WHOLE-BODY CHANGE OF DIRECTION TASK EXECUTION ASYMMETRIES AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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The angle and speed at which a change of direction (COD) manoeuvre is performed is strongly associated with lower limb mechanical loading. Asymmetries present in these factors after anterior cruciate ligament reconstruction (ACLR) may therefore influence the interpretation of inter-limb differences in joint-level biomechanical variables. We investigated the presence of asymmetries in centre of mass (COM) deflection and body rotation during a 90° COD manoeuvre in 144 male athletes 9 months after ACLR. COM deflection during stance phase was reduced on the operated limb, and differences in body orientation, COM heading angle and velocity at touchdown were observed. Differences in task execution may require consideration when interpreting joint-level inter-limb asymmetries after ACLR, although further work is needed to determine clinical relevance.

KEYWORDS: sidestep, cut, ACL, return to play, asymmetry, running.

INTRODUCTION: Changing direction while running (COD) involves deflection of the centre of mass and rotation of the body in the new direction of travel. COD is the single task associated with the highest proportion of non-contact anterior cruciate ligament (ACL) ruptures, and joint-level biomechanical asymmetries associated with altered knee loading have been observed more than nine months after ACL reconstruction surgery (ACLR; King et al., 2018; Stearns and Pollard, 2013). Objective assessment of inter-limb differences during running COD manoeuvres has hence been proposed as a useful approach in monitoring late-stage rehabilitation after ACL reconstruction and in return to play assessment (King et al., 2019).

The deceleration and deflection demands of COD, and hence the lower-limb joint-level mechanics, are substantially affected by the speed and angle at which the movement is performed. Both increased running speeds and increased deflection angles are associated with greater peak ground reaction forces and knee joint moments in healthy athletes (Havens & Sigward, 2015a; Havens & Sigward., 2015b; Schreurs, Benjaminse, & Lemmink, 2017), and appear to trade off against each other when maximum-effort manoeuvres are attempted (Dos'Santos, Thomas, Comfort, & Jones, 2018). In order to interpret any observed joint-level inter-limb differences in COD mechanics after ACLR it is necessary to understand how these basic whole-body determinants of mechanical demand are affected on the operated limb. Small asymmetries in approach velocity have previously been identified following ACLR (King et al., 2018), with lower velocities observed when cutting off the operated limb. However, it is not known whether differences are also found in the magnitude of COM heading angle deflection and/or body rotation within the COD step. Such differences, which may reflect reduced confidence in the operated limb and/or reduced ability to tolerate the demands of the task, would indicate that there are side-to-side post-ACLR asymmetries in the whole-body manoeuvre and that joint-level mechanical differences should be interpreted in this context.

The aim of this study was to investigate the presence of asymmetries in COM deflection and body rotation during the COD stance phase after ACLR. We hypothesised that post-ACLR athletes would reduce COM heading angle deflection and body rotation when cutting from the operated limb.

METHODS: Male multidirectional field sport athletes (n=144; mean±SD age 25±4 years, height 179±7 cm, body mass 83±14 kg) participated in the study. All had undergone primary ACLR surgery using a bone-patellar tendon-bone or hamstrings tendon (semitendinosus and gracilis) autograft 8-10 months prior to testing and intended to return to multidirectional sport. Informed written consent was obtained from all participants.

Following a standardised warm-up, participants completed three practice trials then three maximum-effort running COD manoeuvre trials in each direction. For each trial, the participant ran straight through a gate positioned 2 m from the centre of a force platform, performed a side-step cut turn, planting the limb on the contralateral side to the intended direction of travel (i.e. planting the right foot on the force platform to cut to the left, rotating the body towards the new direction of travel). The athlete then continued running straight through a second 1.5 m wide gate positioned 2 m from the force platform at 90° to the angle of the start gate (Figure 1). Participants had a 3 m run-up to the first gate and were instructed to complete the task as quickly as possible between the first and the second gate. Trials in which the participant cut from their non-operated limb were performed first. A 10-camera optical motion capture system (200Hz; Bonita B10, Vicon Motion Systems Ltd, UK) synchronised with two force platforms (1000 Hz, AMTI, USA) recorded ground reaction forces (GRFs) and the positions of reflective markers placed on the body, which were then filtered (4th order zero-lag Butterworth with corner frequency 15 Hz). Data were processed using the Vicon Plug-In Gait model to calculate segment kinematics and the position of the centre of body mass (COM). Stance phase of the COD step was identified using GRF > 10 N.

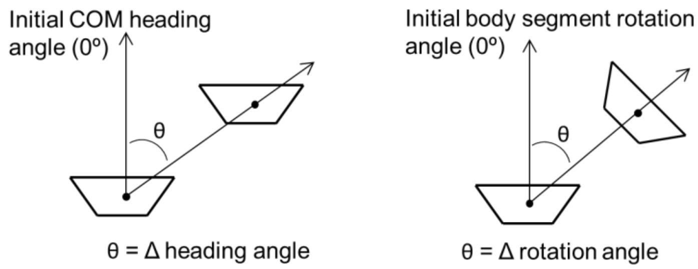

Figure 1: Variables defining COM deflection (left) and pelvis and thorax rotation (right).

COM heading angle, thorax rotation angle and pelvis rotation angle were identified at the start and end of COD stance phase. Angles were defined as in Figure 1. The mean of the three trials in each direction was then used for analysis. Paired Student's t-tests were used to test the null hypotheses that the following variables did not differ between the operated and non-operated limbs at initial contact and did not differ in the magnitude of their change from start to end of stance phase: COM heading angle, pelvis rotation angle and thorax rotation angle. Horizontal velocity (resultant velocity of the COM in the horizontal plane) at initial contact was also analysed for completeness, although inter-limb asymmetries in this variable have previously been published in an overlapping cohort (King et al., 2018). Cohen's d standardised effect size (ES) was reported for all comparisons.

RESULTS: The COM trajectory was more oriented towards the new intended direction of travel at COD stance initial contact when cutting from the operated limb, but the angle deflection during stance phase was reduced. The pelvis and thorax were less rotated towards the new direction of travel at initial contact when cutting from the operated limb but no differences were identified in the rotation of either segment during stance phase. Horizontal velocity at initial contact was lower when cutting from the operated limb (Table 1).

Table 1: Change of direction stance phase centre of mass heading angle, horizontal velocity and body segment orientation. IC = initial contact; Δ = change from IC to foot-off; CI = confidence intervals; ES = Cohen's d effect size

Variable	Non-operated		Operated		95% CI	p	ES
	Mean	SD	Mean	SD			
COM heading angle at IC (°)	11.8	5.3	14.4	5.5	-3.6--1.9	**<0.001**	0.50
Δ COM heading angle (°)	61.4	8.9	57.3	9.2	3.0-5.6	**<0.001**	0.46
Pelvis rotation angle at IC (°)	32.1	10.6	29.2	10.8	1.1-4.5	**0.001**	0.27
Δ pelvis rotation angle (°)	20.6	8.9	19.8	7.7	-0.5-2.3	0.22	0.09
Thorax rotation angle at IC (°)	18.5	9.3	14.8	9.5	2.0-5.4	**<0.001**	0.40
Δ thorax rotation angle (°)	32.0	12.2	31.6	11.2	-1.4-2.1	0.68	0.03
COM horizontal velocity at IC (m/s)	2.8	0.3	2.6	0.3	0.1-0.2	**<0.001**	0.38

DISCUSSION: COM heading angle deflection and body rotation characterise COD manoeuvres and are key determinants of lower-limb joint loading during this task. Both were reduced in post-ACLR athletes when cutting off the operated limb, demonstrating asymmetries in basic whole-body task execution. Differences in COM heading angle were evident at initial contact: heading angle was oriented more in the direction of the turn when cutting off the operated than off the non-operated limb. There was therefore less than 1.5° inter-limb difference between mean COM heading angles at the end of stance phase, despite the reduced heading angle reorientation during stance on the operated limb. This indicates that athletes may be using anticipatory control to modulate lower-limb joint loading, altering their approach direction as well as their speed to reduce the demand of the task whilst still ensuring that they exit the cut at the required angle to pass through the final gate. Larger pre-contact deviations from the intended approach direction have previously observed in healthy athletes when performing cutting tasks at faster speeds (Vanrenterghem, Venables, Pataky, & Robinson, 2012), which may similarly demonstrate adaptation of the approach phase to modify COD execution in a way that co-optimises task achievement and joint loads.

Changing direction, particularly at higher speeds and through larger angles, takes place over more than one step (Andrews, McLeod, Ward, & Howard, 1977). The change in COM heading angle during COD stance for both limbs was much larger than the change in body (pelvis and thorax) rotation angle (Table 1), and over a third of the total pelvis rotation required for the manoeuvre had already been completed by the time the COD stance foot was planted. This is in contrast to the behaviour exhibited when changing direction in walk, for which the COM is deflected first and then the body rotated (Patla, Adkin, & Ballard, 1999). The body reorientation requirement for running COD appears to be more evenly distributed over multiple steps than COM deflection and may present less of a localised demand on the operated limb during the COD stance step.

All the effects identified had small standardised effect sizes (ES 0.27-0.50) and represented mean asymmetries of 2.6-4.2° (similar to many of the joint-level inter-limb angle differences previously reported (King et al., 2019)), so could only be identified because of the relatively large sample size. Further work is therefore needed to establish the meaningfulness and clinical relevance of these task execution differences, and to identify contexts in which they may or may not need to be considered when interpreting joint-level biomechanical variables after ACLR.

CONCLUSION: Our findings suggest that small asymmetries in task execution are present when COD manoeuvres are performed cutting off the operated *vs* non-operated limb nine months post-ACLR. These differences may require consideration when interpreting joint-level inter-limb asymmetries in athletes returning to sport after ACL reconstruction.

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