EFFECTS OF TASK CONSTRAINTS ON SIDESTEPPING JOINT KINETICS

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The purpose of this study was to assess the change in lower limb joint kinetics associated with anterior cruciate ligament injury (ACL) risk in sidesteps with and without task constraints. Female athletes (n=21) performed pre-planned and unplanned sidesteps with and without task constraints to the trunk and the preparatory step. Statistical differences in negative peak joint power for the hip, knee and ankle during the execution step, the entry velocity and the sidestep angle between the constrained and unconstrained sidesteps were determined with a linear mixed model. The entry velocity decreased for all unplanned sidesteps compared to pre-planned sidesteps. Trunk constraints increased knee joint loading in pre-planned sidesteps (-24.51 ± 11.27 W·kg^{-1}) compared to unconstrained unplanned sidesteps (-17.69 ± 8.58 W·kg^{-1}). Understanding how constraints can alter the magnitude of lower-body joint loading can help design effective drills to overload single-joint capacities.

KEYWORDS: ACL, sidesteps, constraints

INTRODUCTION:

Non-contact anterior cruciate ligament (ACL) injuries during sidestepping occur when the imposed demands exceed the tissue capacities. The combination of externally applied knee flexion, valgus and internal rotation moments elevate ACL loading up to the point of ACL rupture (Besier et al. 2001). ACL loading is affected by the kinematic strategy during sidestepping. Specific postures and single joint alignments across distinct body segments increase ACL loading (e.g., lateral trunk sway or hip abduction during the execution step) (McLean et al. 2004). Subsequently, these insights can inform training interventions to reduce ACL injury risk. Generally, training recommendations often aim to reduce ACL loading by avoiding specific segment alignments. However, training to avoid such kinematic strategies will likely fail to prepare athletes for *in situ* demands and may compromise their robustness and resiliency in the long run as these scenarios can arise in the context of complex game manoeuvres that can lead to increased ACL loading. The concepts of 'specific adaptations to the imposed demands' and 'progressive overload' state that a continuous and systematic application of load can increase tissue tolerance even in kinematically challenging positions (Schmidtbleicher, 1980).

Utilizing task constraints to implicitly change the kinematic strategy alters joint kinetics during jumping (Cushion et al., 2021) and sprinting (Saito et al., 2017). Deliberately exposing athletes to such movement variations changes the habitual magnitude and distribution of joint loading, thus allowing for adaptation compared to unconstrained movements. As preparatory trunk and pelvis kinematics (Staynor et al., 2020) and trunk positioning during sidesteps (Donnelly et al., 2012) are associated with ACL loading, imposing task constraints to intentionally alter those key phases may change knee joint loading. As such, the purpose of this study was to determine 1) the effects of constraining the trunk on knee joint loading during pre-planned and unplanned sidestepping – here, we hypothesized that constraining the trunk by holding an external load at chest level throughout the task increases knee joint loading associated with ACL injury risk; 2) the effects of constraining the penultimate step on knee joint loading during pre-planned and unplanned sidestepping – here, we hypothesized that implicitly lowering the centre of mass (COM) during the penultimate step decreases knee joint loading associated with ACL injury risk.

METHODS:

This observational study was designed to determine the effects of two different task constraints on knee joint kinetics during planned and unplanned sidestepping compared to unconstrained movements. Six different conditions pre-planned & unconstrained (PP_{free}), unplanned & unconstrained (UP_{free}), pre-planned & trunk constrained (PP_{trunk}), unplanned & trunk constrained (UP_{trunk}), pre-planned & preparatory step constrained (PP_{prep}), unplanned & preparatory step constrained (UP_{prep}) were used. The outcome measures included peak negative joint power ($W \cdot kg^{-1}$) for the ankle (JP_{ANKLE}), knee (JP_{KNEE}), and hip (JP_{HIP}) for the cutting step, as well as entry velocity ($m \cdot s^{-1}$) and sidestep angle (°).

Female Australian Rules Football (ARF) players (n=21; age: 23.5 ± 4.5 y, height: 170.6 ± 5.8 cm, weight: 67.5 ± 6.6, ARF experience: 5.8 ± 4.5 y) volunteered in this study. All participants had at least two years of ARF experience and one year of resistance training experience.

Data collection started with the PP_{free} condition to allow for a consistent start and extended warm-up and were followed by PP_{trunk} or PP_{prep}, which were allocated in a counterbalanced and randomised order. Subsequently, the UP_{free} condition followed before either the UP_{trunk} or UP_{prep} conditions were performed, which were allocated in a counterbalanced and randomised order. To simulate the unplanned sidestepping, a direction arrow was displayed immediately after the athlete triggered a set of timing gates 2 m before the force plate (Lee et al., 2013). For a trial to be considered successful, approach velocities prior to the sidestepping are required to be between 3.5-4.5 $m \cdot s^{-1}$. Sidestepping angle of 45° was controlled using a runway line marked on the force plate. Three valid trials for each condition were used for the subsequent data analysis.

For the trunk constrained trials, participants held an external load at chest level of 5-7.5% of body weight throughout the task. Participants under 70 kg used a 4 kg load, and participants above 70 kg used a 6 kg load. This extra mass was added for all subsequent calculations. For the preparatory step constrained trials, participants ducked under an adjustable rope attached at the participant's eye height and placed 50 cm before the centre of the force plate, which corresponded to penultimate foot placement prior to sidestepping.

Kinematics and kinetics were recorded with a 3D motion capture system and in-ground force plates. Thirty-eight retroreflective markers were used following the University of Western Australia lower-body and torso marker set and model (Version 5) (Lee et al., 2013). Instantaneous joint power was calculated from joint angular velocities multiplied by net joint moments for each trial ($P = M \cdot \omega$) and summed for all planes for the first 30% of the stance phase. Sidestep angle was calculated using the x- and y-coordinates of the stance foot ankle joint centre at initial contact (x1 and y1) and the coordinates of the contralateral ankle joint centre at initial contact (x2 and y2) using equation (1). The entry velocity was defined as the horizontal velocity of the centre of mass (COM) at the initial contact of the execution step (V@IC).

(1) Sidestep angle = $tan^{-1}\left(\frac{a}{b}\right)$; where a = $|x2 - x1|$ and b = $|y2 - y1|$

Mean and standard deviation (*SD*) were calculated for all discrete variables. Linear mixed models were performed to analyse between-condition differences (fixed effects) and random intercepts for participants, as well as by-participant random slopes for the effect of condition with $\alpha = 0.05$. Bonferroni correction was used for *post hoc* analysis to determine between condition differences. Cohen's *d* effect size was calculated interpreted as <0.2 (trivial), 0.2-0.49 (small) and 0.5-0.79 (moderate) and >0.8 (large). Significance was calculated using the gamlj package (Version 2.5.5) in R Studio (Version 1.4.11.06, R Core Team 2018, http://www.R-project.org/).

RESULTS:

A statistical difference between all conditions for sidestepping angle ($p = 0.02$) and entry velocity ($p < 0.001$) was observed. *Post hoc* analyses showed sidestep angle differed significantly only between PP_{prep} : UP_{trunk} ($p = 0.03$; $d = 0.73$). V@IC differed significantly between all pre-planned and unplanned conditions ($p < 0.001$; $d > 2.2$), with no significant differences between all pre-planned ($p > 0.28$) and all unplanned conditions ($p = 1.00$) (Table 1).

Table 1. Sidestepping characteristics (Mean ± standard deviation)

Condition	Sidestep angle (°)	V@IC (m·s^{-1})
PP_{free}	38.1 ± 4.5	3.46 ± 0.30 # * †
PP_{trunk}	38.3 ± 4.6	3.54 ± 0.37 # * †
PP_{prep}	37.6 ± 4.6 *	3.65 ± 0.48 # * †
UP_{free}	40.3 ± 5.8	2.78 ± 0.25
UP_{trunk}	40.9 ± 4.7	2.79 ± 0.28
UP_{prep}	39.5 ± 6.3	2.75 ± 0.28

= significant difference compared to UP_{free} ($p < 0.001$); * = significant difference compared to UP_{trunk} ($p < 0.001$); † = significant difference compared to UP_{prep} ($p < 0.001$); V@IC = Entry velocity.

There were no statistical differences in JP_{HIP} ($p = 0.68$) between the conditions. There was a difference in JP_{KNEE} ($p = 0.02$). *Post hoc* analyses showed differences between UP_{free} : PP_{trunk} ($p = 0.01$; $d = 0.68$). Similarly, there was a statistically significant difference in JP_{ANKLE} ($p = 0.03$) between the conditions, but *post hoc* analysis showed no between-group difference ($p = 0.06$) (Table 2).

Table 2. Peak negative joint power (mean ± standard deviation)

Condition	JP_{HIP} (W·kg^{-1})	JP_{KNEE} (W·kg^{-1})	JP_{ANKLE} (W·kg^{-1})
PP_{free}	-3.06 ± 2.79	-19.04 ± 8.87	-8.05 ± 4.69
PP_{trunk}	-3.23 ± 3.31	-24.51 ± 11.27 #	-7.48 ± 4.32
PP_{prep}	-2.62 ± 4.00	-20.16 ± 8.90	-7.41 ± 3.96
UP_{free}	-3.66 ± 3.52	-17.69 ± 8.58	-6.67 ± 4.00
UP_{trunk}	-3.73 ± 3.29	-20.01 ± 7.74	-7.19 ± 5.25
UP_{prep}	-4.04 ± 4.64	-17.82 ± 9.02	-5.89 ± 3.53

= significant difference compared to UP_{free} ($p < 0.001$); JP_{HIP} = Peak negative hip joint power; JP_{KNEE} =Peak negative knee joint power; JP_{ANKLE} = Peak negative ankle joint power.

DISCUSSION:

The study aimed to determine the effects of task constraints on joint kinetics during pre-planned and unplanned sidestepping. Our first hypothesis was partially supported with PP_{trunk} eliciting greater knee joint loading (JP_{KNEE}) compared to UP_{free}. Knee joint loading remained unchanged in the UP_{trunk} condition. Our second hypothesis was rejected as both PP_{prep} and UP_{prep} failed to change the JP_{KNEE} compared to unconstrained sidesteps. Performing planned and unplanned sidesteps while constraining the penultimate step is not effective for overloading isolated lower-body joints.

Higher approach velocities (Vanrenterghem et al., 2012) and unplanned sidestepping (Lee et al., 2013) have previously been shown to increase knee joint loading. Based on the current results, unplanned sidesteps with standardised approach velocities between 3.5-4.5 m·s^{-1} did not increase knee joint loading compared to pre-planned sidesteps (PP_{free}). However, participants reduced their entry velocity for unplanned sidestepping, presumably to allow enough time to perceive the generic stimulus and react accordingly. As approach velocity was standardised in all conditions up to 2 m before the targeted sidestepping area, participants likely decelerated to a greater extent during the penultimate and antepenultimate step prior to sidestepping.

Pre-planned sidesteps with constraints applied to the trunk elicited higher peak knee joint loading (JP_{KNEE}) compared to the unconstrained, unplanned conditions. Constraining the trunk by holding an external load (4-6kg or approximately 5-7.5% of body mass) in front of the chest may have shifted the position of the COM cranially and potentially changed the moment arms of the trunk in relation to lower limb joints. As the trunk position affects lower limb kinetics when sidestepping (Donnelly et al., 2012), further increasing the mass ratio of upper-body vs. lower-body alongside the vertical positioning of the COM may have increased knee joint loading. Interestingly, knee joint loading remained unchanged when comparing UP_{trunk} and UP_{free}, which may have resulted from the reduced V@IC in all unplanned conditions. It can be argued that any deviations of the COM during sidesteps may not affect knee joint loading until the athlete reaches a certain V@IC. Hence, the combination of constraining the trunk and higher entry velocities facilitates increased knee joint loading during sidestepping.

The magnitude and the relative contribution of the hip and ankle joint power remained relatively constant between conditions (Table 2). Further, the relatively low JP_{HIP} values show the hip musculature's low contribution attenuating the imposed demands. The knee joint acted as the dominant load absorber in sidesteps as approximately 65% of the lower-limb joint power ($W \cdot kg^{-1}$) was accepted at the knee during early stance for all conditions. This lower-limb load distribution strategy during sidesteps highlights the necessity of developing adequate physical capacities of the knee surrounding musculature to better counteract the imposed demands. This adds to the understanding of why non-contact ACL injuries are prevalent when sidestepping.

CONCLUSION:

The current study shows how different constraints applied to pre-planned and unplanned sidesteps change the imposed knee joint loading. Adding constraints to the trunk by holding a weighted implement in front of the chest (PP_{trunk}) while sidestepping increased knee joint loading compared to unplanned and unconstrained sidestepping (UP_{free}). Systematically incorporating such drill variations and progressively exposing athletes to greater knee joint loading may provide a protective effect against ACL injury and better prepare for *in situ* demands. All unplanned conditions failed to increase joint loading compared pre-planned conditions, likely due to a reduced entry velocity upon contact. Understanding how constraints can alter the magnitude of lower-body joint loading can help designing effective drills to overload single-joint capacities.

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