of this relationship is perhaps unexpected, as it could be hypothesised that trunk momentum towards the direction of travel is likely to move the weight bearing CoM medially in the desired change of direction; a recommendation to reduce PKVM (Donnelly et al., 2012). Increased LR-TM towards the change of direction is effectively moving the trunk away from the laterally placed sidestepping limb. Increased trunk movements in this direction may alter the ground reaction force vector orientation upon foot contact, leading to increases in PKVM. However, this mechanical rationale is speculative until further analysis can be conducted.

Despite observed associations (Dempsey et al., 2007; Weir et al., 2013), the WA variables only explained 12% of the variance in PKVM, in a non-significant regression model. This result is likely due to peak trunk lateral flexion (r = -.127) and foot to CoM position (r = .208) being

weakly correlated with PKVM in the current study. Weir et al. (2013) identified trunk flexion RoM as one of three, two-dimensional kinematic measures predicting PKVM during UnSS. However, in the current study, there was a significant strong negative correlation ($p < .05$, $r = -.667$) between the trunk flexion RoM and PKVM. Trunk flexion during landing decreases the vertical ground reaction force in single leg landing tasks (Shimokochi et al., 2013). In the current study sagittal trunk flexion motion possibly assists in absorbing the ground reaction force, thereby reducing the load placed on the ACL. Weir et al. (2013) did not compare two-dimensional and three-dimensional kinematics, leaving the possibility that the two-dimensional trunk flexion RoM measurement (Weir et al., 2013) fundamentally differs to the three-dimensional trunk flexion RoM in this study. This hypothesis requires confirmation using a larger cohort.
It is acknowledged the sample in this study was small ($n = 9$), limiting the applied clinical or coaching messages being drawn from these data. However, these analyses have provided initial evidence for an individual's preparatory trunk mechanics being an important biomechanical factor influencing PKVM and ACL injury risk. A larger data set of male and female participants ($n = 116$) is currently being analysed to verify the current results.

CONCLUSION: A relationship between an athlete's preparatory mechanics and PKVM during WA was identified during unplanned sidestepping. Specifically, preparatory AP-TM and LR-TM alongside trunk flexion RoM during WA have been identified as candidate predictors of PKVM. High preparatory anterior and lateral trunk momenta in the direction of travel, may illicit high peak knee valgus moments and associated ACL injury risk during UnSS. Future research within a larger sample ($n \geq 40$) is recommended to further investigate this relationship, before definitive clinical or applied messages can be made.

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