WHOLE-BODY CONTROL STRATEGIES DURING ANTICIPATED AND UNANTICIPATED SIDESTEP MANOEUVRES PERFORMED BY FEMALES AND MALES

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The purpose of this study was to investigate the influence of sex and planning time on spatial and temporal-level whole-body centre of mass (CoM) mechanics during the performance of the sidestep manoeuvre. Nine female and nine male collegiate team sport athletes completed seven anticipated and seven unanticipated sidestepping trials, during which three-dimensional CoM data were recorded. In addition to having a lower vertical CoM position during the preparatory phase ($p < 0.05$), female athletes were found to have lower anterior-posterior velocity, but greater vertical velocity during the stance phase in comparison with their male counterparts ($p < 0.05$). The findings provide evidence that female and male athletes utilise different whole-body dynamic control strategies to perform both anticipated and unanticipated sidestep manoeuvres.

KEYWORDS: Centre of mass, dynamic control, perception

INTRODUCTION: The aim of the sidestep manoeuvre is to efficiently re-orient the centre of mass (CoM) from straight line motion to the direction of intended travel. Successful skill performance requires complex coordinated interactions of limbs, segments and joints, which have been the primary focus of previous sidestepping research. The investigation of CoM throughout the performance of the sidestep manoeuvre offers valuable insight into the control of whole-body dynamics which is typically overlooked by analyses of structures in isolation.
The coordination and control which enables performance of a purposeful movement emerges from an interaction between the individual, task and the environment (Newell et al., 1989). When task and environment are constant, biomechanical and neuromuscular lower-limb differences have been identified between females and males (McLean et al., 2004). The respective findings suggest that female and male athletes may utilise different whole-body control strategies for CoM motoin for sidestep performance.
Performance of the sidestep manoeuvre is challenged when constraints are placed on the task, for example, through the reduction of planning time (Besier et al., 2001). Unanticipated sidestep performance has been found to result in kinematic changes at the hip, knee and ankle, in comparison with anticipated sidestep performance (Kim et al., 2014). Extended understanding of the influence of planning time constraint on the dynamic control system may be evident through the appraisal of CoM mechanics.
The majority of sidestepping research has focused on the stance phase, with the weight acceptance phase widely acknowledged to be the most injurious time period. Evidence of the important relations between preparatory and stance phase mechanics has been presented (Staynor et al., 2016); consideration of both phases are subsequently of interest to further understanding of whole-body mechanics during the sidestep manoeuvre.
The purpose of the current research was to investigate the influence of sex and planning time on spatial and temporal-level CoM mechanics during the performance of the sidestep manoeuvre. It was hypothesised that (1) CoM mechanics would differ between females and males performing anticipated and unanticipated sidestepping; (2) CoM mechanics would differ between anticipated and unanticipated sidestepping manoeuvres for both females and males in the preparatory and stance phases.

METHODS: Nine female (Mean ± SD of age 20.2 ± 1.3 years, 1.66 ± 0.05 m, 59.5 ± 5.5 kg) and nine male (age 20.9 ± 1.1 years, 1.81 ± 0.11 m, 71.6 ± 9.0 kg) collegiate team sport athletes participated in a single biomechanics testing session. Among a random distribution of straight line running and stopping trials used to limit task predictability, participants performed a series of sidestep trials. In response to arrows displayed on a screen at the end of a runway, participants performed either anticipated or unanticipated trials of each skill. For the anticipated trials (n = 7), the type of trial (run, stop or sidestep) was indicated to the participant prior to trial initiation. For unanticipated trials (n = 7), the type of trial was indicated at approximate time of ipsilateral limb toe-off. Approach speed of between 3.5 and 4.5 $m.s^{-1}$ was confirmed by two timing gates 2.5 m apart. As all participants were right-limb dominant, sidestep direction of travel was marked 45° to the left of straight line running, as indicated by tape marking on the floor initiating at the centre of the force plate. Successful sidestepping trials were accepted when the right foot made full contact with the force plate for the stance phase of the manoeuvre.

Three-dimensional kinematic data were recorded at 240 Hz using an 11-camera motion capture system (Oqus 3, Qualisys Inc., Gothenburg, Sweden). Trials were completed over an embedded 1.2 x 0.6 m force plate (AMTI, Watertown, MA), enabling synchronous recording of ground reaction forces at 1200 Hz. Forty-two retroreflective markers were attached to specified landmarks, informing the development of a bilateral eight-segment model in Visual 3D software (C-motion, Inc., Rockville, MD). Subject-specific models, customised in accordance with whole-body height and whole-body mass, consisted of right and left feet, shanks and thighs, in addition to pelvis and trunk segments. Marker coordinate data were filtered using a low-pass bi-directional Butterworth filter at 14 Hz.

Key dependent variables included (1) distance between anterior-posterior (AP) CoM position and the head of the first metatarsal phalange of the stance foot; (2) distance between medio-lateral (ML) CoM position and the first metatarsal base of the stance foot; and (3) vertical (V) CoM displacement from the floor. VCoM data were normalised to participants' height. Whole-body CoM velocity (CoMvel) was subsequently derived in each direction (AP, ML and V). Each variable was analysed for the preparatory flight phase (contralateral limb foot toe-off to ipsilateral limb foot heel strike) and the stance phase (ipsilateral limb foot heel strike to ipsilateral limb foot toe-off). Foot kinematic (0.04 m vertical threshold) and vertical ground reaction force data (10 N threshold) were used for the identification of heel strike and toe-off events. Data for each phase were time normalised to 101 data points (0-100%).

Two-tailed t-tests were undertaken on participant characteristics (age, mass and height) and phase durations using SPSS software (IBM SPSS Statisitics 23, SPSS Inc., Chicago, IL). Continuous data from individual trials informed two-way ANOVA tests, performed to investigate interactions and main effects of sex and condition (anticipated and unanticipated) on CoM displacement and CoMvel. Two-tailed t-tests were performed to test between females and males and paired t-tests were used to test between anticipated and unanticipated conditions throughout the entire approach (preparatory phase) and the stance phase. Statistical tests using continuous data were completed using one-dimensional Statistical Parametric Mapping (SPM1D, Pataky et al., 2013). All SPM1D results were considered in relation to the time across the phase of interest (0-100%). An alpha criterion of 0.05 was set *a priori* for all statistical tests.

RESULTS: Female athletes had significantly lower mass ($p < 0.01$) and height ($p < 0.01$) than their male counterparts. Females were found to spend a significantly shorter duration in the preparatory phase (0.07 ± 0.04 s) than males (0.12 ± 0.04 s) for the unanticipated sidestep condition ($p = 0.02$). No further temporal differences were found.

An interaction effect (sex x condition) was observed for VCoM (0-82%) in the preparatory phase ($p = 0.03$; Fig. 1). The preparatory phase effect was underpinned by significant sex differences for the duration of the phase in the anticipated and unanticipated conditions ($p <$ 0.01, 0-100%); no condition differences were observed for female athletes, whereas males had greater VCoM during unanticipated sidestepping than anticipated ($p < 0.01$, 0-100%).

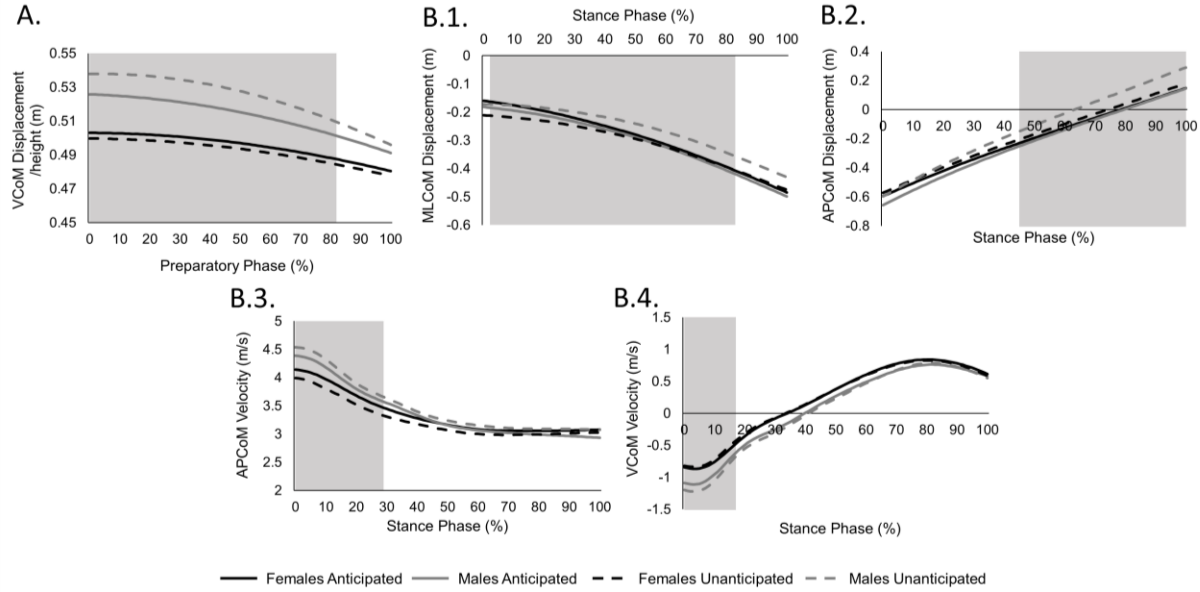

Figure 1: Interaction effects (sex x condition) for CoM displacement and velocity across the preparatory phase (A) and the stance phase (B); shading indicates significance (p < 0.05)

Within the stance phase, interaction effects were revealed for MLCoM (2-83%), APCoM (45-100%), APCoMvel (0-30%) and VCoMvel (0-17%; p < 0.05; Fig. 1). In anticipated sidestepping, females CoM was more anterior (p = 0.01, 0-25%) with lower AP velocity (p = 0.05, 0-14%) and greater V velocity (p < 0.01, 0-65%) than their male counterparts. In relation to the stance foot, female athlete's CoM were significantly more medial (further from the stance foot) and more posterior than males during unanticipated sidestepping (p < 0.05). As in the anticipated condition, females CoMvel was lower in AP (p = 0.01, 0-48%) and greater in V (p < 0.01, 0-64%). Between conditions, CoM for female athletes was further from the stance foot in ML (p = 0.03, 0-54%) and more anterior (p < 0.01, 0-100%), with lower AP velocity (p = 0.01, 0-39%) for the unanticipated than anticipated sidestepping manoeuvres. Unanticipated CoM for males was more lateral (p = 0.05, 41-100%) and more anterior (p = 0.02, 0-100%), with greater AP velocity (p = 0.04, 0-18%) and lower V velocity (p = 0.01, 0-16%) than in the anticipated condition. MLCoM and APCoM displacements from the stance foot for both phases are presented in Figure 2.

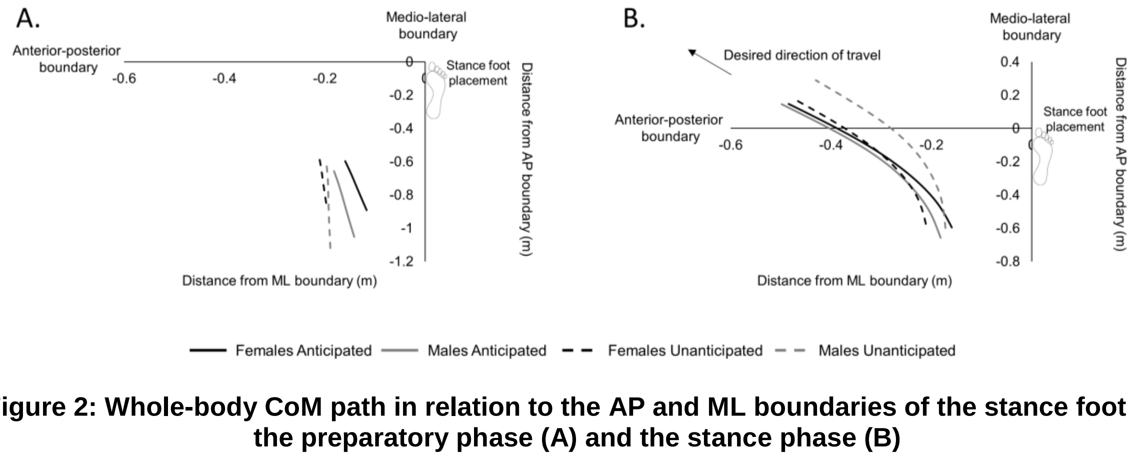

Figure 2: Whole-body CoM path in relation to the AP and ML boundaries of the stance foot for the preparatory phase (A) and the stance phase (B)

DISCUSSION: The purpose of the study was to investigate the influence of sex and planning time on spatial and temporal-level CoM mechanics during the performance of the sidestep manoeuvre. In support of the first hypothesis, the study revealed females use different strategies than their male counterparts to reorient the CoM during anticipated and unanticipated sidestepping manoeuvers. In accordance with findings of significance between anticipated and unanticipated sidestepping, the second hypothesis was additionally accepted, indicating a notable influence of planning time on whole-body mechanics for both female and male athletes.

In agreement with Staynor et al.'s (2016) research, significant sex x condition interaction effects on VCoM within the preparatory phase highlighted the importance of consideration of the mechanics preceding the acknowledged injurious weight acceptance phase, in addition to the stance phase. Whole-body mass distribution may partially account for the CoM positioning between sex, however, male athletes were found to reduce their VCoM in the preparatory phase during the anticipated sidestep manoeuver therefore indicating anticipatory postural adjustments to the CoM were employed prior to stance.

Beyond the preparatory phase, females and males revealed divergent CoM strategies to control and reorient the whole body. Notably, ML displacement of CoM from stance foot was greater in the unanticipated stance phase for females than males, likely indicating wider foot placement, which has been previously related to increased ACL risk (Dempsey et al., 2007).

Male athletes consistently performed sidestepping manoeuvres with increased CoMvel in the AP direction, but reduced VCoMvel, potentially demonstrating increased efficiency of sidestep performance in both the anticipated and unanticipated manoeuvres. The effect of limited planning time was revealed through distinct CoM control strategies in the stance phase, such as increased anterior orientation of CoM for both females and males. Male athlete additionally initiated VCoMvel descent significantly earlier when planning time was greater (anticipated condition), demonstrating well-learnt anticipatory perturbations which are postponed during unanticipated sidestep performance. The findings offer further insight to better our current understanding of the role of whole-body control strategies between females and males and between anticipated and unanticipated sidestepping.

CONCLUSION: Whole-body control strategies were found to differ between females and males as well as between anticipated and unanticipated sidestepping. Importantly, the divergent strategies were apparent in the phase leading up to, as well as the sidestepping manoeuvre itself. Further understanding of the underlying contribution of body segment inertial parameter to CoM strategies is advocated to advance training and injury prevention approaches.

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