ANTICIPATORY EFFECTS ON WHOLE-BODY DYNAMIC STABILITY IN SIDE CUTTING

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The purpose of this study was to identify the anticipatory effects on factors that influence the ability to generate medial ground reaction forces in changes of direction, and the implications for injury risk markers. Twenty recreational soccer players completed 12 anticipated and 12 unanticipated side cutting tasks, whilst 3D motion capture and force plate data were collected. Five distinct movement strategies were found to represent factors that influence the medial ground reaction force vector, and comparisons were made between the two conditions using multiple t-tests in SPM1D. Whole-body dynamic stability is compromised by limited anticipation time, with a greater demand on a corrective hip strategy following a narrower foot placement and reduced sagittal plane loading efficiency. This may have implications for change of direction performance and injury risk.

KEYWORDS: change of direction, centre of mass control, anterior cruciate ligament

INTRODUCTION: The condition of whole-body dynamic stability represents the ability of the performer to mitigate unnecessary movements, whilst the centre of mass (CoM) is being controlled. Control of the CoM is essential in dynamic sporting tasks like side cutting, and is likely to involve several important movement strategies. Deviations in those movement strategies may have negative consequences for performance and injury risk. Typically side cutting tasks in sport are triggered by external stimuli such as movements of other players, and this can influence the time the performer has to deploy the appropriate movement strategies (Besier et al., 2001; Houck, Duncan and De Haven, 2006; Mornieux et al., 2014). If external stimuli become challenging, one may see failures in those movement strategies, and thus, failures in whole-body dynamic stability. This can in turn lead to potentially dangerous movement deviations like those reported for Anterior Cruciate Ligament (ACL) injury (Weinhandl et al., 2013; Brown, Brughelli and Hume, 2014). However, the extent to which the various movement strategies that contribute to whole-body dynamic stability are affected by the level of anticipation remains unknown.

Side cutting performance is dependent on the ability of the performer to generate an impulse against the ground to decelerate and accelerate the CoM in the new direction of travel. Thus, the ability to apply medial ground reaction force (GRF) is essential for side cutting, and factors that influence the medial GRF vector would indicate key movement strategies for medial control of the CoM in the task. Quantifying initial foot placement and centre of pressure position would allow one to express the factors that determine the point of application of the GRF vector. Quantifying factors that influence the magnitude of the medial GRF vector is more challenging, however, Induced Acceleration Analysis (IAA) offers a useful approach that has been previously reported (Kepple et al., 1997). The aim of this study was to quantify the anticipatory effects on whole-body dynamic stability movement strategies in side cutting whilst expressing the consequences for performance and undesirable knee joint moments. It is hypothesised that reduced preparation time, represented by an unanticipated external stimulus, will: 1, result in significant increases in undesirable knee joint moments and significantly poorer performance of the side cutting task; and 2, demonstrate significant differences in the deployment of whole-body dynamic stability movement strategies.

METHODS: Twenty recreational soccer players (train/play 1-2 times per week) completed 45° anticipated (ANT) and unanticipated (UNANT) side cutting with a ~4 ms^{-1} approach speed whilst 3D motion capture and ground reaction force data were collected. UNANT conditions were controlled with a timing-gate light stimulus (Smartspeed™) triggered 3 m before the force plate. A seven camera Vicon system (250 Hz) and Kistler force plate (1500 Hz) were used to collect data. Kinematics and kinetics, and task performance outcome variables were calculated using a lower limb and trunk model. Following 20 Hz low-pass filter, performance outcomes and peak knee abduction moments were calculated for each side cutting task with an average of 12 trials per participant, per condition, which were randomised and counterbalanced. Inverse Kinematic modelling was completed as a pre-requisite for IAA. IAA was run in Visual 3D, and non-negligible contributions to medial GRF (>10N) were consolidated into their respective planes. This allowed us to identify five distinct movement strategies to represent factors that influence the medial GRF vector. Specifically, (1) medio-lateral foot placement, (2) Centre of Pressure (CoP) position, (3) sagittal plane triple acceleration (combined hip, knee and ankle), and (4) frontal and (5) transverse plane hip acceleration, were calculated. We noted that it was possible to represent the extent of sagittal and non-sagittal contributions to change of direction in a single metric, which may be a useful reference for practitioners. Specifically, sagittal triple acceleration impulse was calculated as a proportion of the total IAA derived medial GRF impulse for a *Sagittal Efficiency Ratio* (*<100%* = medial loading from non-sagittal methods included; *100%* = sagittal medial loading only; *>100%* = excessive sagittal loading, non-sagittal lateral unloading included). Multiple t-tests were conducted in SPM1D (v0.4, www.spm1d.org) to investigate the differences between 0D and 1D whole-body dynamic stability, task performance outcomes, and joint loading variables in ANT and UNANT side cutting.

RESULTS: UNANT side cutting was performed significantly slower, with a significantly longer contact time, but with a greater change of direction angle than ANT side cutting. There was no significant difference in peak knee abduction moment (KAM) between UNANT and ANT side cutting (see Table 1). In observation of the distinct movement strategies we see that UNANT side cutting was performed with a significantly narrower foot placement compared to ANT. The Sagittal Efficiency Ratio demonstrated that in both conditions performers apply sagittal plane loading in excess of the total medial GRF (>100%). Furthermore, excessive sagittal plane loading was significantly more pronounced in the UNANT condition compared to ANT (see Figure 1). In UNANT side cutting frontal plane hip acceleration was used significantly more for unloading - generating opposing lateral GRFs - compared to ANT through the majority of ground contact.

Table 1: Comparison of side cutting performance outcome variables over ground contact for ANT and UNANT side cutting. Means are presented with standard deviation [SD]. Parametric or non-parametric (^{np}) paired t-test results (α = 0.008) are also identified.

Performance outcome and joint loading variables	**ANT side cutting** mean [±SD]	**UNANT side cutting** mean [±SD]	**Statistical difference**
Touchdown Velocity (ms^{-1})	4.33 [0.33]	3.95 [0.30]	**p<0.001*
Toe-off Velocity (ms^{-1})	4.38 [0.28]	4.00 [0.24]	**p<0.001*
Change of direction angle (°) ±SD	17.26 [3.45]	20.64 [3.20]	**p<0.001*
Av. medial CoM acceleration (ms^{-2})	5.29 [1.16]	4.91 [0.91]	^{np} *p=0.012*
Contact time (s)	0.235 [0.02]	0.28 [0.03]	**p<0.001*
Peak KAM (Nm/kg)	0.35 [0.29]	0.44 [0.25]	*p=0.062*

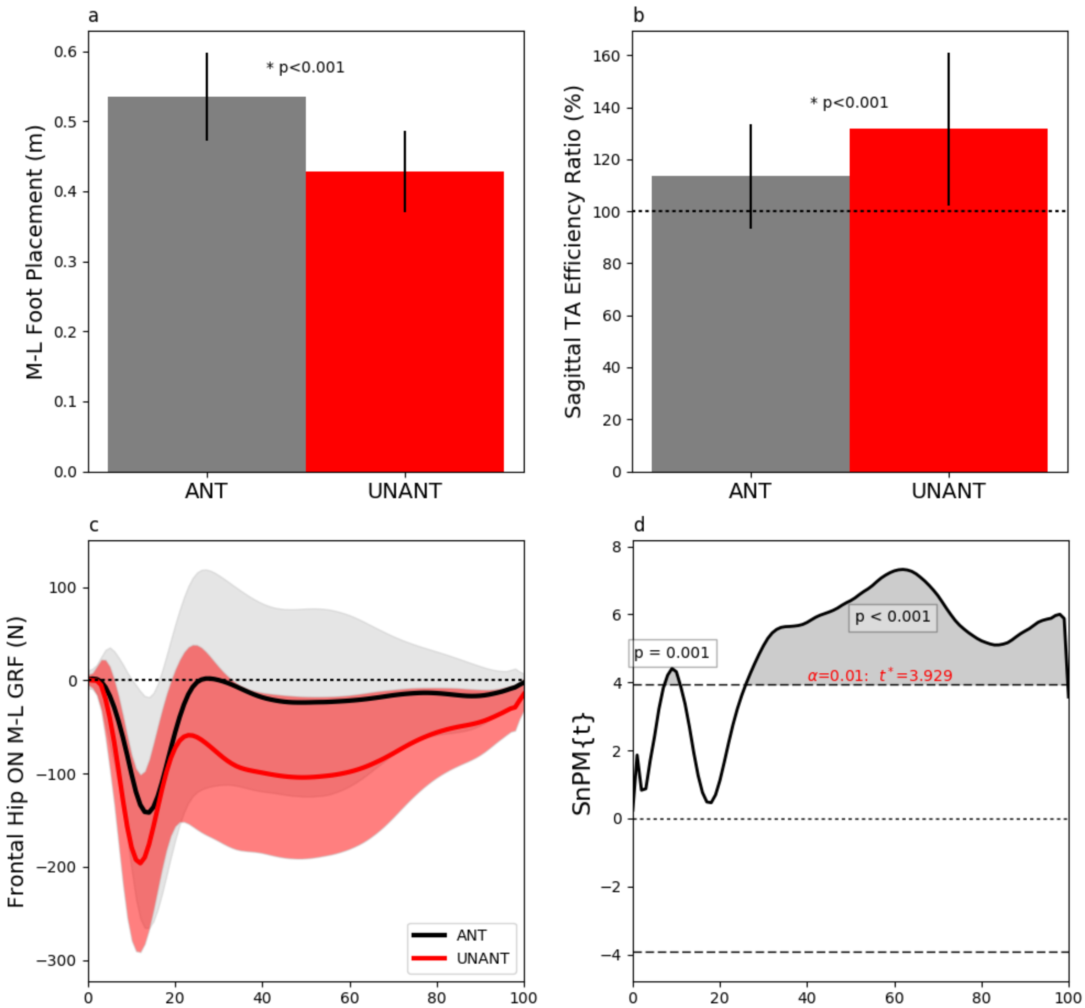

Figure 1. Comparison of selected whole-body movement strategies in *anticipated* (ANT) and *unanticipated* (UNANT) side cutting conditions. Specifically, (a) medio-lateral (M-L) foot placement, and (b) Sagittal [triple acceleration (TA)] Efficiency Ratio and (c,d) frontal plane hip acceleration contributions to medio-lateral (M-L) ground reaction force (GRF) comparisons between conditions are presented. Means and standard deviations are presented for each variable discretely (a,b) or over ground contact (c). In image a '0.00' on the y-axis represents metatarsal head 5 (MTH5). In image b '100%' represents where sagittal plane loading would be entirely responsible for M-L GRF. Statistical differences are presented above the bar chart for 0D data and non-parametric (SnPM{t}) paired t-test results for frontal plane hip acceleration are presented in image d. All statistical comparisons were made in SPM1D and based on Bonferroni correction of alpha for multiple comparisons, *α* = *0.01*.

DISCUSSION: The aim of this investigation was to quantify the effects of anticipatory demands on whole-body dynamic stability movement strategies in side cutting, whilst expressing the implications for change of direction performance and injury risk markers. In side cutting tasks performed with limited anticipation time *(0.5-0.65 seconds reaction time, in this case)*, although participants were able to make a greater change of direction angle, the task was performed with a slower approach velocity. However, average medial CoM acceleration is another key side cutting performance indicator, and this was not significantly affected by anticipation time. In addition, limited anticipation did not significantly affect markers of ACL injury risk (peak knee abduction moment); therefore, the first null hypothesis cannot be fully rejected. All whole-body dynamic stability movement strategies were found to be affected by limited anticipation, which suggests there are anticipatory postural adjustment that are required to retain medial control of the CoM. Thus, the second hypothesis can be fully accepted.

The key anticipatory adjustments in whole-body dynamic stability movement strategies included a narrower foot placement, more excessive sagittal plane loading, and greater countermovement from frontal plane hip acceleration over ground contact. It seems that participants may be forced to deploy a narrower foot placement with limited time to prepare. Subsequently, this means that sagittal plane loading becomes more excessive for a more compact or upright posture, and therefore, may cause greater destabilisation to the centre of mass. Unless, that is, excessive sagittal plane loads are mitigated by non-sagittal methods, and a corrective frontal plane hip movement strategy plays the most important role here. Previous studies have identified that lateral trunk flexion and foot placement may explain anticipatory postural adjustments in side cutting (Brown et al., 2014; Mornieux et al., 2014). However, our findings are in closer agreement to those of Houck et al. (2006) who suggest that frontal plane hip control is probably a more direct movement strategy at work here. In addition, we have been able to identify that, where lateral trunk flexion is likely to be a consequence of frontal plane hip acceleration, the role of this movement strategy is almost exclusively corrective in side cutting, especially with limited anticipation time. Thus, it may not be possible to achieve medial control of the CoM with only sagittal plane loading, and this seems less likely with more challenging change of direction scenarios. However, practitioners may design intervention strategies to improve the efficiency of sagittal and non-sagittal movement strategies to mitigate negative consequences on change of direction performance and injury risk. Specifically, this may involve training foot placement in incrementally challenging change of direction scenarios, whilst encouraging sagittal triple extension of the hip, knee and ankle to control and propel the centre of mass in the turn. If reaction time is challenged, sagittal plane loading may become excessive, so then frontal plane hip training may also help moderate whole-body dynamic stability, and thus mitigate injury risk.

CONCLUSION: This study identified that whole-body dynamic stability is compromised in change of direction tasks with limited anticipation time. Specifically, there is an increased demand on a corrective frontal plane hip movement strategy to mitigate excessive sagittal plane loading, following a narrower foot placement. Thus, limited preparation time may lead to destabilisation of the centre of mass and adjustment in movement strategies are required to retrieve control. Deviations in these movement strategies affect change of direction performance aspects, and may be a precursor to increases in injury risk. Practitioners should aim to develop their athletes' ability to improve whole-body dynamic stability holistically in challenging change of direction scenarios as part of a progressive training and monitoring intervention strategy.

REFERENCES

Besier, T. F., Lloyd, D. G., Ackland, T. R., and Cochrane, J. L. (2001). Anticipatory effects on knee joint loading. Medicine and Science in Sports and Exercise, 33(7), 1176–1181.

Brown, S. R., Brughelli, M., and Hume, P. A. (2014). Knee Mechanics During Planned and Unplanned Sidestepping: A Systematic Review and Meta-Analysis. Sports Medicine, 1573–1588.

Houck, J. R., Duncan, A., and De Haven, K. E. (2006). Comparison of frontal plane trunk kinematics and hip and knee moments during anticipated and unanticipated walking and side step cutting tasks. Gait and Posture, 24(3), 314–322

Kepple, T. M., Siegel, K. L., and Stanhope, S. J. (1997). Relative contributions of the lower extremity joint moments to forward progression and support during gait. Gait and Posture, 6, 1–8.

Mornieux, G., Gehring, D., Fürst, P., and Gollhofer, A. (2014). Anticipatory postural adjustments during cutting manoeuvres in football and their consequences for knee injury risk. Journal of Sports Sciences, 32(13), 1255–1262.

Weinhandl, J. T., Earl-Boehm, J. E., Ebersole, K. T., Huddleston, W. E., Armstrong, B. S. R., and O'Connor, K. M. (2013). Anticipatory effects on anterior cruciate ligament loading during sidestep cutting. Clinical Biomechanics, 28(6), 655-663.