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THE EFFECT OF ANTICIPATION ON PENULTIMATE STEP STANCE PHASE KINEMATICS IN A RUNNING CHANGE OF DIRECTION MANOEUVRE

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Constraining the time available to pre-plan a change of direction (COD) manoeuvre affects the mechanics of both the penultimate foot contact (PFC) and the COD steps. Understanding the effect of anticipation on the PFC stance phase is important to elucidate the temporal sequence of modifications to gait in preparation for the cut. We investigated the temporal localisation within the PFC of two major preparatory requirements for COD, braking and control of body orientation, by comparing the PFC kinematics of planned and reactive maximal 90° COD manoeuvres in 62 male athletes. Planned manoeuvres were associated with greater deceleration and lower-limb joint flexion in early stance, and with greater body reorientation in later stance. Our findings thus suggest that these components may be prioritised at different temporal periods within the penultimate step.

KEYWORDS: change of direction, cut, penultimate foot contact, kinematics, running.

INTRODUCTION: Change of direction (COD) manoeuvres are ubiquitous in field sports and are a common lower-limb injury mechanism. The ability to pre-plan and therefore implement anticipatory control is important in the context of both performance and injury: planned COD manoeuvres are performed at higher speeds than reactive COD, with a lower rate of task failure and lower stance limb joint loading (Almonroeder, Garcia, & Kurt, 2015; Brown, Brughelli, & Hume, 2014; Lee, Lloyd, Lay, Bourke, & Alderson, 2017). COD in a game situation, however, is commonly performed in response to an unanticipated stimulus such as movement of an opponent or the ball.

In planned COD manoeuvres the penultimate foot contact (PFC) before the outside foot is planted to initiate redirection appears to act as a preparatory step for the turn, decelerating and lowering the body centre of mass (COM) (Dos'Santos, Thomas, Comfort, & Jones, 2018; Jones, Herrington, & Graham-Smith, 2016; Nedergaard, Kersting, & Lake, 2014). Body posture at PFC initial contact is affected by anticipation (Lee, Lloyd, Lay, Bourke, & Alderson, 2013; Wheeler & Sayers, 2010), suggesting that preparatory movement adaptations may arise even earlier in the approach. In order to understand the temporal sequence of anticipatory movement adaptations, and hence the preparation time required for gait modulations and the situations in which high-risk or failure scenarios will arise, it is necessary to evaluate the effects of anticipation on the mechanics of the PFC step throughout stance phase.

We investigated the temporal localisation within the PFC of two major preparatory requirements for the COD, braking and control of body orientation, by comparing the PFC kinematics of planned and reactive 90° COD manoeuvres in healthy athletes across PFC stance phase. We hypothesised that braking would take place in the first phase of the PFC step, in which leg and GRF vector angle are most-posteriorly oriented (Jones et al., 2016), and that both braking and body reorientation would be greatest in the planned condition. We also tested the hypotheses that differences in speed and direction of travel between planned and reactive conditions would be evident prior to penultimate foot contact and manifest themselves at initial contact, demonstrating a mechanical role of anticipatory control preceding the PFC for 90° COD manoeuvres.

METHODS: Sixty-two healthy male multidirectional field sport athletes (mean±SD age 24.8±3.8 years, height 1.83±0.06 m, body mass 82.5±7.2 kg) participated in the study. All gave informed written consent.

Following a standardised warm-up and three practice trials in each direction for each condition, participants completed 90° maximum-effort running COD sidestep cut manoeuvres. Two different anticipation conditions were assessed: in the planned condition the participant was told which direction to cut towards prior to the task; in the reactive condition the participant had to cut in the direction of a visual signal (flashing light to either the right or the left) initiated when they passed through a gate (SMARTSPEED, Fusion Sport, QLD, Australia) positioned 2.5 m in advance of the mannequin and approximately one step before the PFC. Three trials were performed in each direction for each condition: in the reactive condition cutting direction was assigned randomly for each trial and data collection continued until three sidestep trials in the desired direction had been recorded. Only trials in which the participant cut from their self-reported dominant limb were analysed.

A 10-camera optical motion capture system (200Hz; Bonita B10, Vicon Motion Systems Ltd, Oxford, UK) recorded the positions of reflective markers placed on the body during the manoeuvre. Data were processed using the Vicon Plug-In Gait model to calculate joint and segment kinematics and the position of the COM. Marker position data were filtered using a fourth-order bidirectional Butterworth filter with a corner frequency of 15 Hz. The PFC was defined as the foot contact prior to that in which the major component of movement in the new direction is initiated. The start and end of PFC were thresholded using velocity of the toe marker and all trials were visually inspected to ensure accurate stance phase identification. PFC stance kinematic waveforms were then time-normalised to 101 data points.

Paired Student's t tests were used to test the null hypotheses that COM velocity vector angle at PFC initial contact (COM heading angle), change in COM heading angle during PFC, PFC contact time and horizontal velocity at the end of PFC did not differ between the planned and reactive conditions. Statistical parametric mapping was used to investigate differences between conditions throughout PFC stance for COM horizontal deceleration; pelvis and thorax angle and angular velocity; mediolateral and anteroposterior foot position relative to the COM; and hip, knee and angle sagittal plane angles. Cohen's d standardised effect size (ES) was reported for all discrete-point comparisons.

RESULTS: The change in heading angle of the COM in the direction of the cut during PFC was greater for the planned cut than for the reactive cut (p<0.001; ES 0.81). Horizontal velocity was greater in the planned condition at both initial contact (p<0.001; ES 1.40) and foot-off (p<0.001; ES 0.73) of PFC, despite greater mean deceleration during PFC in the planned condition (p<0.001; ES 0.90; Table 1).

Table 1: Centre of mass speed and heading angle during PFC. IC = initial contact; FO = foot-off; Δ = change IC to FO; CI = confidence intervals; ES = Cohen's d effect size

Variable	Planned		Reactive		95% CI	P	ES
	Mean	SD	Mean	SD			
COM heading angle at IC (°)	5.7	3.2	2.8	3.2	1.8-3.7	**<0.001**	0.91
Δ COM heading angle (°)	8.0	2.9	5.5	3.1	1.5-3.7	**<0.001**	0.81
COM speed at IC (m/s)	3.6	0.4	3.1	0.4	0.5-0.7	**<0.001**	1.40
Δ COM speed (m/s)	-1.0	0.3	-0.7	0.4	-0.5--0.2	**<0.001**	0.91
COM speed at FO	2.6	0.3	2.4	0.3	0.2-0.3	**<0.001**	0.73
Contact time (s)	0.17	0.03	0.17	0.03	-0.01-0.01	0.61	0.02

The greater PFC deceleration in the planned condition was localised to the first half of stance phase (2-42%; p<0.001) and concomitant with greater knee flexion (0-27%; p=0.02) and ankle dorsiflexion (4-50%; p=0.004). Thorax and pelvis rotation in the direction of the cut were greater in the second half of stance for the planned condition (66-100%; p=0.04 and 75-100%; p=0.04 respectively), as was thorax rotation angular velocity from 13-100% stance (p<0.001). Pelvis rotation angular velocity demonstrated two distinct peaks, one at ~20% stance and one at ~90% stance, both of which were larger in the planned condition (7-36%; p<0.001 and 74-99%; p<0.001; Figure 1). Greater hip flexion and thorax and pelvis tilt in the direction of the cut were evident in the planned condition throughout stance (all p<0.001), and the stance foot was positioned more anteriorly (0-98%; p=0.017) and more medially (0-100%; p<0.001).

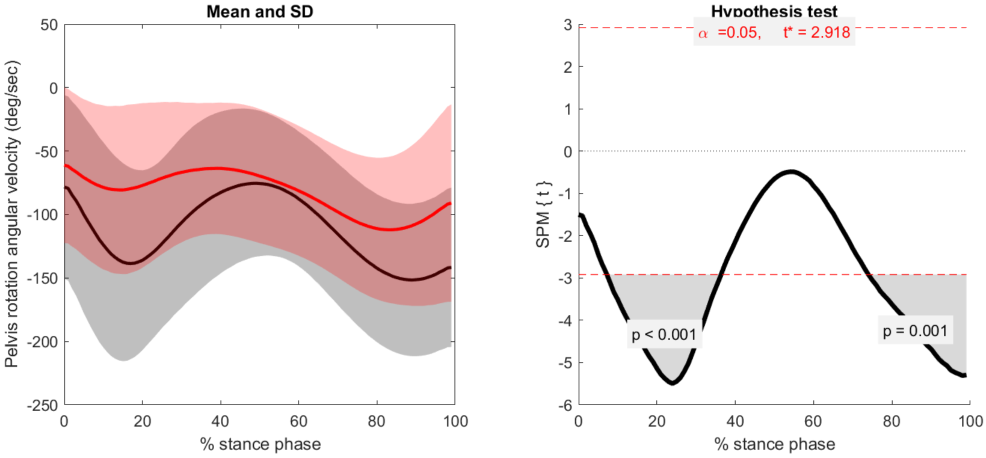

Figure 1: Angular velocity of pelvis rotation during PFC. Solid black line in left-hand panel represents the planned condition; solid red line represents the reactive condition. Negative rotation velocity is towards the stance leg (i.e. in the direction of the COD turn). The right-hand panel shows the t statistic for the difference between planned and reactive cuts as a function of time, with grey areas indicating regions in which the critical threshold was exceeded.

DISCUSSION: Differences in heading angle, speed, foot placement and lower-limb sagittal plane joint angles between planned and reactive conditions with large effect sizes were evident at the start of PFC, demonstrating an effect of anticipation in response to the intended direction of travel (not simply in response to the impending requirement for velocity redirection, which was consistent across conditions) prior to this step. Participants were already directing their COM towards the intended turn in both conditions, as previously reported for 45° cuts (Wheeler & Sayers, 2010), but by a greater angle in the planned condition. The lower horizontal velocity at initial contact in the reactive condition implies that participants given instructions to complete the task maximally, rather than having a pre-defined approach speed enforced (cf. Kim, Lee, Kong, & An, 2014; Mornieux et al., 2014), self-regulated their approach speed in anticipation of impaired deceleration and reorientation ability. This behaviour has also been reported in the COD step for athletes cutting off the operated limb after ACL reconstruction (King et al., 2018).

The temporal sequence of inter-condition differences in PFC mechanics suggested a two-phase role of the PFC step. The first phase was characterised by deceleration, as expected, and was associated with greater sagittal plane joint flexion angles and facilitated by a more anteriorly-placed foot in the planned condition (as previously noted at terminal PFC contact (Mornieux et al., 2014)). The pelvis rotation velocity peak in this phase was concurrent with peak COM horizontal deceleration and likely driven by the inertial transfer of translational to rotational velocity and the protraction of the swing leg. The second phase of the PFC was associated with rotation of the upper body in the new direction of travel, with a larger active peak in pelvis rotation velocity, greater thorax rotation and greater pelvis rotation in the planned condition. Reduced body orientation in the direction of travel early in the COD step is associated with greater external knee abduction and rotation moments (Dempsey et al., 2007; Frank et al., 2013), so these modulations have implications for injury risk as well as for performance. As a number of the variables examined would be expected to be influenced by approach velocity, further work should investigate the relative contribution of this parameter to the identified differences.

CONCLUSION: As the ability to plan the manoeuvre was concomitant with greater deceleration in early stance and greater body reorientation in later stance of PFC, our findings suggest that these components may be prioritised at different temporal periods within the penultimate step and hence may be differentially affected by the nature and timing of COD stimuli and decision-making.

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