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The effect of fatigue on lower limb kinematics post ACL reconstruction and return to sports participation

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SUMMARY
The study reports new information on the effect of fatigue on lower limb kinematics in sports participants who have returned to sports participation post ACL reconstruction, a population which has not been reported in the literature and is at risk of injury. The clinical implication of the findings is that fatigue can be incorporated into a rehabilitation program with potential harmful effects. The findings of this study should however be interpreted with caution, since the post hoc power analysis indicated that at least 45 subjects were required for power at 80%. Furthermore, generalisation of the findings is not possible since the sample was not randomly selected.

INTRODUCTION
Compromised neuromuscular control due to fatigue is postulated to increase ACL loading [1]. Fatigue may increase the likelihood of injury by enhancing at risk biomechanics. These at risk factors may manifest as deficiencies in proprioception, delayed motor responses and altered afferent neuromuscular pathways [2, 3]. A notable finding of a systematic review is that none of the published papers into the effect of fatigue included participants with ACL deficiencies [4]. This synthesis revealed that the effect of fatigue on lower limb biomechanics is not a trivial task. The published body of evidence is marred by variations in research designs, fatigue protocols, study outcomes and subject characteristics. The evidence base for the effect of fatigue on biomechanical performance during single limb drop landing activities is also limited by a small number of studies, biased methodological approaches and equivocal findings [4]. The aim of this study was to ascertain whether a fatigue perturbation has an effect on lower limb biomechanics of sports participants who had an ACL reconstruction (cases) and has returned to sports participation. In this population, the effect of fatigue has not been reported. Therefore, our hypothesis was that there will be no difference in three-dimensional lower limb kinematics between the affected and unaffected side of the cases and matching leg of the controls at baseline and post a general fatigue perturbation.

METHODS
A descriptive, cross-sectional design, with within and between group comparison study was conducted. The study sample comprised of males and females club level soccer, hockey, rugby or netball players aged between 18-30 years old. Cases were the subjects who underwent ACL reconstruction surgery within the past 2 years prior to data collection. The type of surgical technique was not restricted as there is currently no evidence that lower limb biomechanics under fatigued conditions are sensitive to the type of surgical approach. All case subjects should have returned to sports participation at a club levelA motion analysis system was utilised to analyse lower limb kinematics during drop landing pre-and-post a fatigue perturbation. Controls were defined as subjects who did not sustain lower limb injuries within six months prior to data collection, did not have any surgery to the lower limbs as these factors will affect lower limb function. Subjects who suffer from overtraining syndrome were also not eligible as this may impair their biomechanical performance, particularly under fatigued conditions. The case and control subjects were matched for gender, age, height, weight, level of play, club and leg dominance. Leg dominance was defined as the kicking leg [5]. 14 healthy sports participants and 14 cases, were recruited. The VICON motion analysis system was used for all biomechanical was utilized to analyse the hip, knee and ankle kinematic data. A bilateral drop landing jump was selected because it allows for an appropriate comparison between the injured and uninjured lower limbs of the case subject during the same movement. A single leg landing jump may elicit variations in

compensatory movements which may be inconsistent between landing on the injured an uninjured limb. It was also an easily reproducible movement for comparison with control subjects.

Subjects had to perform a drop landing from a 20 cm high step. The arms were held at the sides, and the subjects were instructed to drop off the step and land with both feet on the floor. A digital recording of timed bleeps were used to indicate when subjects had to assume the standing position on the step for 20 seconds, mentally prepare for the drop landing task, and jump off the step. This assured consistency between subjects and excluded the influence that verbal instructions may have on the biomechanics of the movement.

All subjects performed a two-minute slow jogging warm-up prior to the trial capture. Five successful drop landing trials were then captured. A trial was successful if the test movement was performed as instructed according to the timed beeps.

Post the baseline (pre-fatigue) drop landing tasks, a **general fatigue protocol** was followed. The subject performed maximal vertical jump height tests of which height was measured. The subject then performed at least 60 maximal height jumps (sets of 15 with 30 second rest periods) until fatigue was evident. Fatigue was verified when a series of three, consecutive jumps did not reach 80% of the maximal jump height. All subjects then performed five, successful drop-landing trials as described above during the pre-fatigue state. An additional test jump after the protocol was measured to quantify the fatigue index [6].

A repeated measures ANOVA model was used to compare between the injured and uninjured sides of the ACL subjects and the. An alpha level $P < .05$ was used to represent statistical significance for all comparisons. Where a significant effect of fatigue was present, a post hoc Bonferroni test was done to determine where the differences occurred. Mean differences and 95% confidence intervals were calculated to provide information about the size of the effect.

RESULTS AND DISCUSSION

Twenty eight subjects, ten females, participated in this study. Participants played rugby (16), soccer (8), netball (2) or hockey (2) at club level. The mean duration since ACL repair was 2.8 years. Nine of the eleven ACL surgeries were performed at private clinics and the remainder at a large public hospital. All, except one pair of the participants (one case and control) were right leg dominant. Nine of the 14 case subjects had ACL reconstruction surgery on the non-dominant side.

The basic description of the sample is presented in Table 1 and illustrates that the knee function score, as indicated by the Knee injury and Osteoarthritis Outcome Score (KOOS), is less than those of the controls. All ACL subjects returned to playing sport at the same level as before, although six of the cases reported a lower level of activity and therefore the mean Tegner score was less than before their ACL surgery. The Tegner score of the cases (post ACL reconstruction) and controls was similar.

A fatigued state was reached when the participants were not able to reach at least 80% of the jumping height of the pre-fatigue maximal jump height, in three consecutive jumps. Additionally a test jump was performed directly after and a fatigue index [decrease of jump height %] was quantified for each participant to secure the fatigued state. The fatigue index [%] in the control group showed a decrease in performance of M=78.72 and SD=8.1 whereas the ACL group demonstrated a decrease to M=79.9 and SD=6.9.

Table 2 illustrates that the biomechanical performance of the affected side of the cases did not significantly (P>0.05) differ from the unaffected side or the matching lower limb of the control subjects.

The findings of this study illustrate that the biomechanics of the ACL reconstructed limb did not differ from the unaffected limb or matching limb of control subjects post a general fatigue perturbation. Our hypothesis that there will be no difference in three-dimensional lower limb kinematics between the affected and unaffected side of the cases and matching leg of the controls at baseline and post the fatigue perturbation was thus supported. However, although the sample size of this study compares well to similar published reports, the study was under-powered to detect small differences in lower limb kinematics due to fatigue.

The findings of this study are in agreement with a systematic review by Santamaria and Webster [4].The systematic review findings illustrated equivocal findings with respect to the effect of fatigue on lower limb kinematics during a single limb landing task post fatigue. Although the review concluded that fatigue may influence ground reaction force and moments, the findings were also inconsistent between studies. These controversial findings may also be due to relatively small sample sizes, rendering under-powered ability to detect significant differences in biomechanical performance due to fatigue. The effect of fatigue is postulated to affect a number of biomechanical parameters along the lower limb kinetic chain. Therefore, it is often not feasible to calculate the required sample size, due to the inability to select a single, most critical outcome parameter. It is thus plausible to recommend that sample sizes should be considered in future studies which will be sufficiently powered to detect whether a true difference exists.

The fatigue protocol selected for this study was similar to general fatigue protocols in similar published research [4].Based on the criteria for fatigue; all subjects were fatigued to the same level. Cases and controls were unable to reach 80 % of their maximal jump height in three consecutive jumps post the fatigue perturbation. Since all subjects, the cases and controls were active sports participants and had similar Tegner scores, both case and controls participants reached comparable levels of fatigue. Therefore, it is unlikely that the findings of this study were biased by the inability of selected participants to reach comparable levels of fatigue.

The findings of this study differ from the findings of published research into the effect of fatigue during balance activities. Ageberg et al [7] examined the effect of fatigue on balance in single-limb stance in subjects and indicated that individuals with ACL deficient knees seemed to react differently regarding ability to maintain balance in single-limb stance directly after exercise than the control group. In particular, participants with ACL deficient knees demonstrated lower average speed compared to controls. This difference in study findings may be explained by the difference in study population. Ageberg et al [7] included subjects who had non-operated ACL lesions. Since the biomechanical demands may also differ between a drop landing and balance task, it may also explain these contradictory study findings.

It is postulated that individuals who had an ACL reconstruction or injury will be more sensitised to the effects of fatigue due to a number of sensorimotor changes post injury. This may explain the high recurrence rates of ACL injuries [8]. To our knowledge, there is only one study which was aimed at investigating the effect on subjects who had an ACL reconstruction in sports participants during a landing task [8]. The study by Webster indicated that fatigue resulted in small, but notable changes in peak angles of the hip, knee and ankle at initial contact and the peak angles of the entire landing movement. Statistically significant changes were also reported for the peak hip and knee moments post fatigue in case and control subjects. The study by Webster et al [9] included subjects at different stages of rehabilitation, which could have confounded their findings. Webster et al [9] included a homogenous male group, which may be another reason for the differences between study findings. One limitation of our study was that subgroup analysis of gender groups was impossible due to the sample size. This aspect should be addressed in future studies to determine if there is a gender influence due to fatigue on gender performance.

In this study, we have analysed well reported biomechanical parameters which may predispose ACL injuries [10]. Since we have analysed a bilateral drop landing task, it was not necessary to control for compensatory or associated movements of the trunk and upper limbs. Analysis of single leg landing tasks essentially compares two movements which could differ with respect to the trunk and upper limb movement during the landing action. Consequently, these factors may bias lower limb kinetics and kinematics during the fatigued and pre-fatigued conditions. The effects of fatigue on lower limb kinetics and kinematics during complex functional tasks, under anticipated and unanticipated conditions, should also be explored. It would however be advisable to account for associated movements of the rest of the body in such research endeavours.

The findings of our study may suggest that the effect of fatigue on ACL injuries may not manifest as biomechanical alternations. The biomechanical parameters represent the motor output of the central motor control process. This process also includes reception and processing of sensory information at the central control level. It is thus recommended that the combination of biomechanical and neuro-scientific approaches should be explored in future [8].

CONCLUSIONS

The aim of this study was to investigate the effect of a fatigue perturbation on lower limb biomechanics of sports participants who had an ACL reconstruction and has returned to sports participation. The findings illustrated that there was no difference in lower limb kinematics between the affected and unaffected side of case subjects and matching limb of healthy controls. This implies that either fatigue has no effect on lower limb biomechanical output or that the effect of fatigue on motor output is negated by central control mechanisms. Future research into similar populations during anticipated and unanticipated conditions should be investigated.

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Table 1: Description of the sample.

	Age	**Weight (kg)**	**Height (mm)**	**KOOS Score**	**Tegner Score**
CASES Mean(SD)	24.71 (1.97)	80.46 (19.30)	1744.28 (73.06)	77.88 (14.42)	Before ACL: 9.28 (0.79) After ACL: 8.28 (1.43)
CONTROLS Mean(SD)	21.71 (1.38)	73.31 (12.38)	1761.07 (120.86)	98.58 (1.90)	8.92 (0.75)

* Abbreviations: KOOS, Knee injury and Osteoarthritis Outcome Score

TABLE 2. Three-dimensional knee kinematics pre and post fatigue perturbation.

Parameter	Variable	Mean Difference (95%CI) between baseline and fatigue conditions (injured side of case – matching side control	Mean Difference (95%CI) between baseline and fatigue conditions of cases (injured – uninjured leg)
Angle at foot strike	Hip flexion	1.25 (-1.78-4.28)	0.28 (-1.93-2.50)
	Hip ABD	0.23 (-1.09-1.57)	-0.20 (-1.91-1.49)
	Hip Rot	-2.82 (-8.12-2.46)	-4.34 (-10.17-1.47)
	Knee flexion	-0.76(-4.67-3.14)	0.18 (-3.85-4.23)
	Knee ADD	-2.72(-7.58-2.13)	-2.01(-6.60-2.58)
	Knee IR	1.92(-0.86-4.70)	2.55 (-1.08-6.20)
	Ankle DF	-0.97(-5.97-4.02)	0.21 (-2.14-2.56)
Total ROM	Hip flexion	1.26(-1.59-4.12)	1.15(-0.58-2.89)
	Hip ADD	-1.15(-3.54-1.22)	0.28(-1.78-2.36)
	Hip Rot	3.47(-8.44-15.39)	2.55 (-8.01-13.12)
	Knee flexion	1.39(-2.69-5.47)	0.29 (-3.64-4.24)
	Knee ADD	1.77(-4.73-8.27)	-0.46(-4.40-3.47)
	Knee IR	-0.88(-4.34-2.58)	-2.17(-6.45-2.09)
	Ankle DF	1.10 (-4.53-6.73)	0.82 (-1.67-3.33)
Time from FS to LVP		-0.01 (-0.03-0.01)	-0.01(-0.03-0.01)

Abbreviations: ABD, abduction; Rot, rotation; ADD, adduction; IR, internal rotation; DF, dorsi flexion; ROM, range of movement; FS, foot strike; LVP, lowest vertical position