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LOWER LIMB COORDINATION DURING A LAND-CUT TASK FOLLOWING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION AND REHABILITATION

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This study compared the lower limb coordination of the previously injured leg of ACL injured participantsparticipants (ACLr, n=18), against their non-injured leg and a control (nACL, n=18) leg. The lower limb joint and segment couplings were calculated during maximal drop-jump land and unanticipated cutting task. Differences between the previously injured and nACL control leg were present in all but one of the lower limb joint and segment couplings. Differences between the previously injured and nACL control leg were present in the hip rotation - knee abduction adduction, and knee rotation knee abduction adduction couplings. The hip and thigh were the main areas where differences were reported. Altered proximal neuromuscular function may be the origin of these altered coordination patterns.

KEY WORDS: joint coupling, knee, hip, match specific task.

INTRODUCTION: Only 20% of the athletes who undergo reconstructive surgery return to their pre-injury-level of sport participation (Söderman, Pietilä, Alfredson, & Werner 2002). These athletes (ACLr participants) are at an increased risk of repeated ACL injury (Paterno et al., 2010) and the development of osteoarthritis (Øiestad et al., 2010). Altered biomechanical and neuromuscular function of the lower limbs, as a result of the initial ACL injury has been demonstrated in this population (Clarke, Kenny & Harrison 2014), and is thought to increase the risk of a repeated ACL injury (Paterno et al., 2010) and degenerative joint disease (Deneweth et al., 2010). Intra-limb joint and segment coordination has been examined previously in rehabilitated populations, currently injured populations and high injury risk populations (Stergiou and Bates, 1997; Heiderscheit et al., 2002). Stergiou and Bates, (1997) report lower limb coordination as a potential mechanism for lower limb running injuries, where lack of synchronisation between subtalar and knee joint actions was proposed as a potential injury mechanism. Pollard, (2003) compared coordination between male and female athletes during a cutting task and reported differences in thigh rotation leg rotation and hip abduction-adduction knee rotation couplings. The literature to date shows that lower limb coordination has not been previously measured in rehabilitated ACLr participants during landing or cutting tasks. This composite index of lower limb coordination, when measured during a match specific task such as landing or cutting may highlight any compensation present in the function of ACLr participants' previously injured leg. Therefore the purpose of this study was to examine compensations by comparing lower limb coordination of ACLr participant's previously injured leg against the contralateral non-injured leg and a non-injured control during the performance of a maximal drop-jump land and unanticipated cutting task.

METHODS: Eighteen ACLr participants who had returned to full competitive participation in their sport (Males n=9, age 26 ± 4 years, height 1.78 ± 0.1 m, mass 81.74 ± 19.42 kg, time since injury 5 ± 3 years, Females n=9, age 22 ± 2 years, height 1.69 ± 0.06 m, mass 66.21 ± 7.51 kg, time since injury 4 ± 2 years) were recruited for the present investigation. All ACLr participants were screened prior to inclusion, to ensure they were fully rehabilitated. A further 18 gender, height, mass and sport matched participants who had no history of knee injury (nACL) were also recruited for the present study (Males n=9, age 22 ± 3 years, height 1.81 ± 0.09 m, mass 80.39 ± 5.36 kg, Females n=9, age 22 ± 2 years, height 1.67 ± 0.07 m, mass 63.81 ± 6.12 kg). Approval for the use of human participants in this investigation was granted by the University Research Ethics Committee; all participants provided informed consent prior to participation.

Retro-reflective markers (43) were secured on the ASIS, PSIS, sacrum, iliac crest, greater trochanter, medial and lateral epicondoyle and malleolus, upper and lower calcaneous, 2nd and 5th metatarsal of both legs. Marker clusters were also placed on the thigh and shank and were used for calculation of segment rotations. This involved dropping from a 0.30 m bench, and performing an immediate drop and jump to reach and touch a target with both hands. This target was suspended at their maximum drop jump reach height. The suspended target triggered a directional cueing system which randomly indicated which direction the participant had to cut to on landing.

Kinetic and kinematic data were recorded via two AMTI force platforms (1000 Hz) and six Eagle infrared Motion Analysis Corporation cameras (500 Hz). The raw coordinate and ground reaction force data were low-pass filtered with a fourth-order Butterworth filter with a 12 Hz and 50 Hz cut off frequency respectively. Visual 3d™ was used to calculate flexion extension, abduction adduction and internal and external rotation angles joint angles. Five intralimb couplings were calculated using a modified vector coding technique (Heiderscheit, Hamill, & Van Emmerik, 2002); thigh abduction-adduction leg abduction-adduction (thigh-abad_leg-abad), thigh rotation leg rotation (thigh-rot_leg-rot), hip abduction-adduction knee rotation (hip-abad_knee-rot), hip rotation knee abduction-adduction (hip-rot_knee-abad), knee rotation knee abduction-adduction (knee-rot_knee-abad). Kinematic and coordination time-series data were separated into landing and cutting components and normalised to 1001 data points. Average coupling angle was calculated during various regions of landing (initial 40%, 15-30%, 100%) and cutting (70-100%, 100%). The initial 40 ms of landing corresponds to the period were ACL injuries are suggested to occur (Koga et al., 2010). Between 15-30% of landing and 70-100% of cutting were utilised as this was where most subjects displayed minimum knee flexion. Differences were analysed using a repeated measures ANOVA test. Partial eta^2 (η_p^2) was also reported as a measure of effect size. It was calculated using the formula: $\eta_p^2 = SS_{effect}/(SS_{effect} + SS_{error})$, where SS_{effect} = effect variance and SS_{error} = error variance. Interpretation of effect size was based on the scale for effect size classification of Hopkins (2000) < 0.04 = trivial, 0.041 to 0.249 = small, 0.25 to 0.549 = medium, 0.55 to 0.799 = large, and >0.8 = very large.

RESULTS: Several differences were reported between the previously injured (PI) leg and both the non-injured (NI) and control leg controls. Differences between the PI and nACL control leg were present in the thigh-abad_leg-abad, thigh-rot_leg-rot, hip-abad_knee-rot, hip-rot_knee-abad, and knee-rot_knee-abad couplings (Table 1). Differences between the PI leg and contralateral NI leg were present in the hip-rot_knee-abad, and knee-rot_knee-abad couplings (Table 2). Figure 1 illustrates the knee-rot_knee-abad coupling pattern for PI, NI and control legs during landing with areas of significant difference highlighted. The horizontal line at 45° it presented to illustrate a symmetrical pattern where equal contribution is provided from both joint rotations.

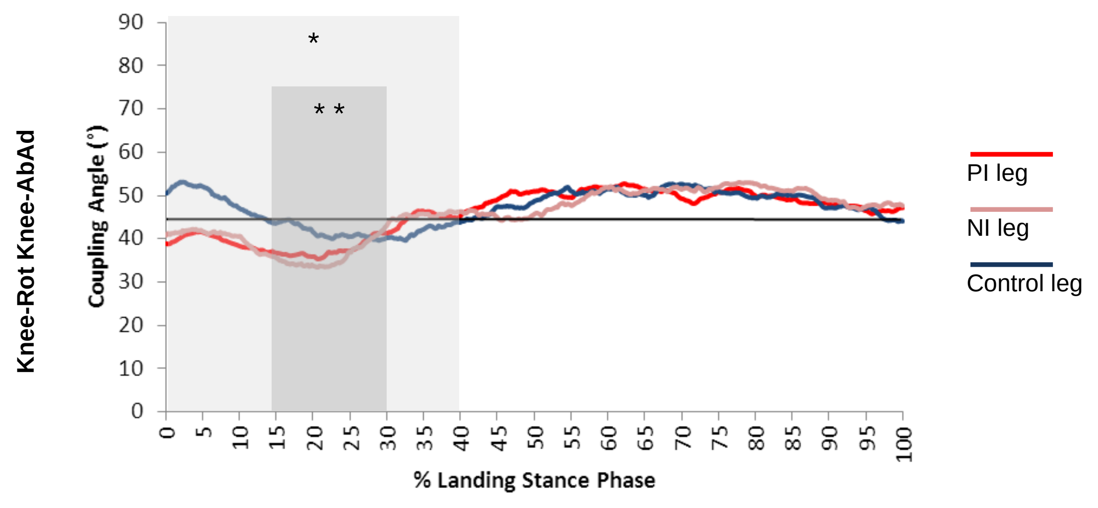
Table 1
Significant differences between ACLr previously injured (PI) and nACL control (C) legs

Coupling Angle (°)		PI (°)	C (°)	Diff (°)	η_p^2	p-value
Thigh-rot_leg-rot	Land 0-40 ms	46.07	38.74	7.33	0.12	0.039*
	Cut 70-100%	34.98	34.37	0.62	0.22	0.004*
Hip-abad_knee-rot	Cut 0-100%	49.21	48.67	0.54	0.26	0.002*
Hip-rot_knee-abad	Land 0-100%	40.19	35.16	5.03	0.24	0.002*
	Land 0-40%	40.73	36.15	4.59	0.13	0.030*
Knee-rot_knee-abad	Land 0-40 ms	38.49	48.95	10.5	0.22	0.004*
	Cut 0-100%	40.18	41.53	1.35	0.15	0.020*

Table 2

Significant differences between ACLr previously injured (PI) and non-injured (NI) legs

Coupling Angle (°)		PI (°)	NI (°)	Diff (°)	η_p^2	p-value
Hip-abad_knee-rot	Cut 70-100%	56.21	52.23	3.97	0.22	0.041*
Hip-rot_knee-abad	Land 0-100%	40.19	39.51	0.68	0.21	0.048*
	Land 0-40%	40.73	39.23	1.51	0.28	0.020*
Knee-rot_knee-abad	Land 15-30%	37.59	36.15	1.45	0.27	0.023*



* = Region for significant PI C differences. ** = Region for significant PI NI differences.

Figure 1: Average coupling angle of knee-rot_knee-abad coupling during landing.

DISCUSSION: The coordination of the PI leg of ACLr participants was significantly different to the coordination reported in the contralateral NI leg for a number of couplings during various regions of the landing and cutting task. These AClr participant between leg differences or asymmetries were compared to nACL participant asymmetries for the selected couplings. No coupling was reported to have a significant difference between the ACLr and nACL populations in the coordination asymmetries. It can therefore may be assumed that the surgical and rehabilitation interventions were successful in allowing the ACLr participants to regain similar lower limb biomechanics in both the PI and NI leg, and that any compensation present has affected both PI and NI legs.

The PI leg utilised significantly different coordination patterns in several couplings during both the landing and cutting components of the task. The majority of these differences, although significant, were classed as trivial or small when considering effect size. This was confirmed when compared with similar research by Pollard et al. (2003) where coordination patterns were reported for male and females athletes during a cutting manoeuvre. Significant group differences in Pollard's (2003) investigation ranged from 14-21°.

The knee-rot_knee-abad coupling coordination pattern illustrated in Figure 1, fluctuates around 45° or a symmetrical movement after the initial landing phase. The general coordination pattern for the cutting component of the task in the present investigation replicates a minimized version of the pattern in Pollard et al. (2003), moving through a narrower range. ACLr and nACL participants diverge on either side of 45° in the initial landing period, and both populations become dominated by frontal plane knee motion in the latter stages of the cut. The initial deceleration phase of the landing for the control leg coordination pattern is dominated by transverse plane knee and the PI leg coordination pattern is dominated by the frontal plane knee motion. This is replicated to a lesser degree in the latter stages of the cut where both PI and control legs are dominated by frontal plane knee motion which is more prominent in the PI leg. The increased contribution of the transverse plane knee motion in this coupling, which may involve external rotation, could act to control the frontal plane motion at the knee. This increase in frontal plane knee motion control may decrease the knee abduction moment and knee abduction angles thought to increase the risk of the osteoarthritis development (Cerejo et al., 2002) and repeated ACL injury (Paterno et al., 2010).

CONCLUSION: The hip and thigh were the main areas where alterations were reported in the previously injured leg compared to the control leg. There were limited between leg differences in coordination patterns between the previously injured and non-injured leg of the ACLr participants. This replicates the similar joint kinematics and kinetics between the previously injured and non-injured leg in previous research with this participant group. The ACL reconstructive surgery and rehabilitation is therefore, thought to restore a level of symmetry in lower limb coordination. Altered proximal control may be the driver in producing these altered coordination patterns between the previously injured leg and control leg. Future work investigating the influence of neuromuscular and strength training at the hip joint on these altered coordination patterns may be insightful.

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