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ACTIVITY PROGRESSION FOR ANTERIOR CRUCIATE LIGAMENT INJURED INDIVIDUALS

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INTRODUCTION

Individuals with Anterior Cruciate Ligament (ACL) injuries are known to adopt movement compensation strategies [1]. Rehabilitation is recommended and functional exercises such as walking (GAIT), double leg squat (DLS) and single leg distance hop (SLDH) are incorporated into rehabilitation programmes with the aim of strengthening muscles and improving motor control [2]. Despite rehabilitation, functional performance deficits persist [3, 4]. Therefore insight into the biomechanics of these functional exercises in ACL injured individuals will allow better targeted exercise application. This study therefore addressed the following two aims. Firstly to identify how GAIT, DLS and distance hop exercises pose different motion, knee loading and control challenges to the knee. Secondly to evaluate if these activities challenge ACL deficient (ACLD) and ACL reconstructed (ACLR) individuals differently compared to controls (CONT). Based on clinical practice it was anticipated that SLDH would be the most challenging task, followed by DLS and GAIT. ACLD were expected to demonstrate most compensation strategies.

METHODS

Preliminary results are reported from 11 ACLR (height: 1.75±0.05 m, mass: 79.6±7.9 kg, age: 26±8 years, gender: 1 female, 10 male) and 12 ACLD (height: 1.77±0.06 m, mass:77.8±9.1 kg, age: 30±5 years, gender: 2 female, 10 male) compared to 14 CONT (height: 1.75±0.12 m, mass: 78.0±19.6 kg, age: 27±7 years, gender: 7 female, 7 male). Participants were asked to perform five GAIT trials at their 'normal' walking speed, eight consecutive DLS to their maximum depth and eight maximal SLDH. Four trials of each activity were included in the analysis. The phases of each activity that were analyzed were: GAIT stance phase, DLS decent and ascent, and SLDH landing phase. Ethical approval was obtained from South East Wales Local Research Ethics Committee.

Motion data were collected using a VICON system (Oxford Metrics Group Ltd., UK) at 250 Hz. Reflective markers were placed using the 'Plug-in-Gait' full body marker set. Ground reaction force data were collected using two Kistler force plates (Kistler Instruments Ltd., Switzerland) at 1,000 Hz. Inverse kinematics and dynamics calculations were performed within VICON Nexus software and analyzed in Matlab R2010b (The Mathworks Inc, USA).

Output parameters were calculated in Matlab for the injured limb of ACL patients and dominant limb of CONT. The performance measures for each of the tasks corresponded to outcomes evaluated in the clinical setting to measure recovery. These were: gait velocity, squat depth and hop distance normalized to body weight and height. To compare exercise difficulty the following key parameters were used: peak knee flexion angle (APkFlex); peak extensor (MPkExt) and peak adductor moment (MPkAdd). Knee control was evaluated using knee fluency scores. This was defined as one divided by the average number of times coronal plane knee velocity crossed zero [4].

A one-way ANOVA with Bonferroni post hoc testing was used to investigate differences between GAIT, DLS and SLDH for the variable representing knee loading and motor control. A univariate analysis was used to evaluate differences between ACLR and CONT and between ACLD and CONT for the performance, motion, loading and knee control variables. Gait velocity, squat depth and hop distance were used as covariates for each of the activities. An alpha level of $p<0.05$ was used to signify significance.

RESULTS AND DISCUSSION

Regardless of subject group; GAIT, DLS and SLDH posed different motion, loading and control challenges to the knee (Table 1). As demonstrated by the control subjects, the range of knee motion was greatest with higher APkFlex during DLS ($p<0.001$), intermediate during SLDH ($p<0.001$) and smallest during GAIT ($p<0.001$). Loading was greatest during SLDH as this activity generated larger MPkExt and MPkAdd than DLS ($p<0.001$) and GAIT ($p<0.001$). There was no difference between DLS and GAIT for MPkExt ($p=0.35$) or MPkAdd ($p=0.116$). Knee control was most challenged during SLDH and GAIT, as demonstrated by fluency scores lower than DLS ($p<0.001$).
In clinical practice difficulty of an exercise is described by performance in combination with knee control. Range of motion and loading during the exercise can also contribute to the level of difficulty. We therefore propose that in this study SLDH was the most challenging exercise, followed by GAIT and DLS. DLS mainly challenges loading and required high flexion angles. GAIT has similar loading and low flexion angles but is much more challenging to knee control. Hop has a large level of loading, intermediate knee flexion and challenges knee control. The high fluency score

during DLS was probably due to the double leg stance used during this activity as opposed to the single leg stance used during GAIT and SLDH. There was no difference in fluency between GAIT and SLDH (p=0.89). The level to which GAIT challenged knee control compared to hopping was unexpected. It was anticipated that due to the larger knee moments that hopping would be more challenging, resulting in lower fluency scores. The current findings suggest that fluency and loading are not automatically related and need to be evaluated separately.

The group comparison (Table 1) confirms that hopping is a challenging activity for ACL participants compared to CONT. Both ACLR and ACLD demonstrated reduced loading; MPkExt (ACLR p=0.003; ACLD p=0.022) and less knee motion; APkFlex (ACLR p=0.002; ACLD p=0.001). There was also a non-significant trend for ACLD to reduce MPkAdd (Overall test: p=0.089). There was a non-significant trend for ACLR to be less fluent at the knee (Overall test: p=0.054). Both ACLD and ACLR used a movement strategy of reduced loading and knee motion, but this was only reflected in reduced performance for ACLD compared to CONT (CONT 76.3±1; ACLR 74.1±17.1; ACLD 58.1±13 % body height; p=0.001). Therefore this activity was even more testing for ACLD than ACLR.

ACLD and ACLR demonstrated fewer compensation strategies during GAIT and all key parameters were of a lower magnitude than during SLDH, suggesting that this activity was less challenging. During GAIT, ACL participants compared to CONT did not demonstrate any difference in gait velocity (CONT 1.48±0.15; ACLR 1.52±0.19 p=0.29; ACLD 1.45±0.16 m/s; p=0.68); knee motion (ACLR p=0.732; ACLD p=0.108) or fluency (ACLR p=0.732; ACLD p=0.34). There was some evidence of increased knee loading because MPkAdd was significantly increased in ACLD (ACLR p=0.34; ACLD p=0.01). It would be important to investigate whether this may have long term implications such as an increased risk of further joint damage. There was no difference in MPkExt (ACLR p=0.732; ACLD p=0.34). Therefore GAIT demonstrated differences in loading between ACLD and ACLR which was however not reflected in altered performance.

During DLS, there was a reduction in squat depth for ACLR compared to CONT and a trend in ACLD (CONT 111±20; ACLR 110±1 p<0.05; ACLD 108±17°; p=0.056). However, this reduced angle for either group was very small and not considered clinically meaningful. Both ACLD and ACLR demonstrated altered loading; MPkExt was reduced in both ACLR and ACLD (ACLR p<0.001; ACLD p<0.001); There was a trend for reduced MPkAdd in ACLD but not for ACLR (Overall test: p=0.053). Fluency of knee movement was not different between ACLD, ACLR and CONT (ACLR p=0.227; ACLD p=0.926). The altered knee loading observed in the ACL groups might be indicative of a strategy to execute the movement cautiously. Although not strongly demonstrated in their performance, their compensation strategies to reduce knee loading may involve altered muscle coordination.

CONCLUSIONS

It can be concluded that regardless of subject group DLS was the least challenging activity, GAIT was intermediate and SLDH was most challenging. This order is a deviation from clinical practice, where GAIT is usually considered less challenging than DLS. During GAIT and DLS the main compensation strategy used by ACL was altered loading.

DLS and GAIT should therefore be used early in rehabilitation as loading was comparable but these activities have different roles. DLS permits loading over a larger range of motion, from a stable double stance position. GAIT loads the knee over a small range of motion but in addition challenges knee control due to the single leg stance. Both of these exercises can be progressed by combination with other training methods. Only SLDH, challenging knee loading and control, was difficult enough to reduce performance but only for ACLD. This confirms that SLDH can be used to evaluate recovery and return to sport on completion of treatment.

Based on the biomechanical analysis these further observations can be made with respect to rehabilitation. Clearly, performance measures alone are not sufficient to evaluate recovery. Additional information about joint loading and control is required. Interestingly, these appear to be unrelated and therefore should be measured separately.

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Table 1: Mean ± standard deviation values for loading, motion and control variables during each task for CONT, ACLR and ACLD. BW stands for body weight and h for height. *p<0.05 ACLR v CONT; ACLD v CONT.

	CONTROL			ACLR			ACLD		
	DLS	GAIT	SLDH	DLS	GAIT	SLDH	DLS	GAIT	SLDH
MPkExt (Nm/BW*h)	0.059 ± 0.020	0.038 ± 0.021	0.42 ± 0.16	0.049 ± 0.01*	0.039 ± 0.018	0.32 ± 0.17*	0.048 ± 0.014*	0.035 ± 0.018	0.30 ± 0.16*
MPkAdd (Nm/BW*h)	0.020 ± 0.008	0.036 ± 0.009	0.19 ± 0.14	0.018 ± 0.006	0.036 ± 0.013	0.16 ± 0.18	0.016 ± 0.009	0.038 ± 0.011*	0.09 ± 0.15
APkFlex (°)	111 ± 20	17 ± 8	57 ± 13	110 ± 11*	19 ± 6	50 ± 14*	108 ± 17	18 ± 7	43 ± 10*
Fluency (s)	0.65 ± 0.47	0.15 ± 0.08	0.19 ± 0.09	0.55 ± 0.34	0.12 ± 0.05	0.14 ± 0.07	0.74 ± 0.50	0.15 ± 0.06	0.17 ± 0.07