TRUNK MUSCLE ACTIVATION DURING PLANNED AND UNPLANNED SIDESTEPPING: IMPLICATIONS FOR FRONTAL PLANE TRUNK POSITIONING AND ACL INJURY RISK

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This study compared time-varying measures of trunk muscle activation and lateral flexion between planned (PSS) and unplanned sidesteps (UPSS) in seven male participants. Fine-wire and surface electromyography signals from nine muscles characterised trunk muscle activation. Greater trunk activation was observed in UPSS during the penultimate stance and action-stance, but not during flight phase preceding the action-stance. Significant differences were observed in flight phase trunk lateral flexion angle between tasks. No differences were found in lateral contraction ratios between movement conditions. These preliminary results indicate that trunk muscle activation differences between PSS and UPSS are not sufficient to account for the increased lateral forces experienced during UPSS. Thereby, resulting in the higher trunk lateral flexion observed during UPSS.

KEYWORDS: injury mechanism, neuromuscular, preparatory mechanics, knee.

INTRODUCTION: The majority of anterior cruciate ligament (ACL) injuries occur in non-contact situations, and are most often observed during sidestepping movements (Koga et al., 2010). Biomechanical investigation of sidestepping has identified kinematic and neuromuscular factors associated with ACL injury risk, or peak knee valgus moments (PKVM) (Hewett et al., 2016). Despite reported associations between trunk lateral flexion and PKVM (Dempsey et al., 2007), as well as trunk stability and ACL injury incidence (Zazulak et al., 2007), there is sparse investigation into the role of trunk muscle activation. A surface electromyography (EMG) study by Jamison et al., (2013) found no relationship between co-contraction of ipsilateral and contralateral muscle pairs (i.e. left and right obliques) with lateral trunk positioning. Limitations of that study included the use of surface EMG and analysis of discrete measures of muscle activation. Investigation into trunk muscle activation should consider using fine-wire EMG to record from deep lying muscles. Additionally, time-varying analysis may assist in characterising the activation of the trunk during sidestepping.

It is reported that unplanned sidesteps (UPSS) have higher PKVM, and subsequent injury risk predisposition, than planned sidesteps (PSS), and are thought to better represent real-world observations of non-contact ACL injuries (Brown et al., 2014). Differences between PSS and UPSS in lower-limb kinematic, kinetic and neuromuscular measures are well studied (Brown et al., 2014; Hewett., 2016). However, there is a paucity of published research examining the role of trunk activation on lateral trunk position during PSS and UPSS. Explorative research comparing PSS and UPSS could give insight into time-varying trunk neuromuscular strategies that may influence trunk lateral flexion and associated PKVM (Dempsey., 2007).

The aim of this exploratory study was to compare preparatory trunk activation between PSS and UPSS. It is hypothesised that differences in average magnitude will be observed in time-varying trunk EMG between conditions. Differences in contralateral and ipsilateral trunk contraction ratio (CR) are not expected to be observed between PSS and UPSS.

METHODS: Seven male participants (22.6 ± 2.1 years, 1.80 ± 0.1 m and 76.1 ± 7.0 Kg) completed a series of planned and unplanned straight line runs, sidesteps and crossovers (Donnelly et al., 2015). A force plate (AMTI, America) and a 26 Vicon camera motion capture system (Oxford Metrics, United Kingdom) synchronously recorded ground reaction forces and marker motion respectively. Motion data was recorded at 250 Hz, and EMG and force data at 4000 Hz. Force and marker trajectories were used to define the phases of movement during the tasks. A global lateral flexion angle of the trunk was calculated relative to vertical, with lateral flexion towards the stance-limb during the action-step defined as positive. A retrofitted wireless EMG system (Myon AG, Switzerland) was used to record electrical activity from nine trunk muscles. Activation of the rectus abdominus, along with bilateral erector spinae were recorded using bipolar surface electrodes (3M, United States). Muscle activation of bilateral external obliques, internal obliques and quadratus lumborum were measured with fine-wire EMG (Chalgren Enterprises Inc, United States), which were inserted into the muscle while under ultrasound guidance by a trained researcher.

Along with the series of runs and sidesteps; functional squat, single-leg squat, counter-movement jump and drop-jump trials were recorded to establish a functional maximum voluntary contraction (MVC) for each recorded muscle. During analysis raw signals and power spectrums were visually inspected for quality. Trials with abnormally high voltage recordings or low-frequency noise were removed from the analysis. For all signals the DC offset was removed, and a fourth order Butterworth bandpass filter applied, set to 30/300 Hz for surface and 40/300 Hz for fine-wire signals. The power spectrum of the raw fine-wire signals contained 50 Hz noise, and as such the band-passed fine-wire signals were additionally notch filtered at 50 Hz. All signals were then full-wave rectified and linear enveloped with a second order Butterworth filter at 6 Hz. For each muscle, linear enveloped signals were reported as a percentage of the maximum signal observed for the muscle across all trials.

For each participant, data from three trials of each movement condition were time-normalized (Figure 1) to three distinct phases using a cubic spline interpolation: 1) stance of the penultimate step (0-33%), 2) flight phase of the penultimate step (34-55%) and 3) stance of the action-step (56-100%). Average functional muscle group activations were calculated as per previous lower-limb EMG analysis during sidestepping (Donnelly et al., 2015). Trunk muscle activation was calculated as the average activation of all recorded trunk muscles. Average ipsilateral (same side as the action-step stance limb) and contralateral activation were calculated using external oblique, internal oblique, erector spinae and quadratus lumborum of the relevant side. Lastly, a CR for average ipsilateral and contralateral signals was calculated (ipsilateral ÷ contralateral). For each participant muscle activation variables were averaged across three trials to create average time-normalised measures for each condition.

A paired samples t-test ($\alpha < 0.05$) was used to test for differences between PSS and UPSS. The analysis was conducted on time-varying data using statistical parametric mapping (SPM) (Pataky et al., 2013). As this was an exploratory analysis, inferences were made on data where the effect size for differences was considered very large ($d > 1.30$) (Sullivan & Feinn, 2012).

Left to right: penultimate stance (0-33%), penultimate flight phase (34-55%) and action-stance (56-100%).

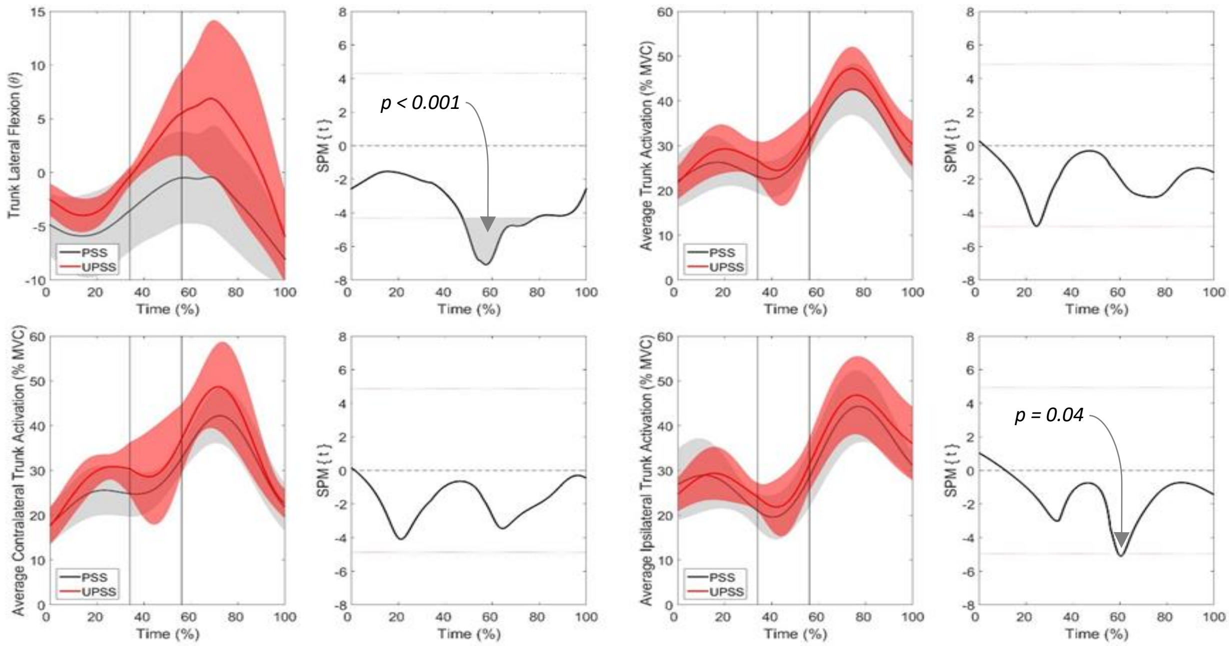
Figure 1: Time-normalized phases during PSS and UPSS.

RESULTS: Significant differences between conditions were identified for trunk lateral flexion and average activation of the ipsilateral trunk musculature. Time-varying statistical outputs for average trunk activation measures and trunk lateral flexion are presented in Figure 2. Large effect size differences were found for several paired comparisons (Table 1). No significant differences or large effect sizes were observed when comparing average lateral CR between movement conditions (maximum difference = 0.16).

Table 1. Paired time-varying comparisons between PSS and UPSS

Measurement	Paired t-test	Effect Size > 1.30		
	Movement (%)	Movement (%)	Min MD	Max MD
Trunk Lateral Flexion	49 – 80	45 - 98	-2.4°	-7.3°
Average Trunk Activation	-	20 - 29	-3.2%	-3.7%
Average Contralateral Activation	-	18 - 25 & 64 - 65	-4.5%	-6.1%
Average Ipsilateral Activation	59 – 62	56 - 66	-2.8%	-3.2%

Note. N = 7. Movement percentages are reported for significant paired t-tests ($p < 0.05$), and where effect sizes > 1.30. Measurement differences (MD = PSS – UPSS) were calculated during movement where the effect size difference was > 1.30.



Time-normalised mean and standard deviation clouds and SPM paired t-tests for average: trunk lateral flexion (top left), trunk activation (top right), contralateral trunk activation (bottom left) and ipsilateral trunk activation (bottom right). Vertical lines represent start of the penultimate flight phase (34%) and action-stance (56%).

Figure 2: One-dimensional analysis of trunk lateral flexion and trunk muscle activation.

DISCUSSION: This study examined trunk muscle activation between a planned and an unplanned sidestepping condition. The first hypothesis was supported, with very large effect size differences found in time-varying trunk EMG between PSS and UPSS. The second hypothesis was also supported, with no significant or meaningful differences in lateral CR observed across the two conditions.

Large effect sizes were observed for differences in trunk activation measures. UPSS had greater average trunk and contralateral trunk activation during the penultimate step, and greater average contralateral and ipsilateral trunk activation during the action-step. Increased average trunk activation during the penultimate step of UPSS may indicate an initial neuromuscular response to the timed arrow stimuli. This neuromuscular response possibly acts to stiffen the trunk, and thereby reduce inertial effects of the upper body. A stiffened trunk would provide greater "core-stability", allowing for improved control of the swinging lower-limb (Kibler et al., 2006). Activation differences early in the action-step may be due to reactionary or reflexive muscle activation. From an injury perspective these activations occur too late to influence injury risk, given that the time from foot contact to injury event (40ms) is shorter than the electromechanical delay (50ms) (Cavanagh & Komi, 1979; Koga et al., 2010).

Trunk muscle activation may be inadequate to maintain vertical positioning of the trunk during UPSS. Trunk lateral flexion during flight phase and early action-stance was significantly greater in UPSS, which is associated with increased PKVM (Dempsey et al., 2007). However, differences between PSS and UPSS in trunk activation were not observed immediately preceding, or during this flight phase. An absence of meaningful differences in trunk activation during this time period, along with the potential for higher lateral perturbative forces, may partially explain the greater trunk lateral flexion observed in UPSS. These results indicate the need for future research to investigate trunk stability during the penultimate flight phase of sidestepping and its potential influence on ACL injury risk factors.

Despite similarities in the lateral CR across conditions, differences were observed in trunk lateral flexion. This is in agreement with previous research which found no effect of ipsilateral and contralateral activation asymmetry on lateral trunk positioning (Jamison et al., 2013). In the current study contralateral musculature does not appear to be selectively activated to combat lateral trunk lean observed during UPSS. However, during PSS similar lateral activation strategies are sufficient for maintaining frontal-plane trunk position. Shifting the CR towards contralateral trunk muscles in UPSS may act to resist forces tilting the trunk laterally over the sidestepping stance-limb, and thereby reduce PKVM (Dempsey et al., 2007).

The current sample is relatively small (n = 7), however, these analyses have provided evidence of differences in trunk muscle activation during PSS and UPSS. Data collections are ongoing, with an aim to have a final sample of 12 to further investigate these preliminary findings.

CONCLUSION: Greater trunk activation in UPSS compared to PSS, fails to provide equivalent control of lateral trunk positioning across the two conditions. Higher trunk lateral flexion angles were seen during UPSS, which may be attributable to an absence of meaningful activation differences during the penultimate flight phase between conditions. This suggests that trunk activation during this time is not sufficient to control frontal-plane trunk positioning which may place individuals at a greater risk of ACL injury during UPSS.

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