ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΙΑΣ

ΤΜΗΜΑ ΕΠΙΣΤΗΜΗΣ ΦΥΣΙΚΗΣ ΑΓΩΓΗΣ ΚΑΙ ΑΘΛΗΤΙΣΜΟΥ

Η επίδραση της κόπωσης στις στρατηγικές προσγείωσης σε άλμα με ένα πόδι μετά από επέμβαση αποκατάστασης Πρόσθιου Χιαστού Συνδέσμου

Fatigue induced changes on single leg landing strategies after Anterior Cruciate Ligament reconstruction.

ΣΙΔΕΡΗΣ ΒΑΣΙΛΕΙΟΣ

ΕΠΙΒΛΕΠΩΝ ΚΑΘΗΓΗΤΗΣ

ΓΙΑΚΑΣ ΙΩΑΝΝΗΣ

Μεταπτυχιακή Διατριβή που υποβάλλεται στο καθηγητικό σώμα για τη μερική εκπλήρωση των υποχρεώσεων απόκτησης του μεταπτυχιακού τίτλου του Προγράμματος Μεταπτυχιακών Σπουδών «Άσκηση και Υγεία» του Τμήματος Επιστήμης Φυσικής Αγωγής και Αθλητισμού του Πανεπιστημίου Θεσσαλίας.

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Περίληψη

Η πλειοψηφία των αθλητών που έχουν υποβληθεί σε επέμβαση αποκατάστασης πρόσθιου χιαστού συνδέσμου (ΠΧΣ) αδυνατούν μετά τον τραυματισμό να επανέλθουν στα αρχικά επίπεδα απόδοσης. Ακόμη και μετά από μια «επιτυχημένη» επέμβαση και αποκατάσταση οι ασθενείς αντιμετωπίζουν αυξημένη αστάθεια στο γόνατο, που θα μπορούσε να οδηγήσει σε υποτροπή με περεταίρω κάκωση στο μηνίσκο και εμφάνιση οστεοαρθρίτιδας. Η νευρομυϊκή κόπωση επίσης συνδέεται με αυξημένη αστάθεια γόνατος, χαλαρότητα (laxity) και αυξημένο ρίσκο τραυματισμού κατή τη διάρκεια αθλητικών δραστηριοτήτων που περιλαμβάνουν κινήσεις όπως άλματα και απότομη αλλαγή κατεύθυνσης. Ο σκοπός της παρούσας μελέτης ήταν να εξεταστεί η επίδραση της κόπωσης στις στρατηγικές προσγείωσης σε άτομα που έχουν υποβληθεί σε επέμβαση αποκατάστασης ΠΧΣ. Στην παρούσα έρευνα πήραν μέρος εννέα εθελοντές που είχαν υποβληθεί σε αποκατάσταση του ΠΧΣ ηλικίας 25.7±8.75 έτη και δείκτης μάζας σώματος (ΔΜΣ) 24.6 ± 1.58 kg·m^{-2}. Η ομάδα ελέγχου αποτελούνταν από επτά άνδρες ηλικίας 21±1έτος και ΔΜΣ 23.1 ± 1.76 kg·m^{-2}. Το πρωτόκολλο κόπωσης περιελάμβανε επαναλαμβανόμενα σετ με ισοκινητικές μειομετρικές κάμψεις-εκτάσεις γόνατος στις 180°/sec μέχρις ότου οι πέντε πρώτες επαναλήψεις το επομένου σετ να είναι κάτω από το 50% της μέγιστης ισοκινητικής ροπής. Τα κινηματικά και κινητικά δεδομένα αναλύθηκαν για τρία επιτυχημένα άλματα με ένα πόδι για απόσταση ίση με το 80% του μήκους ποδιού πριν και μετά την εφαρμογή του πρωτοκόλλου κόπωσης. Για την στατιστική ανάλυση των δεδομένων εφαρμόστηκε ανάλυση διακύμανσης δύο παραγόντων με επαναλαμβανόμενες μετρήσεις στον παράγοντα χρόνο. Δεν υπήρχε αλληλεπίδραση μεταξύ ομάδας και χρόνου. Προέκυψε κύρια επίδραση του χρόνου στις μεταβλητές γωνία κάμψης γόνατος, ροπή κάμψης γόνατος, μέγιστη δύναμη αντίδρασης του εδάφους και ύψος πτήσης. Οι συμμετέχοντες μετά από κόπωση προσγειωνόταν με μικρότερη γωνία κάμψης γόνατος και είχαν μειωμένες αρθρικές ροπές στο γόνατο. Επίσης, εμφάνισαν μειωμένη δύναμη αντίδρασης του εδάφους λόγω χαμηλότερης πτήσης ($p<.05$). Οι αθλούμενοι που έχουν υποβληθεί σε επέμβαση αποκατάστασης ΠΧΣ εμφανίζουν παρόμοια στρατηγική προσγείωσης με υγιείς αθλούμενους μετά από κόπωση. Η στρατηγική αυτή χαρακτηρίζεται από αυξημένη σκληρότητα στο γόνατο, που θα μπορούσε να οδηγήσει σε τραυματισμό. Οπότε, η κόπωση είναι μια σημαντική παράμετρος και θα πρέπει να λαμβάνεται υπόψη τόσο κατά το σχεδιασμό προγραμμάτων αποκατάστασης όσο και κατά τις λειτουργικές δοκιμασίες.

Abstract

The majority of athletes undergoing ACL reconstruction are unable to successfully return to pre-injury levels of sport participation and even after successful reconstruction and rehabilitation they are exposed to increased knee instability that might lead to damage of the knee menisci and the development of osteoarthritis. Neuromuscular fatigue is also related to increased knee instability, increased knee laxity and risk factors for knee injuries during sport activities with landings and cutting movements. The purpose of the proposed study was to examine the fatigue induced changes in landing strategies after ACL reconstruction. Nine physically-active ACL-reconstructed male individuals with an average age of 25.7±8.75 years, and BMI of 24.6 ± 1.58 $\text{kg}\cdot\text{m}^{-2}$ participated in this current study. Seven healthy and physically-active male subjects with an average age of 21±1 years, and BMI of 23.1 ± 1.76 $\text{kg}\cdot\text{m}^{-2}$ were used as control group. The subjects performed alternating concentric knee flexion/extension contractions at 180°/sec until the first five repetitions of a set were below 50% of the peak torque assessed at a previous set of Maximum Voluntary Contractions on the isokinetic dynamometer. Three dimensional kinetics and kinematics were analyzed for the lower extremities during three pre and post-fatigue single leg hops at a distance of 80% of subject's leg length. Two-way ANOVA with repeated measures (pre-post) was used to analyse the data. There was no interaction between group and time. Significant main effect of time came up for the parameters: knee flexion angle, knee extension moment, peak vertical ground reaction force, max jump height. Results indicated that the post-fatigue vertical jump height was lower and subjects landed with more extended knee and demonstrated lower knee joint moments. A further decrease in vertical Ground Reaction Forces and jump height was also observed ($p<.05$). In conclusion, ACL reconstructed recreational athletes demonstrate landing strategies similar to uninjured subjects after fatigue. Those patterns are characterized of increased knee stiffness that could lead to re injury. Fatigue should be considered for the planning of rehabilitation programs and functional tests.

Πίνακας περιεχομένων

Λίστα πινάκων

Λίστα εικόνων και γραφημάτων

Λίστα συντμήσεων

ACL	Anterior cruciate ligament
GRF	Ground reaction force
MVC	Maximum voluntary contraction
BMI	Body mass index
FP	Force plate
IC	Initial contact

1. Introduction

The knee joint is highly susceptible to injury during sports and recreational activities (Louw, Manilall, & Grimmer, 2008). Amongst all knee injuries the incidence of ACL tear is estimated at almost 20% (Majewski, Susanne, & Klaus, 2006). Regardless of the severity of the incidence, ACL injury causes great pain and leads to absence from work or sport. There are approximately 100.000 ACL ruptures reported each year in the US (Prodromos, 2008) and the ACL reconstructions are estimated to be at 6.600 annually in Scandinavian countries (Chen et al., 2008). Furthermore, complete ACL rupture can instigate other pathological knee conditions, including knee instability, damage to the menisci and development of osteoarthritis (Yu & Garrett, 2007).

The majority of athletes undergoing ACL reconstruction are unable to successfully return to pre-injury levels of sport participation and therefore retire from sports (Ortiz et al., 2008). There is a variety of functional tests that are used after ACL reconstruction to estimate the surgery success, the patients' progress during the rehabilitation program and the ability to return to sport activities. The dynamic stability of the knee seems to be the most important factor to return back in sport activities. Single-leg hop test is the most commonly used test in current clinical practice to assess knee function following ACL reconstruction (Augustsson, Thomeé, & Karlsson, 2004). Single limb landing tasks could also be useful for detecting changes in dynamic knee stability (Webster, Gonzalez-Adrio, & Feller, 2004).

1.1 Significance of the proposed study

It is reported that patients with ACL injury are exposed to neuromuscular and proprioceptive deficits even after surgical reconstruction and rehabilitation (Ortiz, et al., 2008).It is also well-documented that neuromuscular fatigue alters lower limb biomechanics during demanding sport movements and leads to high risk movement patterns, especially during landing and cutting maneuvers (Benjaminse et al., 2008; Kernozek, Torry, & Iwasaki, 2008; McLean & Samorezov, 2009; Thomas, McLean, & Palmieri-Smith, 2010).

To our knowledge, the effects of neuromuscular fatigue on landing performance have not been examined for physically active patients who have undergone ACL reconstruction. Defining the probable differences could lead to a new methodology in functional clinical examination using the available up-to-date technological equipment. New methods of examination could help clinicians to make safer decisions regarding the ability of injured athletes to return to high level physical activities. Moreover, the early recognition of incorrect strategies could help to further refine rehabilitation programs and avoid future problems such as knee osteoarthritis etc.

1.2 Purpose of the Proposed Study

The purpose of this study is to examine the fatigue induced changes in landing strategies after ACL reconstruction. We expect that the ACL-reconstructed (ACLr) group will show different adaptations at the post-fatigue state compared to the healthy control group. We expect to define strategies appertaining to injury mechanisms.

2. Review

2.1 ACL anatomy and function

The function of the ACL is to limit the combined motions of the anterior tibial translation and the internal tibial rotation (Zancan, Beretta, Schmid, & Schieppati, 2004). The ACL is a structure composed of numerous fascicles of dense connective tissue (Prodromos, 2008). It is attached proximally to the posteriomedial edge of the lateral femoral condyle and distally to the anterior intercondylar fossa on the tibial plateau (Zancan, et al., 2004). Two bundles of the ACL were described for the first time in 1938 by Palmer et al (Prodromos, 2008). The two distinct functional bundles have been termed anteromedial (AM) and posterolateral (PL) bundles, based on their tibial insertions (Husemann, Müller, Krewer, Heller, & Koenig, 2007). It is approved that each bundle has a different contribution to resist anterior tibial translation and tibial rotation, depending on the tibiofemoral joint flexion. In vitro studies show that the anteromedial (AM) bundle functions more in high flexion angles whilst the posterolateral (PL) is more stressed at low flexion angles (Wu et al., 2010).

2.2 Epidemiology

The ACL injury continues to be the largest single problem in orthopedic sports medicine (Renstrom et al., 2008). As reported from a number of researchers, there are variations to ACL tear according to gender and sport. It is commonly reported that females have a greater incidence of ACL tear than males. The latest meta-analysis stated that the female/male ratio of incidence of ACL tear is 3:1

(Prodromos, Han, Rogowski, Joyce, & Shi, 2007). With regards to differentiations between sports, those of American football, skiing and soccer have been characterized as high-risk events when considering ACL injury (Bradley, Klimkiewicz, Rytel, & Powell, 2002).

2.3 Mechanisms of ACL injury and risk factors

Non-contact ACL injuries are likely to occur during deceleration and acceleration motions with excessive quadriceps contraction and reduced hamstring co-contraction (Shimokochi & Shultz, 2008).

Generally speaking, sagittal plane biomechanical factors such as small knee flexion angles and great posterior ground reaction forces, are the major ACL loading mechanisms (Yu & Garrett, 2007). Churchill at al (2003) using a cadaveric model showed that an aggressive quadriceps load with the knee near full extension, produces significant anterior tibial translation causing injury to the ACL, which suggests that the quadriceps can serve as the major intrinsic force in a noncontact ACL injury.

2.4 Reconstruction and rehabilitation

In recent years, ACL reconstruction has been a common surgical approach to restore knee stability after ACL injury. The surgery is performed arthroscopically. The torn ligament has to be completely removed from the knee and reconstructed. There are many surgical approaches in terms of graft choice and reconstruction techniques.

Both allograft and autograft can be used. The allograft is the use of tissue from a donor’s (cadaver) body. The patella tendon, anterior tibialis or achilles tendon can be utilized. It is significant that there is a risk of rejection when using allograft. The autograft is the use of tissue from the patient’s body. The patella tendon or hamstring tissue is commonly used.

Graft choice is subjective with regards to all the options having both advantages and disadvantages. The most common practice nowadays is to employ the hamstring graft as it is easier and causes les knee pain post operation.

Alongside the graft choice, there are also different techniques available. It has long been debated whether double- bundle technique would lead to improved anteroposterior and transverse plane stability compared to the single-bundle technique (Tsarouhas et al., 2010).

2.5 Muscle Fatigue

Over the past years there have been several different definitions for muscle fatigue. Despite the complexity of the issue according to Gandevia (2001) the most useful definition for muscle fatigue is “any exercise induced reduction in force generating capacity”. It is also known that fatigue can be caused by many different mechanisms and there is no global mechanism responsible for neuromuscular fatigue (Enoka & Duchateau, 2008).

Those mechanisms are divided as central and peripheral. Central fatigue refers to a progressive reduction in voluntary activation of muscle during exercise, whether fatigue produced by changes at or distal to the neuromuscular junction is described as peripheral fatigue (Gandevia, 2001). Both mechanisms are responsible for the failure to maintain the initial maximal force during exercise.

In terms of competitive sport fatigue is believed to have been contributing to injuries through several changes that affect proprioception and postural control.

2.6 Effects of fatigue and ACL injury on lower extremity biomechanics

As discussed above, a wide range of changes on many physiological aspects are related to fatigue. Those changes are believed to affect negatively proprioception and muscle response while resulting in altered biomechanics.

Concerning movements that involve rapid deceleration such as landings and cutting manures there is increasing evidence that neuromuscular fatigue leads to altered patterns that may increase ACL injury risk. Thomas et al (2010) investigated the effects of quadriceps and hamstrings fatigue on single leg landing strategies, using a concentric fatigue protocol on isokinetic dynamometer. The subjects show significant increases in initial contact hip internal rotation and knee extension and external rotation angles, with the increases in knee extension and external rotation being maintained at the time of peak vGRF.

In their study Benjaminse et al. (2008) investigated the effects of fatigue induced via exhaustive running changes on single-leg jump for male and female subjects. They found significant decrease on knee valgus and knee flexion at initial contact post-fatigue.

There is a controversy in the literature about the ability of the patients that have undergone ACL reconstruction to restore physiological movement patterns during daily life or more stressful sport movements. It has been reported that patients after ACL reconstruction demonstrate adaptations such as earlier onset of muscles and increased knee joint stiffness as a protective mechanism.

Although there is increasing evidence that despite the existing differences ACL reconstructed patients tent to demonstrate similar patterns with uninjured patients. Ortiz et al (2008) examined the biomechanics during single leg drop jump and 20 cm up and down hop task for women. They concluded that ACL reconstructed patients land similar to uninjured individuals.

On the other hand Gokeler et al (2010) concluded that landing strategies after ACL reconstruction are abnormal. In this study the researchers analyzed the muscle activity and movement patterns for male and female ACL reconstructed patients. They found significantly earlier onset times for all muscles, except vastus medialis for the involved leg and differences in the kinematic variables.

Decker and colleges (2002) compared kinematic and kinetic performance of ACL reconstructed recreational athletes during a 60 cm drop-jump. This study concluded that ACL reconstructed athletes have an adapted landing strategy that employ the hip extensors less and the ankle plantarflexor muscles more.

Gait analysis studies show that the parameters shift towards normal values patterns (Bulgheroni, Bulgheroni, Andrini, Guffanti, & Giughello, 1997) but there are also graft- specific differences in knee biomechanics (Webster, Wittwer, O'Brien, & Feller, 2005).

3. Methods

3.1 Participants

Nine physically-active ACL-r male individuals with an average age of 25.7±8.75 years, and BMI of 24.6 ± 1.58 kg·m^{-2} participated in this study. Seven healthy and physically-active male subjects with an average age of 21±1 years, and BMI of 23.1 ± 1.76 kg·m^{-2} participated as the control group. The inclusion criteria for the ACL-r group were: 12 months post-operatively, and participation in recreational or competitive sports activity from three to five times per week. The Exclusion criteria_included other ligamentous injuries in the same knee, reported knee pain or instability during sports. The control group exercised three to five times per week in recreational sports such as football, basketball etc. The subjects signed an informed consent-form approved by the Institutional Review board to participate in the study.

3.2Equipment

Pelvic and lower extremity kinematic data were collected via a ten-camera optoelectronic system (Vicon T-series, Oxford, UK), sampling at 100 Hz. A force platform (type 4060, Bertec, Worthington, OH) was used to collect Ground Reaction Force (GRF) data at a sampling frequency of 1000 Hz and was synchronized with the Vicon system. An isokinetic dynamometer (Cybex-Norm, Ronkonkoma, NY) was used for the assessment of muscular strength and the performance of the fatigue protocol.

3.3 Experimental procedures

A pre-post design was used to examine the effects of fatigue on landing strategies. The subjects' maximum voluntary contraction (MVC) for knee extension/flexion was assessed at 60 and 180 degrees/s for both legs on the isokinetic dynamometer. Subsequently the participants performed the single-leg hop task. Three successful hops were recorded and then the subjects underwent the fatigue protocol on the isokinetic dynamometer. When the fatigue protocol ended they repeated this single-leg hop task.

3.4 MVC Assessment and Fatigue Procedures

A warm-up protocol of seven minutes cycling at 50 Watts and stretching of the major muscle groups of lower limbs were systematically applied before isokinetic testing could take place (Tsatalas et al., 2010). Participants were securely seated (100° hip angle) on the dynamometer and the axis of the rotation was aligned with the most prominent point of the lateral femoral condyle. The alignment was performed at 90° to the knee flexion under sub-maximal muscle-contraction conditions. The ROM of the knee was set at 0-100° and 100- 0° for the knee flexors, respectively (0°= full knee extension). Gravitational corrections were also employed. All contractions were performed at a speed of 180°/s through a knee range of motion 0-100°.

The subjects performed a set of five alternating quadriceps- and hamstrings-maximum-voluntary contractions. The peak torque value for both extension and flexion was recorded so that it could later be used to quantify percentage-strength degradation and fatigue (Thomas, et al., 2010).

To fatigue the knee extensors and flexors, the participants performed alternating maximum voluntary contractions (MVC) until the torque, measured in both groups, dropped below 50% of that of the peak torque measured before (Ochsendorf, Mattacola, & Arnold, 2000). Once the point was reached, subjects were given 20 s of rest and then asked to resume the alternating tasks of MVC and rest, and was repeated until fatigue was achieved. This then corresponded to when the first five repetitions of a quadriceps and hamstrings MVC performed below 50% of subjects' baseline peak torque in both muscle groups.(Thomas, et al., 2010). Immediately after the fatigue protocol the subjects performed the hop task.

3.5 Single-leg hopping procedures

The participants were asked to perform a single-leg forward hop on to the force platform. The hopping distance was determined at 80% of each subject's leg-length, recorded from the anterior superior iliac spine (ASIS) to the medial malleolus.

Figure 1. Initial Position

Figure 2. Landing on the FP

3.6 Kinematic and kinetic analyses

Twenty-four retro-reflective markers were attached to the pelvis and lower extremities of each subject, according to the model described by Schwartz and Rozumalski (2005). According to this model there are two stages, static and dynamic, in order to calculate the joint centres and axes of rotation. The standard Davis model (Davis Iii, Õunpuu, Tyburski, & Gage, 1991) is used at the static stage to define the initial position of joint centres and axes of rotation. During the dynamic stage, the subject is asked to perform specific movements such as knee extension- flexion and hip adduction- abduction, and the new positions are refined based on mathematical optimization procedures. The maximum jump height was calculated as the maximum value of the left or right posterior iliac spine marker on the Z axis. The marker was chosen according to the leg used for the movement.

Figure 3. Position of 24 reflective markers. The model includes the well-known position of the 16 markers from Davis model with the addition of 2 markers positioned on a plate strapped tightly around the calves and thighs

3.7 Statistical Analysis

Two-way ANOVA (pre-post X 2 groups) with repeated measures (pre-post) was used to compare the kinetic and kinematic variables during the single-hop task. The SPSS was used to perform statistical analyses. Post-hoc analysis of significant interactions and main effects were further investigated using Bonferroni adjustment. Paired t-tests were used to examine differences on peak isokinetic torque and knee flexors/extensors ratios between groups and between involved and uninvolved legs for the ACLr group. The significance level was set at $p < 0.05$.

4. Results

4.1 Sagittal Plane Kinematics at Initial Contact

There was no interaction between group and time for any joint angle at Initial Contact (IC) (p > .05). There were no significant differences between ACL-r and control group for the hip joint at IC. Fatigue did not affect hip flexion/extension at IC. There was no significant difference between groups, although both groups landed with more extended knee (less knee flexion angle) at the post fatigue state (p=.005).

Table 1.Sagittal Plane Joint angles at Initial Contact

	ACL				**CONTROL**			
	Prefatigue		**Postfatigue**		**Prefatigue**		**Postfatigue**	
Hip Flex/Ext	38.26	±7.66	37.04	±8.80	34.93	±8.55	36.18	±5.57
Knee	20.96	±4.08	16.78*	±6.86	18.90	±4.26	15.58*	±4.53

Note. Values are presented as mean ±sd.
*indicates statistically significant differences for the factor time

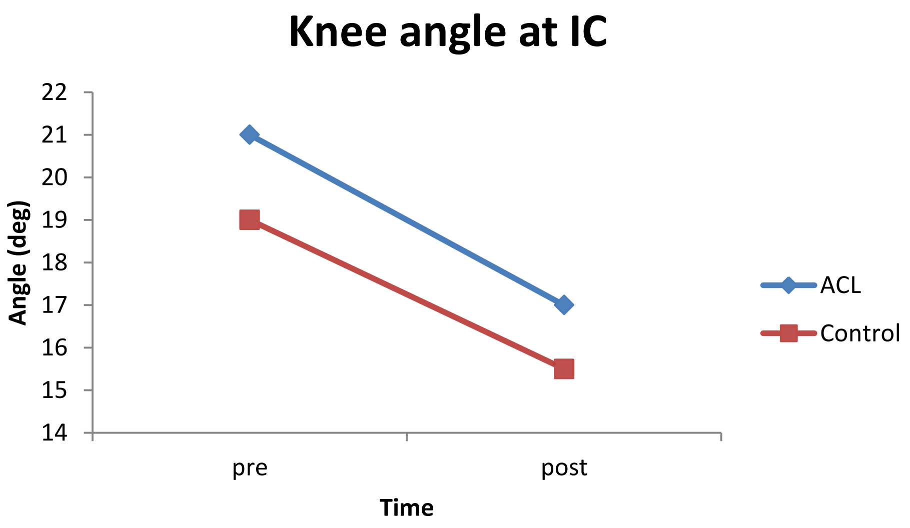

Figure 5. Knee angle at IC pre and post fatigue.

4.2 Joint angles at Peak GRF

There was no interaction between group and time for any joint angle at peak vertical GRF (vGRF) (p> .05). There were no significant differences between ACL-r and control group for the hip joint at peak vGRF. Fatigue did not affect hip flexion/extension at peak vGRF. There was no significant difference between groups, although both groups demonstrated less knee flexion at the post fatigue state at peak vGRF (p=.039).

Table 2. Sagittal Plane Joint angles at peak GRF

	ACL				**CONTROL**			
	Prefatigue		**Postfatigue**		**Prefatigue**		**Postfatigue**	
Hip	39.28	±11.49	40.10	±10.42	38.55	±8.97	40.19	±6.64
Knee*	26.84	±8.61	25.09	±12.36	33.58	±3.03	30.43	±6.38

Note. Values are presented as mean ±sd.
*indicates statistically significant differences for the factor time

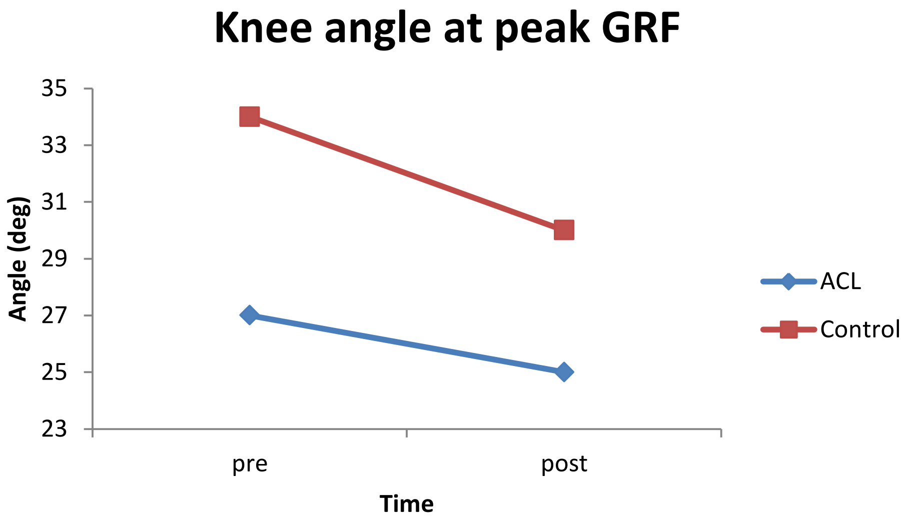

Figure 5. Knee angle at peak GRF pre and post fatigue.

4.3 Maximum Joint moments

There was no interaction between group and time for the hip maximum joint moments. Peak knee external moment was significantly decreased at the post fatigue state ($p<.05$) and hip external moment tended to decrease ($p=.075$).

Table 3. Peak Joint Moments ($Nm/kg\ m^{-1}$)

	ACL				CONTROL			
	Prefatigue		Postfatigue		Prefatigue		Postfatigue	
Hip External	2.13	±0.84	1.40	±0.76	1.66	±1.25	1.42	±0.79
Knee External*	2.04	±0.55	1.75	±0.57	2.12	±0.42	1.76	±0.43

Note. Values are presented as mean (sd).
*indicates statistically significant differences for the factor time

4.4 Time to Peak Vertical GRF

The peak vGRF was significantly lower at the post-fatigue state for both groups. The jump height was significant lower for both groups at the post fatigue state.

Table 4. Max Normalized GRF and Max jump height

	ACL				**CONTROL**			
	Prefatigue		**Postfatigue**		**Prefatigue**		**Postfatigue**	
Max Normalized vGRF(%BW)*	285.94	±70.14	256.74	±38.63	341.15	±43.33	316.52	±31.40
Max Jump Height (m)*	1.31	±0.10	1.24	±0.07	1.25	±0.04	1.22	±0.04

Note. Values are presented as mean (sd).
*indicates statistically significant differences for the factor time

4.5 Muscle Strength

The ACL-r group demonstrated normal values for the peak torque ratio between knee flexors and extensors for both uninvolved and involved leg. Although we detected statically significant differences for the knee extensors peak torque ratio between involved and uninvolved side. They had an average deficiency of 5% at the involved side.

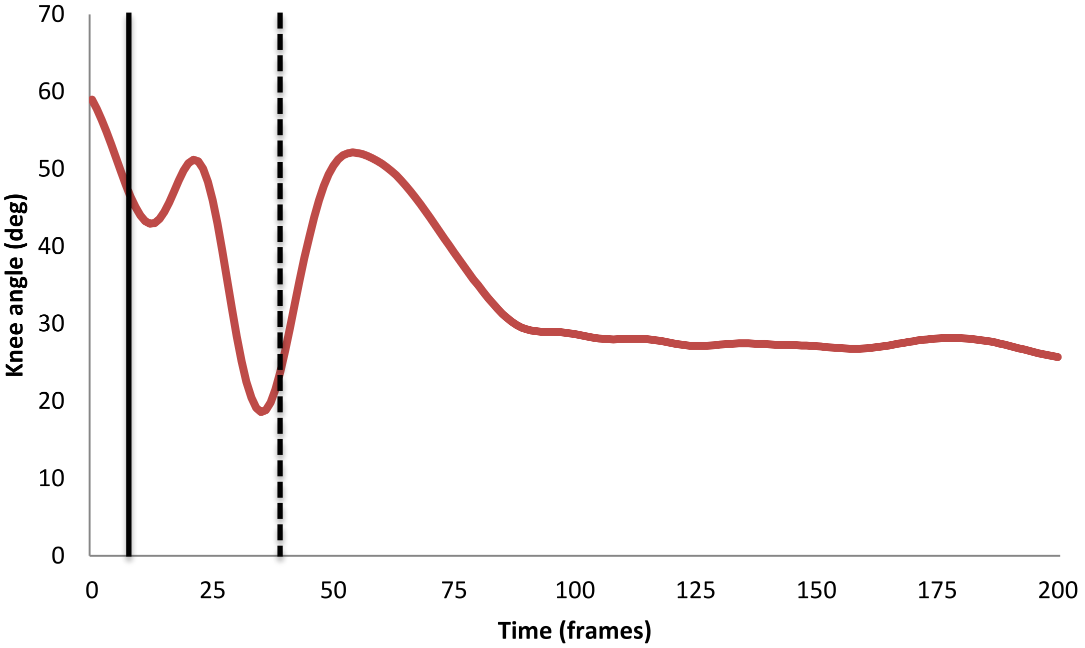

Figure 4. Knee flexion extension angle during single leg hop task. The solid vertical line represents the take-off, while the dashed vertical line indicates the initial contact.

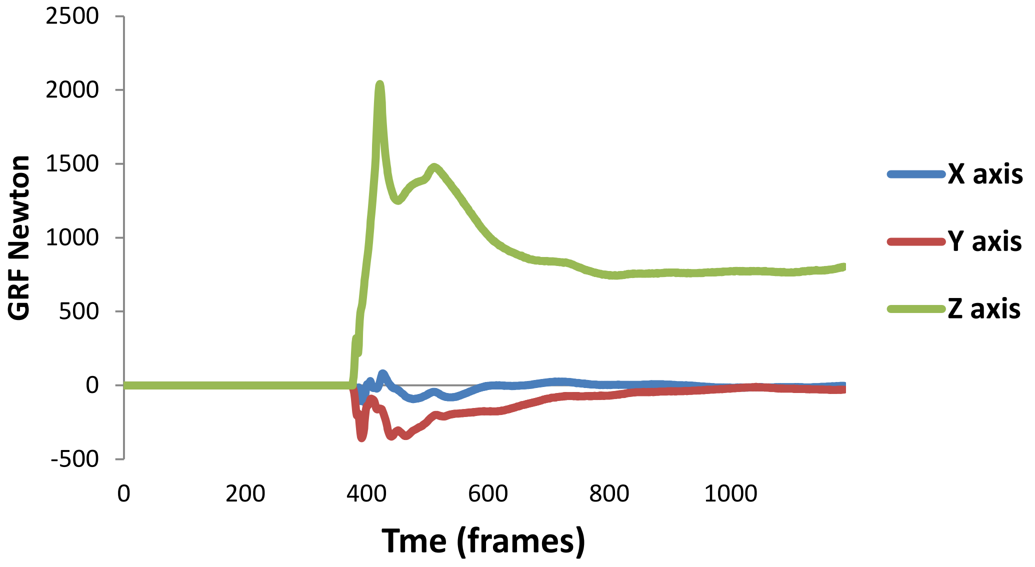

Figure 5. Ground reaction forces during single leg landing

5. Discussion

The main objective of the present study was to examine the effects of quadriceps and hamstrings fatigue on the lower extremity kinetics and kinematics for ACL-r recreational athletes during demanding sport movements. In contrast to our hypothesis, both ACL-r and healthy group had similar landing strategies after exercise demonstrating comparable adaptation to fatigue.

As commonly reported (McLean et al., 2007; Thomas, et al., 2010), lower extremity fatigue leads to abnormal landing strategies with a high risk of ACL injury. Furthermore, the majority of the athletes who have undergone ACL reconstruction are unable to successfully return to pre-injury level sport participation as impairments in muscle strength, functional performance and postural control have been reported to continue even after surgical reconstruction and rehabilitation (Ortiz, et al., 2008). Thus, functional tests are commonly used in order to estimate the ability to return in challenging sport activities. Recent studies suggest that functional testing should be performed both under non-fatigued and fatigued conditions (Augustsson, et al., 2004).

5.2 Kinemantics

The single-leg hop task was selected to describe better the proposed highly demanding sport activities that usually lead to ACL tear (Shimokochi & Shultz, 2008). We analysed hip and knee joint parameters focusing in sagittal plane. There were no significant differences for hip joint angles before and after fatigue protocol. Similar to our findings, Thomas et al. (2010) did not observe significant changes for the hip joint during single leg landings after fatigue. We agree with Thomas's theory that the non-fatigued hip flexors and extensors were able to maintain the pre-fatigue postures and loads.

We observed significant decrease in knee joint flexion angle at initial contact post-exercise for both groups. Knee flexion angle decrease was also observed at maximum vertical GRF. This fact confirmed our hypothesis that subjects would demonstrate strategies related to knee injury. Reduced knee flexion angles increase the likelihood for knee injury by decreasing the ability of the hamstrings to resist to anterior shear forces on tibia (Ortiz et al., 2010). The majority of the researchers that investigated the effects of fatigue on landing strategies found decreased knee flexion angle during landing and/or peak vertical GRF, as in our study. The most common theory is that at the post fatigue state subjects tend to have increased knee joint stiffness during landing as a protective strategy against great knee flexion and subsequent collapse (Ortiz, et al., 2010; Thomas, et al., 2010), or trying to keep trunk centred within the base of support (Ortiz, et al., 2010). Decreasing knee flexion is reported to increase the risk of ACL injury (Churchill, et al., 2003; Yu & Garrett, 2007).

5.3 Kinetics

After fatigue protocol the kinetic parameters of both groups were also altered. We observed significant decreased vertical GRF at the post fatigue state. This fact could be explained by the significant decrease in vertical jump height at the post fatigue state. Our results are comparable to those in a previous study, where significant decrease in jump height was observed during double leg stop-jump performance after fatigue (Yu & Garrett, 2007). It is likely that this reduction is observed due to impaired ability to produce muscle force because of fatigue.

The reduction in joint external rotation moments was probably due to the decreased GRF. Especially the decrease in knee joint external moment resulted due to the decreased knee flexion that alters the moment arm about the knee.

5.4 Limitations

The present study analyzed the effects of fatigue on single leg landing strategies. There are also different fatigue protocols that could have different effects on landing performance. The ACL-r patients that took part in our study used to take part in recreational sporting activities three to five times per week. The majority of the ACLr patients may not have the same level of physical activity and thus may demonstrate different strategies. Given that the majority of the athletes do not return to competitive sports after ACL reconstruction (Ardern, Webster, Taylor, &

Feller, 2011), if we had chosen inactive subjects they might had shown different landing strategies.

6. Conclusion

Our study showed that ACL reconstructed recreational athletes demonstrate similar landing strategies with uninjured individuals after a fatigue exercise protocol of quadriceps and hamstrings. Those patterns are related to knee injuries and thus biomechanical analysis of specific high demanding sport movements could be used in order to address wrong technique and improve the rehabilitation programs. Fatigue is a parameter that everyone should consider when designs functional tests. Further research should be focused on the effects of different fatigue protocols on landing performance and the improvement of the functional tests in order to provide more reliable assessment of the functional ability of the ACL-r patient to participate in competitive level in sport activities.

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9.Appendix

9.1 Έντυπο συναίνεσης

Τίτλος έρευνας : Η επίδραση της κόπωσης στα εμβιομηχανικά χαρακτηριστικά των κάτω άκρων μετά από επέμβαση αποκατάστασης Πρόσθιου Χιαστού Συνδέσμου.
Επιστημονικώς υπεύθυνος: Δρ. Γιάννης Γιάκας

Έντυπο συναίνεσης δοκιμαζόμενου σε ερευνητική εργασία

1. **Σκοπός της ερευνητικής εργασίας**

Σκοπός της μελέτης είναι να διερευνηθεί η επίδραση της μυϊκής κόπωσης στα εμβιομηχανικά χαρακτηριστικά των κάτω άκρων κατά την εκτέλεση άλματος, στροφών και απότομης αλλαγής διεύθυνσης μετά από κόπωση για άτομα που έχουν υποβληθεί σε επέμβαση αποκατάστασης Προσθίου Χιαστού Συνδέσμου (ΠΧΣ). Επιπλέον να εντοπιστούν πιθανές διαφορές ανάμεσα στις δύο τεχνικές αποκατάστασης, απλού και διπλού μοσχεύματος.

2. **Διαδικασία μετρήσεων**

Οι συμμετέχοντες θα αξιολογηθούν στη μέγιστη ισοκινητική και ισομετρική δύναμη πρόσθιων και οπίσθιων μηριαίων μυών σε ισοκινητικό δυναμόμετρο. Στη συνέχεια να τοποθετηθούν στο σώμα του εξεταζόμενο με αυτοκόλλητη ταινία, ανακλαστήρες(markers) προκειμένου να γίνει η καταγραφή των εξεταζόμενων κινήσεων με το οπτοηλεκτρονικό σύστημα καταγραφής και ανάλυσης κίνησης του εργαστηρίου μας (Vicon).

Με την ολοκλήρωση της αρχικής αξιολόγησης και την τοποθέτηση των ανακλαστήρων ο εξεταζόμενος θα κλιθεί να πραγματοποιήσει τις εξής κινήσεις 1) άλμα σε μήκος με ένα πόδι 2) άλμα σε μήκος και στροφή στηριζόμενος στο ένα πόδι 3) άλμα σε μήκος και αλλαγή διεύθυνσης 4) έσω και έξω στροφή στηριζόμενος στο ένα πόδι.

Μετά την ολοκλήρωση των κινήσεων ο εξεταζόμενος θα πραγματοποιήσει ένα πρωτόκολλο κόπωσης πρόσθιων και οπίσθιων στο ισοκινητικό δυναμόμετρο που αποτελείται από δεκάδες εκούσιες κάμψεις και εκτάσεις του γόνατος μέχρι να φτάσει σε αδυναμία παραγωγής δύναμης ίσης με το 50% της μέγιστης δύναμής του στις 180 μοίρες/ δευτερόλεπτο.

Έπειτα θα εκτελεστεί η αρχική ρουτίνα κινήσεων οι οποίες θα καταγραφούν από το οπτοηλεκτρονικό σύστημα.

3. Κίνδυνοι και ενοχλήσεις

Δεν υπάρχει κανένας κίνδυνος τραυματισμού κατά τη διάρκεια των δοκιμασιών. Παρ' όλα αυτά υπάρχει πρόβλεψη πρώτων βοηθειών και εκπαιδευμένο προσωπικό για κάθε ενδεχόμενο. Οι διαδικασίες αξιολόγησης και κόπωσης γίνονται με εκούσιες κινήσεις. Αν αισθανθείς οποιαδήποτε ενόχληση η διαδικασία διακόπτεται άμεσα.

4. Προσδοκώμενες ωφέλειες

- Οι συμμετέχοντες θα λάβουν άμεσα την **αξιολόγηση της δύναμης** πρόσθιων και οπίσθιων μηριαίων κάτι που αποτελεί βασικό στοιχείο για την εκτίμησης κατάσταση και της πορείας αποκατάστασης μετά τον τραυματισμό.
- Με βάση την παραπάνω αξιολόγηση θα μπορούν να δοθούν ασφαλείς προπονητικές οδηγίες και συμβουλές
- Ηθική ικανοποίηση από τη συμβολή στην παραγωγή νέας γνώσης.

5. Δημοσίευση δεδομένων – αποτελεσμάτων

Η συμμετοχή σου στην έρευνα συνεπάγεται ότι συμφωνείς με τη δημοσίευση των δεδομένων και των αποτελεσμάτων της, με την προϋπόθεση ότι οι πληροφορίες θα είναι ανώνυμες και δε θα αποκαλυφθούν τα ονόματα των συμμετεχόντων. Τα δεδομένα που θα συγκεντρωθούν θα κωδικοποιηθούν με αριθμό, ώστε το όνομα σου δε θα φαίνεται πουθενά.

6. Πληροφορίες

Μη διστάσεις να κάνεις ερωτήσεις γύρω από το σκοπό ή/και τον τρόπο πραγματοποίησης της εργασίας. Αν έχεις κάποιες αμφιβολίες ή ερωτήσεις, ζήτησέ μας να σου δώσουμε πρόσθετες εξηγήσεις.

7. Ελευθερία συναίνεσης

Η άδειά σου να συμμετάσχεις στην εργασία είναι εθελοντική. Είσαι ελεύθερος να μην συναινέσεις ή να διακόψεις τη συμμετοχή σου όποτε επιθυμείς.

Διάβασα το έντυπο αυτό και κατανοώ τις διαδικασίες που θα εκτελέσω. Συναινώ να συμμετέχω στην εργασία.

Ημερομηνία: __/__/__

Ονοματεπώνυμο και
υπογραφή συμμετέχοντος

Υπογραφή ερευνητή

Ονοματεπώνυμο και
υπογραφή παρατηρητή

9.2 Muscular strength ratio

Isokinetic peak torque ratio(%) measured at 60˚/sec for knee extensors and flexors(ACL-r group)

	Involved Leg Flexors/ Extensors	Uninvolved Leg Flexors/ Extensors	Knee Extensors Uninvolved/involved	Knee Flexors Uninvolved/involved
	75.09	75.00	99.62	99.50
	64.36	64.22	100.99	100.77
	78.18	73.36	97.27	91.28
	63.69	69.75	90.50	99.12
	66.56	72.16	95.41	103.45
	73.54	74.29	92.59	93.53
	75.83	77.39	94.31	96.25
	76.19	87.94	94.76	109.38
	65.31	64.29	97.14	95.63
Mean	70.97	73.16	95.84	98.77
SD	5.86	7.18	3.30	5.46

Isokinetic peak torque ratio(%) measured at 60˚/sec for knee extensors and flexors (Control group)

	Dominant leg Flexors/ Extensors	Non-dominant Flexors/ Extensors	Knee extensors Dominant/non-dominant	Knee flexors Dominant/non-dominant
	65.19	66.67	99.448	101.69
	80.25	80.65	98.726	99.21
	76.50	71.98	99.454	93.57
	88.48	94.58	100.606	107.53
	67.63	67.32	99.034	98.57
	64.33	59.35	98.726	91.09
	66.39	66.67	100.840	101.27
Mean	72.68	72.46	99.548	98.99
SD	9.24	11.70	0.859	5.44