THE ROLE OF PREVIOUS ANTERIOR CRUCIATE LIGAMENT INJURY ON THE VARIABILITY OF JOINT KINEMATICS AND COORDINATION DURING A MATCH SPECIFIC LAND-CUT TASK

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This study compared the movement and coordination variability of the previously injured leg of ACL injured subjects (ACLr, n=9), against their non-injured leg and a control (nACL, n=9) leg. The variability of lower limb joint angles and couplings were calculated during a land-cut task (n=20). The previously injured leg had less variability than the non-injured leg in the knee rotation–knee abd-adduction coupling, and more variability than the nACL leg in frontal and transverse knee joint angles and hip rotation–knee abd-adduction coupling. Reduced coordination variability could produce a more repetitive loading pattern linked to cartilage degeneration. Increased movement and coordination variability may stem from proprioceptive deficits on the previously injured leg and decrease the ability to adapt to perturbations.

KEY WORDS: joint coupling, knee, osteoarthritis, rehabilitation, re-injury.

INTRODUCTION: Rupture of the anterior cruciate ligament (ACL) is one of the most common and serious sports injuries (Boden, Griffin, & Garrett, 2000). Approximately 80% of athletes undergoing ACL reconstructive surgery fail to return to pre-injury-level sport participation (Chong & Tan, 2004). Athletes who are successful in returning to their sport are at an increased risk of repeated ACL injury (Tanaka, Yonetani, Shiozaki, Kitaguchi, Sato, Takeshita, & Horibe, 2010) and the development of osteoarthritis (OA) (Øiestad, Holm, Aune, et al., 2010). Altered lower limb biomechanics as a result of the initial ACL injury, are likely to increase the risk of a repeated ACL injury (Paterno , Schmitt, Ford, Rauh, Myer, Huang, & Hewett, 2010) and degenerative joint disease (Cerejo, Dunlop, Cahue, Channin, Song, & Sharma, 2002). Altered levels of variability in the repetition of these lower limb biomechanics, has also been associated with these risks.

After ACL reconstruction the previously injured knee demonstrates a more variable and unpredictable behaviour (Kiefer, Ford, Paterno, Myer, Riley, Shockley, & Hewett, 2008) than control subjects. A small cohort of the rehabilitated ACL (ACLr) subjects tested by Kiefer et al., (2008) had a repeated ACL injury (Foster, 2009). During balance task varying between low and high difficulty, these ACLr re-injury subjects demonstrated had more and less variability than the other ACLr subjects when the balance task was more and less difficult respectively. The purpose of this study was to compare the variability of the hip and knee joint kinematics, and lower extremity coordination of ACLr individuals, against their contralateral non-injured leg and a healthy control leg during a maximal drop-jump land and unanticipated cut task.

METHODS: Eighteen ACLr subjects who were back in full competitive participation in their sport (Males n=9, 26 ±4 y; 1.78 ±0.1 m; 81.7 ±19.4 kg. Females n=9, 22 ±2 y; 1.69 ±0.06 m; 66.21 ±7.51 kg) were recruited for the present investigation. All ACLr subjects were screened to ensure full rehabilitation. Eighteen subjects matched for gender, height, weight and sport with no history of knee injury (nACL) were also recruited for the present study (Males n=9, 22 ±3 y; 1.81 ±0.09 m; 80.4 ±5.4 kg. Females n=9, 22 ±2 y; 1.67 ±0.07 m; 63.8 ±6.1 kg). Approval for the participation of human subjects in this investigation was granted by the University Research Ethics Committee; all subjects gave 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. Subjects stood for a static trial prior to completion of 20 trials of the dynamic task. This involved dropping from a 0.30 m bench, and performing an immediate drop and jump to reach and touch a target suspended at their maximum drop jump reach height. The suspended target triggered a directional cueing system which randomly indicated which direction the subject 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. The landing and cutting components of the dynamic task were identified by inspection of the vertical ground reaction force. 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 rotation leg rotation, hip abduction-adduction knee rotation, hip rotation knee abduction-adduction, knee rotation knee abduction-adduction. Kinematic and coordination time-series data were separated into landing and cutting components and normalised to 1001 data points. Variability of the normalised coupling and joint angles time-series' was calculated on a point by point basis from the mean ensemble curves. Average variability was calculated during various regions of landing (initial 40%, 15-30% 100%) and cutting (70-100%, 100%). Differences in average variability between the ACLr subject's previously injured leg and contralateral non-injured leg and a nACL subject's control leg were assessed using paired t-tests or Wilcoxin signed-rank tests and independent t-tests or Mann-Whitney U tests respectively. Cohen's d was utilised as a measure of effect size with a 0.2=small, 0.5=moderate, >0.8=large, scale.

Table 1: Average movement and coordination variability (°) of the ACLr previously injured (PI), contralateral non-injured (NI) and nACL control (C) legs are shown with the group differences (°), Cohen's d and p-values.

ACLr-nACL comparison			*PI*	*C*	*Diff*	*d*	*p-value*
Knee Flexion Extension Angle	Cut	70-100%	5.41	**7.17**	1.77	0.76	0.015
Knee Abduction-Adduction Angle	Land	Initial 40%	**1.99**	1.26	0.73	1.56	<0.001
		15-30%	**2.01**	1.22	0.79	1.57	<0.001
		100%	**2.48**	1.72	0.73	1.22	0.001
	Cut	100%	**2.35**	1.67	0.68	0.98	0.008
Knee Internal-External Rotation Angle	Land	Initial 40%	**3.36**	1.90	1.45	1.42	<0.001
		15-30%	**3.37**	2.00	1.38	1.27	0.001
		100%	**3.22**	2.16	1.06	1.10	0.001
Hip-rotation knee abduction adduction Coupling	Land	100%	**20.6**	18.86	1.75	0.91	0.011
Hip Internal-External Rotation Angle	Cut	70-100%	4.92	**6.44**	1.52	0.74	0.035
		100%	5.06	**6.86**	1.80	0.95	0.010
ACLr bilateral comparison			*PI*	*NI*	*Diff*	*d*	*p-value*
Knee-rotation knee abduction adduction Coupling	Land	Initial 40%	23.43	**24.50**	1.12	0.73	0.012
		100%	23.98	**25.00**	0.99	1.02	0.001
Knee-rotation knee abduction adduction Coupling	Cut	100%	**23.2**	22.4	0.87	0.56	0.048
Knee Flexion Extension Angle	Cut	100%	5.66	**6.90**	1.24	0.70	0.044

RESULTS: The previously injured leg had more variability in the transverse plane knee angle and the hip-rotation knee abduction adduction coupling than a matched control subject's leg during landing. During cutting the previously injured leg had more variability than the control leg in the frontal plane knee angle and less variability in the sagittal and transverse plane knee and hip angles respectively. The previously injured leg had less variability than the contralateral non-injured leg for the knee-rotation knee abduction adduction coupling and sagittal plane knee angle, during landing and cutting respectively. The previously injured leg also had more variability than the contralateral non-injured leg, in the knee rotation knee abduction adduction coupling during cutting. These results are presented in Table 1.

DISCUSSION: According to the variability hypothesis the previously injured leg was expected to demonstrate lower and higher levels of variability when compared to the contralateral non-injured and match control leg respectively (Stergiou & Decker, 2011). The previously injured leg had more movement and coordination variability than the control leg for a number of variables. During landing the previously injured leg had more variability in the frontal and transverse plane knee rotations and the hip-rotation knee-abduction adduction coupling, than the control leg. During cutting the previously injured leg had more variability in transverse plane hip motion and frontal plane knee motion, than a control leg. Additionally the previously injured leg was also reported to have decreased sagittal plane knee motion variability than a control leg during cutting. Hip rotation and frontal plane knee motion have been previously linked with ACL injury. Ireland et al., (1999) referred to it as the "position of no return". The increased variability in transverse and frontal plane knee joint rotations and hip-rotation knee abduction adduction coupling is unlikely to increase the risk of OA development, as it should distribute load avoiding repetitive loading patterns. If the variability reported by the nACL population is considered optimal the higher levels of variability in the previously injured leg may render a movement system noisy and unpredictable increasing the risk of re-injury and decreasing the ability to adapt to perturbations (Stergiou & Decker, 2011). Increased movement variability has been previously reported in ACLr populations (Kiefer, et al., 2008; Moraiti, Stergiou, Vasiliadis, Motsis, & Georgoulis, 2010). ACLr individuals were thought to feel ''secure'' enough to add extra movement during gait however proprioceptive deficits resulted in an unstable movement system with higher levels of movement variability. The contrasting findings for the sagittal plane knee motion may indicate that these if these proprioceptive are present they may have a larger effect on transverse and frontal plane knee motions. The increases in movement variability on the previously injured leg are comparable to previous investigations (Kiefer, et al., 2008; Moraiti, et al., 2010). The variability of the hip-rotation knee abduction adduction coupling is also within range of what has been previously reported for nACL subjects (Pollard, Heiderscheit, van Emmerik, & Hamill, 2005). The 9% increase in hip-rotation knee abduction adduction coupling variability is relatively small when considered along previous reports (Kiefer, et al., 2008; Moraiti, et al., 2010) (~14% and 23% respectively). This level of variability is not thought to be sufficiently higher than the optimal reported by the control leg and is unlikely to result in the previously described inflexible movement system.
The previously injured leg of ACLr individuals had less variability in the knee-rotation knee abduction adduction coupling and sagittal plane knee motion than the non-injured leg. Increased abduction and adduction in previously injured knees have been linked with repeated ACL injury (Paterno, et al., 2010) and higher incidence and faster progression of knee OA (Cerejo, et al., 2002) respectively. The previously injured leg also had higher levels of knee-rotation knee-abduction adduction coupling variability than the non-injured leg during cutting. Although this is in contrast to expectations the increase in variability reported is of minimal magnitude. The decreased variability in the knee-rotation knee abduction adduction coupling and sagittal plane knee motion on the previously injured leg compared to the non-injured leg is in accordance with previous research reporting decreased coordination variability in injured and high injury risk populations (Hamill, van Emmerik, Heiderscheit, & Li, 1999; Heiderscheit, et al., 2002; Pollard, Heiderscheit, van Emmerik, & Hamill, 2005). Lower coordination and movement variability could result in a more repetitive loading pattern linked to cartilage degeneration and premature OA in previously injured knees (Gao & Zheng, 2010). Levels of coordination variability lower than what is considered optimal may also increase the risk of repeated ACL injury producing a more predictable system with decreased ability to adapt to perturbations. The percentage differences between the previously injured and non-injured leg (4-7%) are small when considered alongside differences reported by Heiderscheit et al., and Pollard et al., (2002; 2005). The 2-3% reductions in knee-rotation knee abduction adduction coupling variability of the previously injured leg may not be

sufficient to result in a repetitive loading pattern and inflexible movement system with increased risk of the knee OA development and repeated ACL injury respectively.

CONCLUSION: The previously injured leg had less variability than the non-injured leg for the knee-rotation knee abduction adduction coupling and sagittal plane knee motion variability during landing and cutting respectively. The previously injured leg had more variability than the control leg for frontal and transverse plane knee motion and the hip-rotation knee abduction adduction coupling during landing, and more transverse plane hip motion and sagittal plane knee motion variability during cutting. The small differences reported in the present investigation however, minimize these risks. Future work using forward dynamics musculoskeletal modelling may further inform the hypothesis where lower movement or coordination variability and may produce repeated micro trauma, weaken the cartilage and result in degenerative joint disease. The findings from this investigation will inform the design of ACL injury rehabilitation programmes. The inclusion of variability and perturbation training may act to decrease the risk of re-injury and the development of OA.

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