THE EFFECT OF FATIGUE ON REACTIVE STRENGTH IN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTED INDIVIDUALS

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This study examined the effect of fatigue on reactive strength in six subjects who had undergone surgical repair of the anterior cruciate ligament and returned to full sporting activity. Subjects' performance in rebound jumps on a force sledge apparatus was analysed before, during and after a maximal fatigue protocol. Flight time, contact time and reactive strength index were measured for each jump. No differences in reactive strength index were observed between legs in the non-fatigued or fatigued state. The data indicated that the subjects may recover reactive strength at a slower rate on the involved leg following maximal exercise. The data also indicates that reactive strength index is a highly suitable variable to examine during maximal SSC fatigue tasks.

KEY WORDS: Stretch shortening cycle, jumping, ground contact time.

INTRODUCTION: The impetus for this study was to address the gap in the literature on the status of reactive strength in athletes who have recovered from surgical repair of anterior cruciate ligament (ACL) rupture and subsequent rehabilitation. Injuries more often occur in the latter stages of sporting events when participants are in a fatigued state (Ostenberg & Roos, 2000; Zemper, 1989). At a basic level fatigue can be described as a loss of maximal force generating capacity, a loss of maximal power output (Vøllestad, 1997) or a failure to sustain further exercise at a required level (Strojnik & Komi, 1998). Fatigue can contribute to injury through a number of mechanisms. It is thought that fatigued muscles lose their strength and ability to act as a protective mechanism for anatomically weak joints. During vigorous activity, the musculature around a joint can fatigue at different rates due to different muscles containing varying proportions of fatigable and fatigue resistant muscle fibres. Since muscle fatigue leads to decreases in muscle force production (Vøllestad, 1997), force production around the joint can become unbalanced due to the relative fatigue state of each individual muscle. This can lead to abnormal or unnatural motions of the joints creating unbalanced and excessive stress distributions that contribute to injury (Kumar, 2001). Rozzi *et al.* (1999) observed that subjects exhibited deficiencies in proprioception and alterations in the muscular activity of the knee musculature in a fatigued state and concluded that fatigue predisposes athletes to an increased risk of knee ligament injury. Augustsson (2004) examined the effects of a pre-exhaustion exercise protocol on between-leg differences ACL reconstructed (ACL-R) subjects. In baseline testing, all subjects exhibited >90% leg symmetry compared with the fatigued condition in which two-thirds of patients showed abnormal leg symmetry (< 90%). Fatiguing exercise can increase the sensitivity and validity of assessment when examining the lower limb function of ACL-R subjects. Patients who are only examined in a non-fatigued state could be incorrectly cleared to participate in full activities despite retaining an increased injury risk in the fatigued state. The present study sought to examine the reactive strength status of rehabilitated ACL-R subjects who have returned to full activity in their chosen sports during a maximal stretch shortening cycle (SSC) fatigue protocol.

METHODS: Data Collection: ACL-R subjects, who had undergone post-surgery rehabilitation and returned to a level of physical activity comparable to their pre-injury status were recruited. Exclusion criteria included any episode of re-injury to the ACL following reconstructive surgery or any pathology or surgery in the hips, knees, ankles or feet of either leg within the last 6 months. Six adults participated in the study consisting of one male and five females. The group age was (mean ± S.D.) 25.5 ± 5 years; height 165.5 ± 8 cm and mass 65.3 ± 4 kg. Four of 6 reconstructions used a hamstring tendon autograft while 2 used a patellar tendon autograft. Mean time from surgery to participation in the study was 23 ± 12 months. Recruited subjects were from a variety of sports including soccer, martial arts, skiing and basketball. The University's research ethics board approved the study and subjects provided informed consent. Upon visiting the laboratory all subjects performed a standardised warm-up. Each subject's involved (INV) or uninvolved (UNINV) leg was selected at random to perform the testing protocol first. The testing protocol began with subjects performing one maximal set of rebound jumps (RBJ) in the force sledge apparatus. This set of jumps represent the pre-fatigue condition. In the RBJ protocol subjects were seated in the force sledge and winched to a height of 0.30cm from the force plate. The subjects were released and upon on landing performed four, single-legged, repeated maximal jumps. The 2nd, 3rd and 4th jumps in this set are considered RBJs and data to be analysed are derived from these jumps. This pre-fatigue data was analysed to find the average height jumped during each RBJ and represented the pre-fatigue condition. Ninety percent of this value was marked with a reflective marker on the sledge from a position where the subject was seated in the sledge chair with the leg fully extended at the hip and knee and with the ankle plantar flexed. Following this, subjects performed the fatigue protocol on the same leg. The fatigue protocol involved the subject being dropped from a height of 30cm and performing consecutive RBJs until they failed to reach the 90% level for three consecutive jumps. These three consecutive jumps below the 90% level represented the fatigued condition RBJs. An OMRON Opto-Switch (EE-SY410) was attached to the sledge chair and when it reached the reflective tape at the 90% level the light on the switch illuminated. It was clearly apparent whether or not the subject was reaching the 90% level on each jump. Komi (2000) has stated that these SSC fatigue protocols tax all the major elements of muscle function: metabolic, mechanical, and neural. These protocols cause disturbances in stretch reflex activation and consequently provide a strong basis for studying muscle function. Immediately following the fatigue protocol a further set of RBJs was performed. These jumps represented the post-fatigue condition. This set was performed an average of 50 seconds after the cessation of the fatigue protocol. Subjects were then given a 10 minute recovery period. Following this they performed the same series of protocols on the opposite leg. During all jumps ground reaction force was measured using an AMTI force plate sampling at 1000 Hz in the pre- and post-fatigue RBJs and at 100Hz during the fatigue protocol.

Data Analysis: Instants of take-off and landing were identified using the force traces for every jump performed. Flight time (FT) was calculated as the time between take-off and landing. Contact time (CT) was defined as the time between initial foot contact and take-off. RSI was calculated as the height jumped divided by CT, where, considering the 30° inclination of the force sledge apparatus, jump height was approximated as $(9.81 * FT^2)/16$.

Statistical Analyses: The three dependent variables analysed were FT, CT and RSI. Analyses focused on between-leg effects (INV and UNINV) and on within-legs between-condition effects (pre-fatigue, fatigued, post-fatigue). In the present study a small sample size was used (n = 6) and the pre- and post-fatigue data was not normally distributed so a GLM ANOVA was not deemed approriate for use in the comparative analysis, between legs or between conditions. Means and standard deviations were reported and effect sizes were used to determine the magnitude of difference legs and between conditions. Effect sizes were calculated using η_p^2 and interpreted using the scale for effect size classification by Hopkins (2004). The behaviour of the lower limbs during the fatigue protocol was investigated using correlation analysis. The strength of the relationship between the fatigue process and the dependent variables was expressed using the variance explained statistic (r^2).

RESULTS: On both legs RSI diminished considerably from the pre-fatigue to the fatigued condition (see table 1). The reduction in RSI from the pre-fatigue to the fatigued condition was evident on both legs with very large effects sizes observed (η_p^2 = 0.881 and 0.907 for the INV and UNINV legs respectively). On both legs in the post-fatigue condition subjects'

RSI had returned toward levels comparable to that of the pre-fatigue condition but a deficit still remained on the INV leg with very large effect sizes observed between the pre- and post-fatigue conditions (η_p^2 = 0.696). No major differences in RSI were seen between legs across conditions. In the pre-fatigue and fatigued condition small effects sizes were in evidence between legs (η_p^2 = 0.248 and 0.063 for the pre-fatigue and fatigued conditions respectively). In the post-fatigue condition the subjects produced a moderately higher RSI on the involved leg than the uninvolved leg (η_p^2 = 0.431).

Table 1: RSI on the INV and UNINV leg, across conditions.

	Pre-Fatigue	Fatigued	Post-Fatigue
Involved Leg	0.506 (±0.20)	0.172 (±0.08)	0.459 (±0.17)
Uninvolved Leg	0.454 (±0.13)	0.189 (±0.10)	0.410 (±0.14)

On both legs FT reduced considerably from the pre-fatigue to the fatigued condition with large effect sizes observed (η_p^2 = 0.997 and 0.919 for the INV and UNINV legs respectively). On both legs CT increased with a large effect from the pre-fatigue to the fatigued condition (η_p^2 = 0.918 and 0.928 for the INV and UNINV legs respectively). Subjects' FT performance restored to pre-fatigue levels in the post-fatigue condition on both legs with small effect sizes observed between conditions (η_p^2 = 0.241 and 0.039 on INV and UNINV legs respectively). Moderate effect sizes in CT remained between the pre- and post- conditions with CT not fully returning to pre-fatigue levels (η_p^2 = 0.561 and 0.560 on the INV and UNINV legs respectively). A very strong negative correlation was observed between RSI and the fatigue protocol duration. This correlation was consistent between subjects and between legs. The average correlation coefficient on the involved leg was -0.942 (range: -0.893 to -0.975) and was -0.932 (range: -0.893 to -0.971) on the uninvolved leg (see figure 1). FT was strongly negatively correlated and CT was strongly positively correlated to the fatigue protocol duration between legs and between subjects.

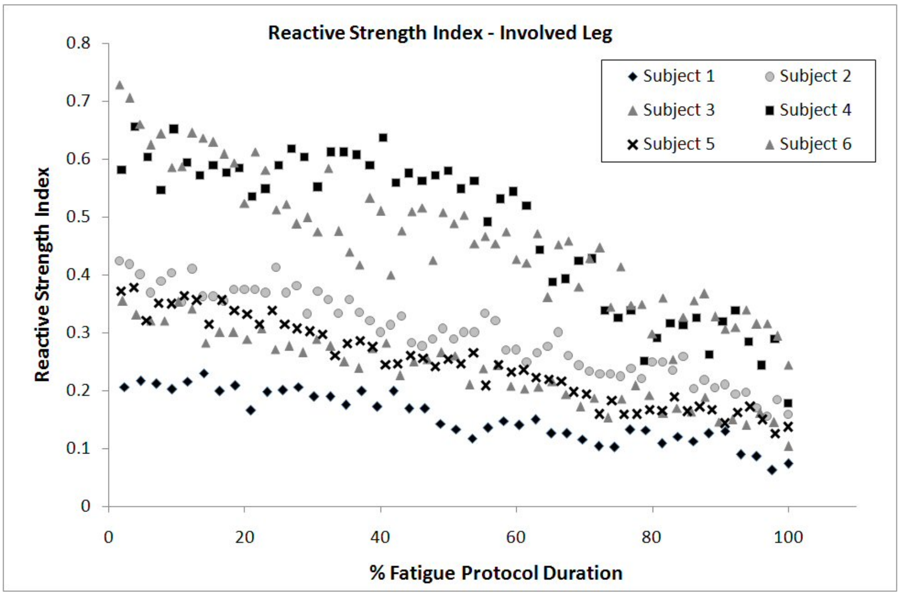

Figure 2: RSI during the fatigue protocol on the INV leg

DISCUSSION: Following reconstruction and rehabilitation no considerable differences in RSI were observed between the INV or UNINV legs in the pre-fatigue or the fatigued state. Subjects appeared to be able to restore reactive strength in ACL-R legs to levels comparable to that of their UNINV legs. Fatigue does not appear to degrade this capacity of the INV leg to a greater extent than it does on the UNINV limb. There was an indication of a deficiency on the INV leg in recovery following high intensity exercise as evidenced by a slower recovery of that leg to express RSI in the post-fatigue condition. This was evidenced by a large difference in RSI observed between the pre- and post-fatigue conditions on the involved leg ($\eta_p^2 = 0.696$).

To our knowledge, this is the first research study which has examined RSI throughout fatiguing exercise. An important finding of this study, in relation to the use of RSI as a marker of fatigue, was the very strong correlation between RSI and the fatigue protocol duration. The analysis of RSI throughout the fatigue protocol in this study reveals the importance of analyzing both jump height and ground contact time during fatiguing SSC exercise. A strong reduction in FT was observed in the fatigued condition on both legs. However, analysis of the mean FT and RSI data revealed that the reduction in RSI was twice as large as that of FT due to progressive elongation of CT in each jump. RSI is particularly important in the examination of fast SSC movements as the goal in such tasks is not just maximal jump height but also short ground contacts (Flanagan & Comyns, 2008). An individual may be able to attenuate declines in jump height but at the cost of elongating ground contact phases. In a sporting context, this would result in slower running velocities and reduced capacity to rapidly accelerate or change direction (Flanagan & Comyns, 2008). In the present study FT decreased, but CT increased in parallel. This had the net effect of drastically reducing subjects' RSI. Previous studies which have solely examined jump height during of after fatiguing SSC exercise may have underestimated the effect of fatigue on SSC function.

CONCLUSION: ACL-R subjects appear to be able to restore reactive strength in ACL-R legs to levels comparable to that of their UNINV legs and fatigue appears to degrade reactive strength function similarly on both legs. The data indicated that ACL-R subjects may have a possible deficiency on the INV leg in recovery following high intensity exercise as evident by a slower recovery capacity of that leg to express RSI 50 seconds after a maximally fatiguing exercise bout. RSI was very strongly negatively correlated with the duration of the fatigue protocol. The data presented outlines the suitability for using the RSI when monitoring fatigue during SSC exercise and its greater sensitivity during fatiguing exercise over FT or jump height alone.

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