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THE EFFECTS OF TWO DIFFERENT FATIGUE PROTOCOLS ON LOWER EXTREMITY KINEMATICS AND KINETICS DURING AN UNANTICIPATED RUNNING STOP-JUMP

By

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BATR May 2008, Minnesota State University, Mankato

A Thesis Submitted to the faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE IN EDUCATION

ATHLETIC TRAINING

OLD DOMINION UNIVERSITY
May 2010

Approved by:

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ABSTRACT

THE EFFECTS OF TWO DIFFERENT FATIGUE PROTOCOLS ON LOWER EXTREMITY KINEMATICS AND KINETICS DURING AN UNANTICIPATED RUNNING STOP-JUMP

David L. Quammen
Old Dominion University
Co-Directors: Dr. James A. Oñate, and Dr. Bonnie Van Lunen

Altered neuromuscular control strategies and biomechanical movement risk factors are most likely to contribute to the increased incidence of non-contact ACL injury for female athletes. Neuromuscular control strategies and movement patterns are further altered when the effects of fatigue are present. The purpose of this study was to determine neuromechanical differences between two fatigue protocols [Slow Linear Oxidative Fatigue Protocol (SLO-FP) and Functional Agility Short-Term Fatigue Protocol (FAST-FP)] when performing a running stop-jump task (RS). A sample of convenience of fifteen Division I female soccer players (age = 19.2 ± 0.8 years; height = 1.67 ± 0.05 m; mass = 61.7 ± 8.1 kg) participated in this study. Participants performed five successful trials of a RS task pre and post fatigue protocols. For the SLO-FP, a VO_{2peak} test was conducted prior to the fatigue protocol. Five minutes after the conclusion of VO_{2peak} test subjects started the fatigue protocol by performing a 30-minute interval run with six intervals. The FAST-FP consisted of 4 sets of a functional circuit that included: L-Drill, Ladder, Vertical Jumps, and step-ups. Repeated 2 (time) x 2 (protocol) ANOVAs were conducted to assess task and fatigue differences. Alpha level was set at .05. During SLO-FP participants had increased internal varus moment at initial contact (0.064±0.09Nm/Kgm) when compared with the FAST-FP (0.024±0.06Nm/kgm),p=0.033. Participants were in significantly lower hip flexion at

initial contact post-fatigue (44.7±8.1°) when compared with pre-fatigue (50.1±9.5°),p=0.001 as well as at peak vertical ground reaction force post-fatigue (44.7±8.4°) when compared with pre-fatigue (50.4±10.3°),p=0.001; at peak posterior ground reaction force post-fatigue (45.2±8.6°) when compared with pre-fatigue (51.1±10.8°),p=0.001; at peak knee flexion post-fatigue (38.7±8.7°) when compared with pre-fatigue (45.1±11.6°),p=0.001, and at max hip flexion post-fatigue (47.3±8.2°) when compared with pre-fatigue (53.3±10.95°), p=0.001. During SLO-FP subjects had increased knee extension moment (2.01±.32Nm/Kgm) when compared with the FAST-FP (1.9±.36Nm/Kgm),p=0.033. Both protocols induced similar changes to our subjects lower extremity biomechanics, the FAST-FP induced changes in as little as five minutes whereas the SLO-FP took 45 minutes to induce similar biomechanical changes. Our results demonstrated a decrease in hip and knee flexion angles at post-fatigue condition. Landing in an upright position has been shown to increase anterior tibial shear force, which augments the loads on the ACL.

DEDICATION.

I would like to dedicate this work to my Mom, who has supported, encouraged and inspired me in all of my educational endeavors. Also to my family, friends, and mentors who have helped me to develop into the person I am today.

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CHAPTER I

INTRODUCTION

Current research on ACL injury and the implications of gender, continue to reveal an increased incidence in females sustaining noncontact ACL injury (Agel, Arendt, & Bershadsky, 2005; Hewett, Myer, & Ford, 2006; Mihata, Beutler, & Boden, 2006; Mountcastle, Posner, Kragh, & Taylor, 2007; Uhorchak, et al., 2003). Research examining West Point injury data from 1994-2003 reveals that 89.4% of ACL injuries incurred by females were non-contact, and 67.2% incurred by males were non-contact (Mountcastle, et al., 2007). When analyzing intercollegiate athletics, three of the four sports with the highest rate for ACL injury were women's sports including, gymnastics, soccer and basketball (Hootman, Dick, & Agel, 2007). An estimated 80,000 to more than 250,000 ACL injuries occur each year, with an estimated 2,200 occurring in female intercollegiate athletics (Griffin, et al., 2006; Hewett, Lindenfeld, Riccobene, & Noyes, 1999). In the US alone an estimated 646 million dollars is spent annually on ACL surgery and rehabilitation for the female athlete (Hewett, Myer, Ford, et al., 2005). ACL injury has multiple negative health consequences including, early onset of osteoarthritis, damage to menisci and chondral surface, increased probability of additional surgery and decreased activity level due to functional instability (Maletius & Messner, 1999; Yu & Garrett, 2007). Maletius and Messner (1999) performed a 20 year follow up study of surgically repaired ACL ruptures and found that 87% of patients had signs of osteoarthritis upon radiographic examination, 45% of patients had undergone additional surgery, and only 23% of patients were satisfied with their knee function.

Anterior cruciate ligament injury risk factors fall under one of four categories including, anatomic, hormonal, environmental or neuromuscular (Griffin, et al., 2000; Schulz, Ashton-Miller, & Alexander, 2008). Of all the risk factors associated with ACL injury, altered neuromuscular control strategies and movement parameters are most likely to contribute to the increased incidence of non-contact ACL injury for female athletes (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Neuromuscular control strategies are further altered when the effects of fatigue are combined with unanticipated movement (Borotikar, Newcomer, Koppes, & McLean, 2008). Fatigue has been found to increase peak proximal tibial anterior shear force, increase knee abduction angle, decrease knee flexion angle, decrease hip flexion angle, increase peak valgus angle and maximum valgus angle, and result in a greater knee extension moment (Borotikar, et al., 2008; Chappell, et al., 2005; McLean, et al., 2007; Sanna & O'Connor, 2008). Unanticipated movement has been found to induce an increase in knee valgus moment, hip internal rotation, knee abduction and knee internal rotation (Besier, Lloyd, Ackland, & Cochrane, 2001; Borotikar, et al., 2008). When fatigue and unanticipated movement are combined it typically results in altered lower extremity mechanics, where the foot is planted, knee near full extension in an abducted position, and femur (hip) internally rotated; all hypothesized mechanics for ACL injury (Boden, Dean, Feagin, & Garrett, 2000; Hewett, Myer, & Ford, 2005; Olsen, Myklebust, Engebretsen, & Bahr, 2004; Yu & Garrett, 2007).

The occurrence of the theorized risk factors, associated with ACL injury, vary depending on the task being analyzed. A variety of different tasks have been used in previous research, including sidestep cutting task (Borotikar, et al., 2008; McLean &

Samorezov, 2009), drop jump task (Kernozek, Torry, & Iwasaki, 2008; McLean, et al., 2007), and stop jump task (Chappell, Creighton, Giuliani, Yu, & Garrett, 2007; Chappell, et al., 2005). The use of different tasks when analyzing the same lower extremity biomechanical parameters has yielded conflicting results. Researchers utilizing the sidestep cutting task have reported that fatigue mainly produces changes in frontal plane kinematics and kinetics (Borotikar, et al., 2008; McLean & Samorezov, 2009). However, previous research in which the stop jump task was analyzed, found that fatigue produces changes in both frontal and sagittal plane kinematics and kinetics (Chappell, et al., 2005). Researchers have not only used different tasks to assess lower extremity mechanics, but the fatigue protocols have also been distinct.

Current research on fatigue and its associated relationship between non-contact ACL injuries has focused on either short-term fatigue protocols or long-term fatigue protocols (Borotikar, et al., 2008; Chappell, et al., 2005; Gehring, Melnyk, & Gollhofer, 2009; McLean, Huang, & van den Bogert, 2008; McLean & Samorezov, 2009; Melnyk & Gollhofer, 2007; Sanna & O'Connor, 2008). Short-term fatigue protocols have induced fatigue through single leg squats (Mclean et al. 2009), consecutive repetitions of vertical jumps and short sprints (Chappell et al. 2005), and maximum repetitions on a leg press machine (Gehring, et al., 2009). The variety of different fatigue protocols previously used has resulted in a contradiction in the literature between which types of fatigue results in greater biomechanical alterations to the lower extremity during unanticipated movement. Furthermore, there is a lack of research comparing the effects of functional sport specific fatigue on lower extremity joint kinematics and kinetics. Soccer specific fatigue utilizing various aspects of an actual soccer practice should be implemented in order to accurately and effectively analyze the neuromuscular changes that occur during fatigued states.

Purpose Statement

The purpose of this study is to determine neuromechanical differences between two fatigue protocols (SLO-FP and FAST-FP) as measured by kinematic and kinetic variables of hip flexion, hip internal rotation, hip abduction, knee flexion, knee flexion moment, knee abduction moment, and knee abduction, at all time instants (initial contact, peak stance phase, peak knee flexion, peak vertical and posterior ground reaction forces), when performing an unanticipated running-stop jump task.

Null Hypotheses

Null Hypothesis 1

There will be no statistical significant differences between fatigue protocols on kinematic (hip flexion, internal rotation, and abduction, and knee flexion, and abduction) and kinetic (knee flexion moment, knee abduction moment, vertical and posterior ground reaction forces) variables at all time instants (initial contact, peak stance phase, peak knee flexion, peak vertical and posterior ground reaction forces) during a running-stop task.

Null Hypothesis 2

There will be no statistical significant differences between fatigue conditions (pre and post fatigue) for either one of the protocols (SLO-FP and FAST-FP) on kinematic (hip flexion, internal rotation, and abduction, and knee flexion, and abduction) and kinetic (knee flexion moment, knee abduction moment, vertical and posterior ground reaction forces) variables at all time instants (initial contact, peak stance phase, peak vertical and posterior ground reaction forces) during a running-stop task.

Research Hypotheses

Research Hypothesis 1

The post fatigue condition for either one of the protocols (SLO-FP and FAST-FP) will produce significantly lower hip flexion, knee flexion, and increased knee valgus, hip abduction, vertical ground reaction force and posterior ground reaction force at all time instants when compared to the pre-fatigue condition while performing a running-stop task.

Research Hypothesis2

The FAST-FP will produce significantly lower hip flexion, knee flexion, and increased knee valgus, hip abduction, vertical ground reaction force and posterior ground reaction force at all time instants when compared to the SLO-FP while performing a running-stop task (Borotikar, et al., 2008; Chappell, et al., 2005; McLean, et al., 2007; McLean & Samorezov, 2009).

Independent Variables

The independent variables for this study were:

- Fatigue protocols: (SLO-FP and FAST-FP)
- Time (pre and post fatigue)

Dependent Variables

The dependent variables for this study were:

Kinematics:

- Hip flexion at initial contact, peak vertical ground reaction force, peak posterior ground reaction force, peak knee flexion, and peak stance – measured in degrees
- Hip Abduction at initial contact and peak knee flexion – measured in degrees
- Knee flexion at initial contact, peak vertical ground reaction force, peak posterior ground reaction force, and peak knee flexion – measured in degrees
- Knee abduction at initial contact, peak posterior ground reaction force, peak knee flexion, and peak stance – measured in degrees

Kinetics:

- Vertical ground reaction force at peak vertical ground reaction force – measured in multiples of bodyweight (mbw)
- Posterior ground reaction force at peak posterior ground reaction force and peak knee flexion– measured in multiples of bodyweight (mbw)
- Knee extension-flexion moment at initial contact and peak stance – measured in N.m/Kg.m
- Knee adduction-abduction moment at initial contact and peak stance – measured in N.m/Kg.m
- Hip Abduction moment – measured in N.m/Kg.m

Operational Definitions

1. Slow Linear Oxidative Fatigue Protocol (SLO-FP) – The SLO-FP will involve the subjects performing a VO2 Max test, as described in the methodology. Following the VO2 Max test, the subjects will perform 30 minutes of continuous running. The subject will jog 4 minutes at 70% of their VO2 Max speed, followed by 1 minute of running at 90% of their VO2 Max speed. Subjects will complete this cycle of jogging and running until the 30 minutes have elapsed, 6 cycles.

2. Functional Agility Short-Term Fatigue Protocol (FAST-FP) – The FAST-FP will involve the subjects completing four cycles of the four exercises (step-ups, L-drill, vertical jump, and ladder drill). Following cessation of the four cycles the subjects will begin performing the unanticipated running-stop task. Before each running stop trial the subjects will perform three maximum vertical jumps, to ensure the state of anaerobic fatigue is maintained throughout the entire data collection.

3. Unanticipated Cutting Task – The software utilized for this study created either a running-stop or side step cutting task option during the kinematic/kinetic analysis. For the purposes of this study we are only focusing on the running-stop task.

4. Subject population – Division I female soccer athletes.

5. Running-stop – The subject will begin by running down the run way towards the force plates, as the subject approaches the force plates they will plant one foot on

each force plate and jump up vertically as high as possible, as if they are performing a soccer header.

6. Stop-jump phase – The Stance phase of the stop-jump phase was defined as the duration from initial contact to take off (Chappell et al. 2002).

Assumptions

1. All subjects completing the SLO-FP and FAST-FP will do so with maximum effort.

2. All subjects will put forth maximum effort when completing the unanticipated cutting tasks, both pre and post fatigue states.

3. The motion analysis hardware (Force plates and Vicon capture cameras) used in collecting the subject's kinematics and kinetics will provide reliable and valid data.

Limitations

1. It is not possible to objectively determine the subject's actual state of fatigue, and the level of fatigue may differ between subjects.

2. Sample of convenience – All subjects involved in the study were members of the Old Dominion University women's soccer team.

Delimitations

1. Subjects outlined initial marker placement sites between data collections in order to minimize marker placement error.

2. Subjects will complete all fatigue protocols and data collection wearing the same model of shoes (Adidas Supernova, AG, Herzogenaurach, Germany).

3. Subjects were required to have no previous history of cardiovascular or respiratory disease and no previous ACL injury and no operable lower extremity injury that would prevent them from participating in the fatigue protocols or dynamic tasks.

CHAPTER II

REVIEW OF LITERATURE

Anatomy of the Anterior Cruciate Ligament

The Anterior Cruciate Ligament (ACL) consists of a dense band of connective tissue, approximately 30 to 40 mm long and 11 mm wide (Giron, Cuomo, Aglietti, Bull, & Amis, 2006; Zantop, Petersen, & Fu, 2005; Zantop, Petersen, Sekiya, Musahl, & Fu, 2006). The ACL originates at the posteromedial aspect of the intercondylar notch on the lateral femoral condyle, the ligament runs through the intercondylar fossa and inserts on the medial tibial eminence in between the medial and lateral tibial eminence (Beasley, 2005; Zantop, et al., 2005; Zantop, et al., 2006). A variety of Authors describe the ACL as having two bundles, an Anteromedial (AM) and a Posterolateral (PL) bundle (Beasley, 2005; Ferretti, Ekdahl, Shen, & Fu, 2007; Zantop, et al., 2005). The function of the two bundles and the resulting tension placed on each bundle differs throughout various ranges of motion. The PL bundle is under the most stress when the knee is in full extension, conversely the AM bundle is under the highest amount of stress when the knee is in a position of flexion (Zantop, et al., 2005; Zantop, et al., 2006).

Ferretti, et al., (2007) observed the femoral attachment of the ACL histologically, arthroscopically, and grossly. The author's findings indicate two distinct ridges that outlined the femoral attachment of the ACL, the lateral intercondylar ridge and the lateral bifurcate ridge (Ferretti, et al., 2007). With the axis of the femur in a position parallel to the floor, the lateral intercondylar ridge forms the superior border of the femoral ACL attachment and runs proximo-distal along the entire ACL attachment. The lateral bifurcate ridge divides the anterior portion of the AM and PL femoral attachments, running in an antero-posterior direction (Ferretti, et al., 2007). The ACL fans out into a circular pattern over the femoral attachment with an average area of 113 to 153 mm2 (Ferretti, et al., 2007; Harner, et al., 1999). The tibial attachment of the ACL resembles a shape of a footprint. This unique shape allows the anterior fibers of the ACL to tuck under the anterior edge of the intercondylar notch when the knee is in full extension, known as "physiological impingement" (Luites, Wymenga, Blankevoort, & Kooloos, 2007; Zantop, et al., 2006). The average area of the tibial attachment of the ACL is 136 mm2. Harner et al., (1999) analyzed the area of the ACL insertion sites and found the tibial and femoral insertions to be 3.5 times larger then the midsubstance of the ACL (Harner, et al., 1999).

The proximal portion of the ACL is supplied by blood vessels from the middle geniculate artery, where as the distal portion of the ACL is supplied by vessels from the inferior geniculate artery (Petersen & Hansen, 1997; Zantop, et al., 2006). The synovial tissue that surrounds the ACL receives its blood supply from both geniculate arteries (Petersen & Hansen, 1997). The most common neural structures found in the ACL are Ruffini receptors, free nerve-endings, and Pacini receptors (Hogervorst & Brand, 1998). Ruffini receptors function as stretch receptors, free nerve endings primarily function as nociceptors, and Pacini receptors are mainly activated by compression (Hogervorst & Brand, 1998).

Epidemiology of Anterior Cruciate Ligament Injury

Injury to the Anterior Cruciate Ligament (ACL) is one of the most common sports related injuries (Yu & Garrett, 2007). An estimated 80,000 to more than 250,000 ACL injuries occur each year, many of which happen in young athletes age 15 to 25 (Griffin, et al., 2006). When analyzing ACL injury rates in intercollegiate athletics, Women's Basketball, Men's Lacrosse, and Football were observed to have the highest ACL injury rate (Mountcastle, et al., 2007). Hewett, et al., (1999) estimated 10,000 knee injuries occur each year in female athletes at the collegiate level, of those 10,000 knee injuries 2,200 are expected to be ACL ruptures (Hewett, et al., 1999). The negative physical, mental, emotional, and economic effects of ACL injury has initiated a vast amount of research into the associated risk factors (Gilchrist, et al., 2008). The negative physical effects of ACL injury include early onset of osteoarthritis, damage to menisci and chondral surface, increase probability of additional surgery, and decreased activity level due to functional instability (Maletius & Messner, 1999; Yu & Garrett, 2007). A variety of different emotions are present following ACL injury and ACL reconstruction. Carson & Polman, (2008) found the following motions to be present following ACL reconstruction; anger, sense of helplessness, feeling of uselessness, loss of independence, frustration, and depression. Maletius and Messner (1999) performed at 20 year follow up study of surgically repaired ACL ruptures and found 87% of the patients had signs of osteoarthritis upon radiographic examination (Maletius & Messner, 1999). Of the 56 subjects assessed, 25 (45%) had undergone additional surgery. Following surgery and full rehabilitation 40 of the 55 patients (73%) were satisfied with their knee function, 20 year follow up revealed that only 13 of 55 patients (23%) were still completely satisfied with their knee function. The authors also found an increase in severity and incidence of radiographic changes (osteoarthritis) when ACL injury was combined with meniscectomy at the initial surgery. In the US an estimated 646 million dollars is spent annually on ACL surgery and rehabilitation for female athletes (Hewett, Myer, & Ford, 2005).

Anterior Cruciate Ligament Mechanism of Injury

Mechanisms of ACL injury can be grouped into two categories, contact and non-contact. Contact ACL injuries are a result of a direct blow to the lower extremity. Non-contact ACL injuries have a variety of mechanisms, a common mechanism includes a sudden deceleration prior to a change in direction or landing motion (Olsen, et al., 2004). Lower extremity joint position during non-contact ACL injuries typically involve the foot being firmly planted on the ground, knee near full extension in a abducted position, femur typically internally rotated, and tibia in a position of external rotation (Boden, et al., 2000; Hewett, Myer, & Ford, 2005; Olsen, et al., 2004; Yu & Garrett, 2007). A study done by Krosshaug, et al., (2007) analyzed videotape of a variety of ACL injuries. The authors found that while the majority of injuries did not involve contact at the point of injury, an opponent perturbed the movements of the injured players, for example a push or contact during a rebound (Krosshaug, et al., 2007). Mihata, et al., (2006) further categorized non-contact ACL injuries into minimal-contact injuries. Minimal-contact ACL injury is defined as injuries sustained while attempting to avoid contact or while being distracted by potential contact with another player (Mihata, et al., 2006). Minimal-contact ACL injuries are of interest because perturbations or distractions caused by opponents could result in losing control of one self, resulting in the ACL injury.

Risk Factors of Anterior Cruciate Ligament Injuries

Risk factors associated with non-contact ACL injuries typically fall under one of four categories, anatomic, hormonal, environmental, and neuromuscular (Boden, et al., 2000). When comparing males to females in the above categories, females seem to be predisposed to an increased risk of ACL injury regardless of the risk factor.

Anatomical risk factors

Anatomic risk factors include lower limb malalignment, quadriceps femoris angle (Q-angle), static and dynamic knee valgus, femoral notch width, eminence width index, notch width/eminence width index, ACL size, knee joint laxity, and muscle flexibility (Boden, et al., 2000; Griffin, et al., 2006; Hughes & Watkins, 2006; Uhorchak, et al., 2003). An increased Q-Angle common in female athletes, typically increases knee valgus angle, which could place the ACL at an increased risk of injury (Boden, et al., 2000; Hughes & Watkins, 2006). Hewett, Myer, Ford, et al., (2005) found that females who had sustained an ACL injury demonstrated significant increases in dynamic lower extremity valgus and knee abduction loading. Dynamic valgus was defined as the position of motion in which the distal femur moved toward and the distal tibia moved away form the midline of the body, the above motion was a result of a combination of knee abduction moment and knee abduction angle (Hewett, Myer, Ford, et al., 2005). Hewett, Myer, et al., (2006) stated that dynamic lower extremity knee valgus is a combination of motions and rotations at all 3 lower extremity joints. Dynamic lower extremity knee valgus potentially includes hip adduction and internal rotation, knee abduction, tibial external rotation and anterior translation, and ankle eversion (Hewett, Myer, et al., 2006). Hughes & Watkins, (2006) defined the valgus angle using the Q-angle, one axis was the line from the ASIS to the patella and the other axis was the line bisecting the patella to the tibial tubercle (Hughes & Watkins, 2006). Hewett, Myer, Ford, et al., (2005) found increased knee abduction angles and increased knee abduction moments to be a predictor of ACL injury in female athletes. The authors specifically found knee abduction moment to predict ACL injury with a specificity of 73% and sensitivity of 78%. When comparing knee abduction angles at initial contact from a drop jump, females who went on to have an ACL injury had 8.4 degrees greater knee abduction angle (Hewett, Myer, Ford, et al., 2005). Ford, Myer, & Hewett, (2003) examined knee valgus angle in male and female high school athletes performing a vertical jump landing, results showed that females displayed a greater maximum knee valgus angle compared to males. Ford, et al., (2003) and Uhorchak, et al., (2003) examined radiographic images of males and females and evaluated the condylar width, femoral notch width, tibial width, and tibial eminence width (Ford, Myer, & Hewett, 2003; Uhorchak, et al., 2003). The eminence width is the distance between the two tibial eminences, the eminence width index describes the estimated size of the ACL in relation to the size of the tibia. The notch width/eminence width index attempts to describe the relationship between the size of the ACL and the area in which it is accommodated, being the femoral notch width. Subjects sustaining and ACL injury as opposed to uninjured subjects, were found to have decreased femoral notch width, decreased eminence width, and decreased notch width/eminence width index. A comparison on females to males sustaining an ACL injury found females to have decreased femoral notch width, decreased eminence width, and decreased notch width/eminence width index (Uhorchak, et al., 2003). The overall effect of femoral notch width, eminence width, and notch width/eminence with index concludes that subjects sustaining ACL injury and females seem to have a decreased amount of space for their ACL to function out of. Chandrashekar, Slauterbeck, & Hashemi, (2005) examined gender differences in the tensile properties of the ACL (Chandrashekar, Slauterbeck, & Hashemi, 2005). Their results found the structural properties of the female ACL to be weaker, female ACL's offer less resistance during straining, and fail at lower stress levels when compared to males. Uhorchak, et al., (2003) measured knee joint laxity of males and females using a KT-2000 arthrometer at various loads. Results showed increased laxity when comparing females to males, injured (subjects sustaining noncontact ACL injury) to uninjured, injured males to uninjured males, and injured females to uninjured females.

Hormonal risk factors

The increased risk of females sustaining ACL injury has brought up research concerning the circulating hormones of the female menstrual cycle and the effect each has on the ACL. Current research has yielded conflicting and unreliable results due to the small sample size of subjects being assessed, limiting testing to a specific day or days of the menstrual cycle, lack of hormone confirmation to define cycle phase, lack of comparison between sexes, and inconsistent definition of the phase of the menstrual cycle (Griffin, et al., 2006; Hughes & Watkins, 2006).

Environmental risk factors

Environmental Factors include shoe-surface interaction, bracing, and meteorological conditions (Griffin, et al., 2006; Hewett, Myer, et al., 2006). Shoe-surface interaction refers to the amount of friction present between the athletes shoe and the playing surface. Olsen, et al., (2004) examined ACL injuries in team handball, their results found an increased risk of ACL injury for women on the artificial floor when compared to the wooden floor (Olsen, et al., 2004). Another study examined the friction coefficient of the artificial and wooden floors, the artificial floors were found to have a higher coefficient of friction when compared to the wooden floors (Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2003).

Neuromuscular risk factors

Malinzak, et al., (2001) stated that of all the intrinsic and extrinsic risk factors rick factors of ACL injury, altered neuromuscular control strategies and movement parameters were the most likely to contribute to the increased incidence of non-contact ACL injury for female athletes (Malinzak, et al., 2001). Hewett, Myer, Ford, et al., (2005) suggested that increased knee abduction motion and moments demonstrated in females before ACL injury, is a result of decreased neuromuscular control of the lower extremity in the coronal plane. Neuromuscular risk factors include antagonist-agonist relationships, altered biomechanical movement patterns, altered muscle activation patterns, inadequate muscle stiffness, and fatigue (Griffin, et al., 2006; Hewett, Myer, et al., 2006; Hughes & Watkins, 2006; Yu & Garrett, 2007). Antagonist-agonist relationship refers to the co-contraction of the hamstring and quadriceps muscle group. The antagonist muscle in this relationship refers to the quadricep muscle group, and the agonist refers to the hamstring muscle group (Boden, et al., 2000; Hughes & Watkins, 2006). Muscular co-contraction increases joint compression, which allows more of the knee abduction/valgus load to be absorbed by articular contact forces in the knee (Hewett, Myer, Ford, et al., 2005). Muscle power and recruitment patterns between the quadriceps and hamstrings are crucial in maintaining functional knee stability (Boden, et al., 2000). Females have been found to have increased quadriceps activation and decreased hamstring activation during jumping and cutting tasks when compared to their male counterparts (Chappell, et al., 2007; Malinzak, et al., 2001). Chappell, Yu, Kirkendall, & Garrett, (2000) found female recreational athletes to have increased proximal tibia anterior shear force when compared to males during the landing phase of a stop jump task (Kirkendall & Garrett, 2000). Chappell, et al., (2007) analyzed male and female landing characteristics during the landing phase of a jump. The authors found females landed in a more extended position, specifically less hip and knee flexion, when compared to males (Chappell, et al., 2007). Yu & Garrett, (2007) found the quadriceps muscle to be the major contributor of anterior shear force at the proximal end of the tibia, via the patellar tendon (Yu & Garrett, 2007). The patellar tendon-tibia shaft angle, is the angle formed between the long axis of the tibia and the line of action of the patellar ligament (Hughes & Watkins, 2006). Contraction of the quadriceps pulls on the patellar tendon causing an anterior shear force on the proximal end of the tibia. This angle becomes larger when the knee is near full extension, and an increased patellar tendon-tibia shaft angle results in an increased anterior shear force on the proximal end of the tibia (Hughes & Watkins, 2006; Yu & Garrett, 2007). Besier, et al., (2001) examined knee joint loading during anticipated and unanticipated cutting tasks, the authors found the external valgus moment to increase when performing unanticipated cutting tasks (Besier, et al., 2001).

Gender disparity associated with noncontact ACL injury

Research on the implications of gender and ACL injury, continue to reveal an increased incidence in females sustaining noncontact ACL injury (Agel, et al., 2005; Hewett, Ford, & Myer, 2006; Mihata, et al., 2006; Mountcastle, et al., 2007; Uhorchak, et al., 2003). A study done by Bjordal, Frode, Arnoy, Hannestad, & Strand, (2007) found that junior level girls, age 15-18, were 5.4 times more likely to have an ACL injury when compared to males of the same age (Bjordal, Arnly, Hannestad, & Strand, 1997). Arendt & Dick, (1995) found ACL injury rate for women to be 4.1 times that of males, with females 3 times more likely to have non-contact injury as males (Arendt & Dick, 1995). Agel, et al., (2005) found 67% of female ACL injuries to be non-contact when compared to only 58% of males having a non-contact ACL injury (Agel, et al., 2005). Uhorchak, et al., (2003) found the mechanism of ACL injury to be non-contact in 83% of the cases (Uhorchak, et al., 2003). Mountcastle, et al., (2007) examined West Point injury data from 1994-2003 and found that 89.4% of ACL injuries incurred by females were non-contact, and 67.2% incurred by males were non-contact (Mountcastle, et al., 2007).

Fatigue – effects on ACL injury and lower extremity kinematics and Kinetics

Current research continues to implicate fatigue as a risk factor leading to the increase in incidence of noncontact ACL injury (Hewett et al., 2006; Kernozek et al., 2008; Griffin et al., 2006; Borotikar et al., 2008; Chappell et al, 2005; Benjaminse et al., 2008; Sanna et al., 2008). Fatigue is defined as any exercise-induced reduction in the ability of a muscle to generate force or power, which includes both peripheral and central contributions (Gandevia, 2001). Central fatigue refers to the progressive decline in voluntary activation of a muscle during exercise (Gandevia, 1996). Central fatigue encompasses changes at any or all sites in the pathway from the motor cortex to the neuromuscular junction (Gandevia, 1996). A subset of central fatigue, supraspinal fatigue refers to the failure to generate maximal output from the motor cortex (Gandevia, 2001; Taylor & Gandevia, 2008). Gandevia, Allen, Butler, & Taylor, (1996) examined the effects of transcranial magnetic stimulation of the motor cortex during a maximal voluntary contraction. The authors found that such stimulation resulted in a superimposed twitch, indicating even at maximal voluntary contraction motor cortical output is not optimal (Gandevia, Allen, Butler, & Taylor, 1996). Peripheral fatigue is a decrease in the muscles ability to generate force, which occurs at or distal to the neuromuscular junction (Gandevia, 2001).

Neuromuscular fatigue has been shown to negatively affect knee motions and loads, causing altered landing characteristics consistent with non-contact ACL injury mechanisms (Kernozek, et al., 2008; McLean, et al., 2007). Specifically, fatigue has been shown to alter various biomechanical parameters including: increased peak proximal tibial anterior shear force (Chappell, et al., 2005), increased knee abduction and knee internal rotation moments (McLean, et al., 2007; McLean & Samorezov, 2009), decreased knee flexion angle (Chappell, et al., 2005; McLean & Samorezov, 2009), increased hip internal rotation moment (Mclean & Samorezov, 2009). When comparing genders across fatigued states, females were found to have increased hip flexion, larger peak valgus angle and maximum knee valgus angle, decreased knee flexion, greater knee extension moment, and higher peak proximal tibial anterior shear force (Chappell, et al., 2005; Kernozek, et al., 2008; McLean, et al., 2007).

Recent research has examined the combined effects fatigue and decision making have on ACL injury (Mclean & Samorezov, 2009). Specifically the research observed the effect of fatigue on anticipated and unanticipated landing/cutting tasks. The unanticipated tasks, which combine an open environment (similar to a game situation) and fatigue, were found to illicit the largest changes in lower extremity biomechanics. Kinematic results showed an increase in hip internal rotation, knee abduction, and knee internal rotation, as well as decreased hip flexion when compared to the anticipated tasks. Kinetic results found hip internal rotation moment, knee flexion moment, knee abduction moment, and knee internal rotation moment to be larger when comparing unanticipated to anticipated tasks (Mclean & Samorezov, 2009).

CHAPTER III

METHODOLOGY

A quasi-experimental design consisting of pre-fatigue baseline measures, immediate post-fatigue measures, and a one-week counterbalanced post second-fatigue measure was conducted. The fatigue protocols (SLO-FP and FAST-FP) were counter-balanced between subjects. Biomechanical baseline measures were taken at pre-fatigue condition while the subjects performed a running stop task. After these measures, the subjects underwent the assigned fatigue protocol for that session. Immediately following the fatigue protocol, post-fatigue biomechanical measures were obtained once again. They returned one week after to perform the second fatigue protocol. Independent variables were: fatigue protocol, which had two levels, slow linear oxidative (SLO-FP) and functional agility short-term (FAST-FP); and time, which had two separate levels, pre and post-fatigue. The dependent variables were split into kinematic and kinetic variables. The kinematic variables (all measured in degrees) were knee flexion, knee abduction, knee rotation, hip flexion, hip abduction, and hip rotation. The kinetic variables were vertical ground reaction force, posterior ground reaction force (both measured in multiples of body weight (mBw), knee flexion/extension moment, knee adduction/abduction moment, and hip abduction/adduction moment (all moments normalized to mass and height $Nm.kg^{-1}.m^{-1}$).

Subjects

An *a priori* power calculation was conducted to estimate the sample needed to establish differences between athletic tasks. Using data from the literature (Borotikar, et al., 2008; Chappell, et al., 2005; McLean, et al., 2007) for a power level of 80% and an alpha level of 0.05, a necessary sample size of approximately 15 subjects was required. A sample of convenience of fifteen NCAA Division I female soccer players (age = 19.2 ± 0.8 years; height = 1.67 ± 0.05 m; mass = 61.7 ± 8.1 kg) volunteered to participate in this study, previous injury demographics shown in figure 1. Criteria for inclusion for NCAA Division I female soccer players involved no previous history of cardiovascular or respiratory disease, and all subjects had to be cleared by the team physician for practice and games at the moment of data collection. Demographics pertaining to past injuries, and years of experience were obtained. The dominant leg, defined as the leg that the participant would use to kick a soccer ball as far as possible, was used for analysis. Prior to data collection, approval of the research through Institutional Review Board, and written informed consent for all subjects was obtained.

Table 1. Injury Demographic Table

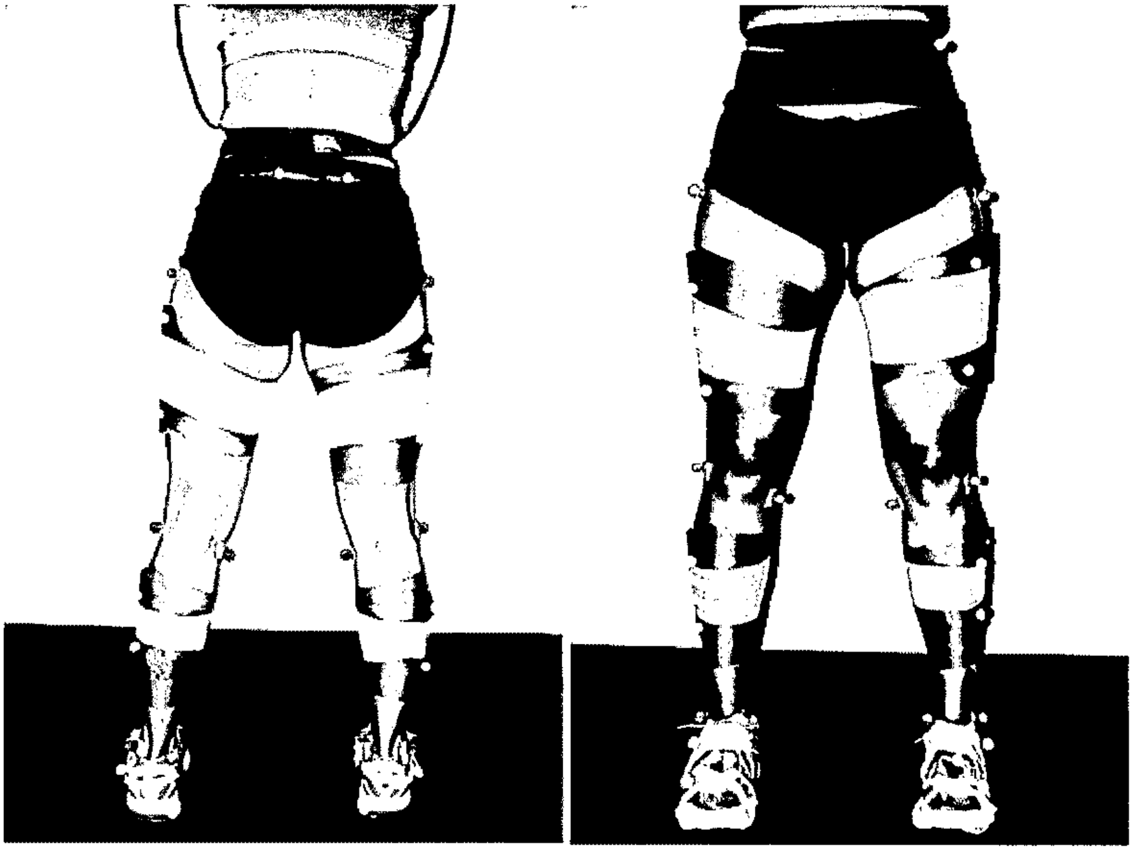
Injury	**Number of Injuries**
Left Ankle Sprains	2
Right Ankle Sprains	1
Both Ankle Sprains	10
Ankle Surgeries	0
Left Hamstring Strains	0
Right Hamstring Strains	2
Both Hamstring Strains	0
Hamstring Surgeries	0
Left ACL Sprains	2
Right ACL Sprains	1
Both ACL Sprains	1
ACL Surgeries	5

Instrumentation

Eight high-speed video cameras (Vicon Motion Systems Ltd., Oxford, England) were used to monitor the motion analysis of the lower extremity, with a sampling rate of 270 Hz. Two Bertec Force Plates, Model 4010 (Bertec Corporation, Columbus OH, USA) with a sampling rate of 1080 Hz were used to measure ground reaction forces. SensorMedics Vmax 29c metabolic cart (Yorba Linda, CA) was used during the SLO fatigue protocol to measure submaximal O_2 consumption and VO_{2peak}. The flow sensor was calibrated against a 3.0 L syringe and CO_2 and O_2 sensors were calibrated against known gases prior to the VO_2 max test. The flow sensor and mouthpiece were attached to a headset, which was used to collect expired air. VO_{2peak} was calculated as the average of the three highest, continuous 20-second interval VO_2 measurements. A Polar heart rate monitor was used to collect resting and exercise heart rate measurements during all testing

Subjects reported to the Motion Analysis Laboratory and filled out a demographic questionnaire and signed the informed consent form once they agreed to participate. The Subjects wore spandex shorts and a sports bra. They used the team running shoes that were provided at the beginning of the season (Adidas Supernova, AG, Herzogenaurach, Germany). The subjects were given a 10-minute warm-up period, consisting of cycling and self-directed stretching. After the warm-up period and stretching, forty reflective markers were placed on specific body landmarks. From those forty, ten were calibration markers, which included greater trochanters, medial and lateral knee, medial and lateral malleoli (Figure 1). The other thirty markers were tracking markers consisting of posterior superior iliac crest, anterior iliac crest, four maker clusters for the thighs and shanks, and five markers on each foot. A standing trial and a dynamic trial to calculate hip joint center were obtained. After those trials, the calibration markers were removed.

Figure 1 – Picture of subject with reflective markers



After explanation of the athletic tasks the subject was given time to practice each one. A light beam was placed across the platform where the subjects were running and 2 meters prior to the force plates. When the subjects' crossed and interrupted the light beam it triggered a software program on the desktop to randomly generate the athletic task and project it onto a screen in front of the subjects. The unanticipation factor and the environment allowed mimicking as much as possible a soccer athletic task. A Brower timing system (Brower Timing Systems, Draper UT, USA) was used to control the approach speed. The subjects had an approach speed of $3.6 \pm .19$ $m.s^{-1}$ pre-SLO-FP, $3.5 \pm .14$ $m.s^{-1}$ post-SLO-FP, $3.6 \pm .12$ $m.s^{-1}$ pre-FAST-FP, and $3.5 \pm .12$ $m.s^{-1}$ post-FAST-FP. The running-stop task consisted of the subjects standing on the beginning of the platform, running and planting onto the force plates with one foot on each force plate and jumping straight into the air as if performing a soccer header. Prior to data collection, the subjects had three trials to practice or until they felt comfortable with the task. The subjects were required to perform five successful trials. There was a 1-minute rest period between trials to minimize fatigue during pre-fatigue assessment.

From the standing (static) trial, a full body kinematic model was created for each participant using Visual 3D (C-Motion, Rockville MD, USA). This kinematic model was used to quantify the motion at the hip, knee, and ankle joints. The standing trial with circular motion of the pelvis was used to estimate a functional hip joint center (Begon, Monnet, & Lacouture, 2007; Schwartz & Rozumalski, 2005). Based on a power spectrum analysis, marker trajectory was filtered with a fourth-order Butterworth zero lag filter with a 7 Hz cutoff frequency and the ground reaction force data were filtered with a similar filter with a 25 Hz cutoff frequency.

Pre-Fatigue

Subjects performed 5 successful trials of a running stop task. Testing trials were repeated if the subject did not land completely on the force plate, or were unable to execute the trials at a minimum speed of 3.5 $m.s^{-1}$. During the pre fatigue data collection subjects had an average of 4.5±3.7 missed trials in order to complete the five successful trials. After completion of the 5 successful unanticipated trials, the subjects received instructions about the fatigue protocol to be performed.

Fatigue Protocols

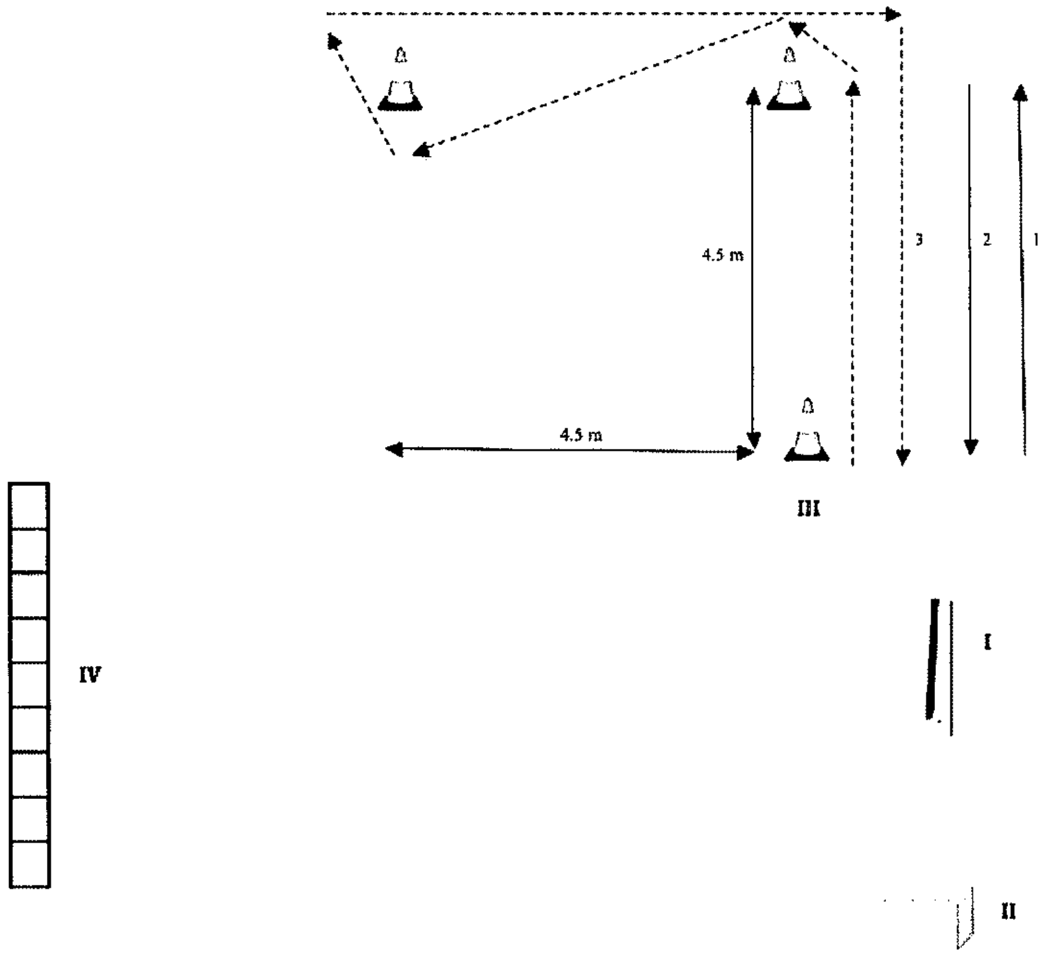
The fatigue protocols created for this study were based on previous research, however, various aspects of each protocol are unique to this study. The FAST-FP utilized tasks from previous research including the vertical jumps (Chappell et al., 2005) and the step-ups (Mclean et al., 2007). To our knowledge the L-Drill and agility ladder have not been previously used for the purposes of inducing neuromuscular fatigue, both of these activities were chosen based on the functional demands of soccer. The VO_2 max protocol used in the SLO-FP was based on previous research by (Flouris, et al., 2004; Metsios, Flouris, Koutedakis, & Theodorakis, 2006). The 30-minute treadmill run was based on the fatigue protocol previously done by Sanna & O'Connor, 2008.

Functional Agility Short-Term Fatigue Protocol (FAST-FP)

Before beginning the FAST-FP, the subjects maximum vertical jump was taken by one of the investigators using a measuring tape set up on the wall. An average of 3 maximal jumps was recorded as the subjects max vertical jump for the protocol.

Subjects began the fatigue protocol by performing a series of step-up and down movements onto a 30-cm height box for 20 seconds, following a metronome set to 220 bpm. The subject had to perform the steps at the rhythm of the metronome. Then the subjects immediately performed 1 repetition of the "L-drill" between 3 cones. Subjects started in a three-point stance in front of three cones that were set up in an L shape, with each cone 4.5 yards apart. They sprinted 4.5 yards to one cone, sprinted back to the starting cone, and then headed back to the second cone where they ran around it and cut right to the third cone. Subjects then ran in a circle around the third cone from the inside to the outside and ran around the second cone before running to the first cone. A schematic of the set-up is presented in figure 2. Immediately following the "L-drill", subject performed 5 consecutive counter-movement jumps staying within 18-22% of their max vertical jump recorded prior to the start of the protocol. Following the vertical jumps, the subjects then ran down and back on an agility ladder. The first and third time the protocol was completed the subject ran in the forward direction making sure that both feet touched inside each space of the ladder. The second and fourth time the protocol was completed the subject went sideways making sure to touch both feet inside the space of the ladder. The metronome was also used for the ladder drill and set at 220 bpm so that the subject would maintain a constant speed throughout the protocol. Completing the four tasks (step-ups and down, L drill, vertical jumps, and ladder drill) counted as one set of the protocol. Subjects had to perform four sets of the protocols with no rest in between, which took approximately 5 minutes per subject.

Figure 2 – Schematic of the FAST-FP.



1=vertical Jump, 2=30 cm step-up box, 3=L-drill, and 4=ladder drill.

Slow Linear Oxidative Fatigue Protocol (SLOW-FP)

The subjects were instructed to put running shorts on over the tracking markers and place skin lube on areas that may rub and cause irritation during a prolonged run. The protocol was explained to the subject and the subject's were fitted with the mouthpiece and headset, which they were required to wear for the VO_2 max test. Subjects began the fatigue protocol by performing a VO_2 max test. The protocol used for the VO_2 max test required the subjects to run at 9km/hr for five minutes, followed by 1km/hr speed increments every two minutes until exhaustion. When the subjects felt as though they were exhausted and could no longer continue running they were instructed to grab the sides of the treadmill, at that point the investigator slowed down the treadmill to a walk. The subjects were considered to be maximally fatigued when two of the four following criteria were met: 1) subject's heart rate reached 90% of their age calculated max heart rate, 2) respiratory quotient greater than 1.1, 3) plateau in the VO_2 max curve, and 4) the subject was unable to continue running. The treadmill gradient was kept at 0° for the entire VO_2 max test. Following the VO_2 max test, the subjects were given a 5-minute rest period. During the 30-minute treadmill run the subjects were required to alternate speeds. Six intervals consisting of running at a speed of 70% of their final VO_2 max speed for 4 minutes, followed by running for 1 minute at 90% of their VO_2 max speed were conducted.

Post-Test Fatigue Assessment

Following each fatigue protocol, the subjects had to complete five successful unanticipated trials of the running stop jump. During the post fatigue data collection subjects had an average of 4.6±3.3 missed trials in order to complete the five successful trials. Following each trial, the subject ran back to the start and immediately performed another trial until all trials had been successfully completed. On days when subjects were completing the FAST-FP, they were required to complete 3 vertical jumps in between each dynamic trial in order to maintain fatigue throughout the post-test fatigue assessment.

Statistical Analysis

Case-wise diagnostics were performed to assess data normalcy. Pre-fatigue conditions (slow linear oxidative vs. functional agility short-term) were compared with a paired *t*-test to assess baseline assumption for possible comparison for post-fatigue conditions between the SLO-FP and FAST-FP.

Fatigue state (FAST-FP or SLOW-FP) and time (Pre or Post) were treated as independent variables. A 2 (fatigue protocol) x 2 (time) factor repeated measures analysis of variance (ANOVA) was conducted for each dependent variable at each time instant. Alpha level was set *a priori* at 0.05. The dependent variables used in this study included: vertical and posterior ground reaction forces, knee flexion, knee abduction, knee rotation, knee flexion-extension moment, knee abduction-adduction moment, hip flexion, hip abduction, hip rotation, hip flexion moment, and hip abduction moment. These variables were measured at different time instants that included: initial contact, peak vertical and posterior ground reaction forces, peak knee flexion, and peak stance.

Data were analyzed between initial contact and maximum knee flexion, which defines the stop-jump phase. All data were reduced using a custom made Matlab 6.1

(The MathWorks, Inc, Natick MA, USA) software program and Visual 3-D (C-Motion Inc., Rockville MD, USA) to export into a Microsoft Excel spreadsheet. Each of the five trials were averaged and exported into SPSS version 16.0 (SPSS Inc, Chicago IL, USA) for data analysis.

CHAPTER IV

RESULTS

Initial Contact

Descriptive statistics are presented in tables 1, 2, 3 and 4. There was a statistically significant interaction between protocol and fatigue condition for knee rotation at initial contact ($F_{1,14}$=7.025, *p*=0.019). Pairwise comparison determined there was a significant increase in knee rotation post FAST-FP (11.92±9.84°) when compared to pre FAST-FP (7.89±7.77°), *p*=0.019, *d*=.41. There were no statistically significant main effects for protocol ($F_{1,14}$ =.551, *p*=.470) or time ($F_{1,14}$=2.894, *p*=.111) for knee rotation at initial contact.

There was a statistically significant main effect between protocols for knee abduction moment ($F_{1,14}$=5.610, *p*=0.033). Pairwise comparison determined that during the FAST-FP subjects had increased internal varus/adduction moment (0.064±0.09Nm/Kgm) when compared with the SLO-FP (0.024±0.06Nm/Kgm), *p*=0.033, *d*=.44. There were no statistically significant main effect for time ($F_{1,14}$ =.578, *p*=.460) and no significant interaction ($F_{1,14}$=1.907, *p*=.189) for knee abduction moment at initial contact.

There was a statistically significant main effect between fatigue conditions for hip flexion ($F_{1,14}$=16.229, *p*=0.001). Pairwise comparison determine that the subjects were in significantly lower hip flexion at initial contact post fatigue (44.7±8.1°) when compared with pre fatigue (50.1±9.5°), *p*=0.001, *d*=.57. There were no statistically significant main effect for protocol ($F_{1,14}$ =.796, *p*=.387) and no significant interaction ($F_{1,14}$=1.495, *p*=.242) for hip flexion at initial contact.

There were no statistically significant main effects for protocol ($F_{1, 14}$=.632, *p*=.440), time ($F_{1, 14}$=.389, *p*=.543) and no significant interaction ($F_{1, 14}$=.276, *p*=.608) for posterior ground reaction force at initial contact; no statistically significant main effects for protocol ($F_{1, 14}$ .054, p=.819), time ($F_{1, 14}$=4.332, p=.056) and no significant interaction ($F_{1, 14}$=1.764, p=.205) for knee flexion at initial contact; no statistically significant main effects for protocol ($F_{1, 14}$=2.312, p=.151), time ($F_{1, 14}$=.517, p=.484) and no significant interaction ($F_{1, 14}$=1.158, p=.300) for knee abduction at initial contact; no statistically significant main effects for protocol ($F_{1, 14}$=.001, p=.971), time ($F_{1, 14}$=.152, p=.703) and no significant interaction ($F_{1, 14}$=1.539, p=.235) for knee flexion moment at initial contact; and no statistically significant main effects for protocol ($F_{1, 14}$=.554, p=.469), time ($F_{1, 14}$=1.901, p=.190) and no significant interaction ($F_{1, 14}$=.030, p=.864) for hip abduction at initial contact.

Table 2. Descriptive Statistics for Kinematic Variables for SLO-FP.

	SLO-FP					
	Pre test			Post Test		
	Mean	SD	95% CI	Mean	SD	95% CI
Initial Contact						
Knee Flexion(-)/Extension(+)	-27.4	8.5	-32.1, -22.7	-24.5	9.2	-29.6, -19.4
Knee Abduction(-)/Adduction(+)	-0.9	3.2	-2.7, 0.8	-1.0	3.9	-3.1, 1.2
Hip Flexion	50.3	10.5	44.4, 56.1	46.5	6.6	42.9, 50.2
Hip Abduction(-)/Adduction(+)	-5.0	5.2	-7.9, -2.1	-5.6	4.6	-8.2, -3.1
PVGRF						
Knee Flexion(-)/Extension(+)	-39.1	5.1	-42.0, -36.3	-36.1	7.4	-40.2, -32.0
Hip Flexion	50.4	11.5	44.0, 56.8	46.9	7.3	42.9, 51.0
PPGRF						
Knee Flexion(-)/Extension(+)	-38.3	5.7	-41.5, -35.2	-36.6	7.8	-40.9, -32.3
Knee Abduction(-)/Adduction(+)	-0.4	4.7	-3.0, 2.1	-1.1	5.2	-4.0, 1.8
Hip Flexion	51.3	12.0	44.6, 58.0	46.9	7.3	42.8, 50.9
PKF						
Knee Flexion(-)/Extension(+)	-55.9	7.8	-60.3, -51.6	-53.3	5.6	-56.4, -50.2
Knee Abduction(-)/Adduction(+)	-2.4	5.9	-5.7, 0.8	-3.7	6.2	-7.1, -0.2
Hip Abduction(-)/Adduction(+)	-1.8	4.1	-4.1, 0.5	-1.9	3.7	-3.9, 0.2
Hip Flexion	44.6	12.8	37.5, 51.7	40.5	7.6	36.3, 44.8
Peak Stance						
Hip Flexion	53.3	11.9	46.7, 59.9	49.1	6.7	45.4, 52.8
Knee Abduction(-)/Adduction(+)	-4.6	3.9	-6.7, -2.4	-5.5	5.1	-8.3, -2.6

Table 3. Descriptive Statistics for Kinematic Variables for FAST-FP.

	FAST-FP					
	Pre test			**Post test**		
	Mean	SD	95% CI	Mean	SD	95% CI
Initial Contact						
Knee Flexion(-)/Extension(+)	-25.9	8.1	-30.4, -21.4	-25.2	9.1	-30.3, -20.2
Knee Abduction(-)/Adduction(+)	-1.3	4.2	-3.6, 1.0	-2.3	5.6	-5.5, 0.8
Hip Flexion	49.9	8.4	45.3, 54.6	42.9	9.6	37.7, 48.3
Hip Abduction(-)/Adduction(+)	-5.5	4.5	-8.0, -3.0	-6.4	5.8	-9.6, -3.2
PVGRF						
Knee Flexion(-)/Extension(+)	-38.4	5.0	-41.1, -35.6	-35.7	5.6	-38.6, -32.6
Hip Flexion	50.5	9.1	45.4, 55.6	42.5	9.5	37.2, 47.8
PPGRF						
Knee Flexion(-)/Extension(+)	-38.5	5.5	-41.5, -31.2	-34.9	6.7	-38.6, -31.2
Knee Abduction(-)/Adduction(+)	-1.8	5.1	-4.7, 1.0	-2.5	6.6	-6.2, 1.2
Hip Flexion	50.8	9.5	45.6, 56.1	43.4	9.9	38.0, 48.9
PKF						
Knee Flexion(-)/Extension(+)	-57.61	8.9	-62.5, -52.7	-51.6	10.1	-57.2, -46.1
Knee Abduction(-)/Adduction(+)	-5.2	5.3	-8.1, -2.3	-5.6	6.4	-9.2, -2.1
Hip Abduction(-)/Adduction(+)	-3.1	4.6	-5.7, -0.6	-4.4	4.7	-7.0, -1.8
Hip Flexion	45.6	10.4	39.9, 51.4	36.8	9.7	31.4, 42.2
Peak Stance						
Hip Flexion	53.3	10.0	47.8, 58.8	45.6	9.8	40.2, 51.0
Knee Abduction(-)/Adduction(+)	-6.1	4.9	-8.8, -3.4	-7.0	5.9	-10.2, -3.7

Table 4. Descriptive Statistics for Kinetic Variables for SLO-FP.

	SLO-FP					
	Pre test			Post Test		
	Mean	SD	95% CI	Mean	SD	95% CI
Initial Contact						
Knee Abduction(-)/Adduction(+) Moment	-0.006	0.28	-0.163, 0.151	-0.03	0.24	-0.163, 0.103
Knee Flexion(-)/Extension(+) Moment	0.08	0.21	-0.04, 0.196	0.02	0.15	-0.056, 0.106
PVGRF						
Vertical Ground Reaction Force	5.1	1.3	4.4, 5.8	5.2	1.1	4.6, 5.8
PPGRF						
Posterior Ground Reaction Force	1.9	0.5	1.6, 2.2	1.8	0.4	1.6, 2.0
PKF						
Posterior Ground Reaction Force	1.3	0.3	1.1, 1.4	1.3	0.3	1.1, 1.5
Peak Stance						
Knee Flexion(-)/Extension(+) Moment	2.09	0.33	1.915, 2.277	2.08	0.30	1.915, 2.251
Knee Abduction(-)/Adduction(+) Moment	0.34	0.16	0.258, 0.431	0.37	0.25	0.226, 0.508

Table 5. Descriptive Statistics for Kinetic Variables for FAST-FP.

	FAST-FP					
	Pre test			Post test		
	Mean	SD	95% CI	Mean	SD	95% CI
Initial Contact						
Knee Abduction(-)/Adduction(+) Moment	0.05	0.20	-0.063, 0.159	0.071	0.23	-0.055, 0.196
Knee Flexion(-)/Extension(+) Moment	0.04	0.18	-0.057, 0.129	0.06	0.23	0.064, 0.19
PVGRF						
Vertical Ground Reaction Force	4.6	1.2	4.0, 5.3	4.9	1.3	4.2, 5.7
PPGRF						
Posterior Ground Reaction Force	1.8	0.4	1.6, 2.0	1.8	0.3	1.6, 2.0
PKF						
Posterior Ground Reaction Force	1.2	0.4	1.0, 1.4	1.3	0.3	1.1, 1.4
Peak Stance						
Knee Flexion(-)/Extension(+) Moment	1.98	0.33	1.79, 2.151	1.92	0.39	1.704, 2.14
Knee Abduction(-)/Adduction(+) Moment	0.33	0.13	0.25, 0.401	0.41	0.22	0.285, 0.529

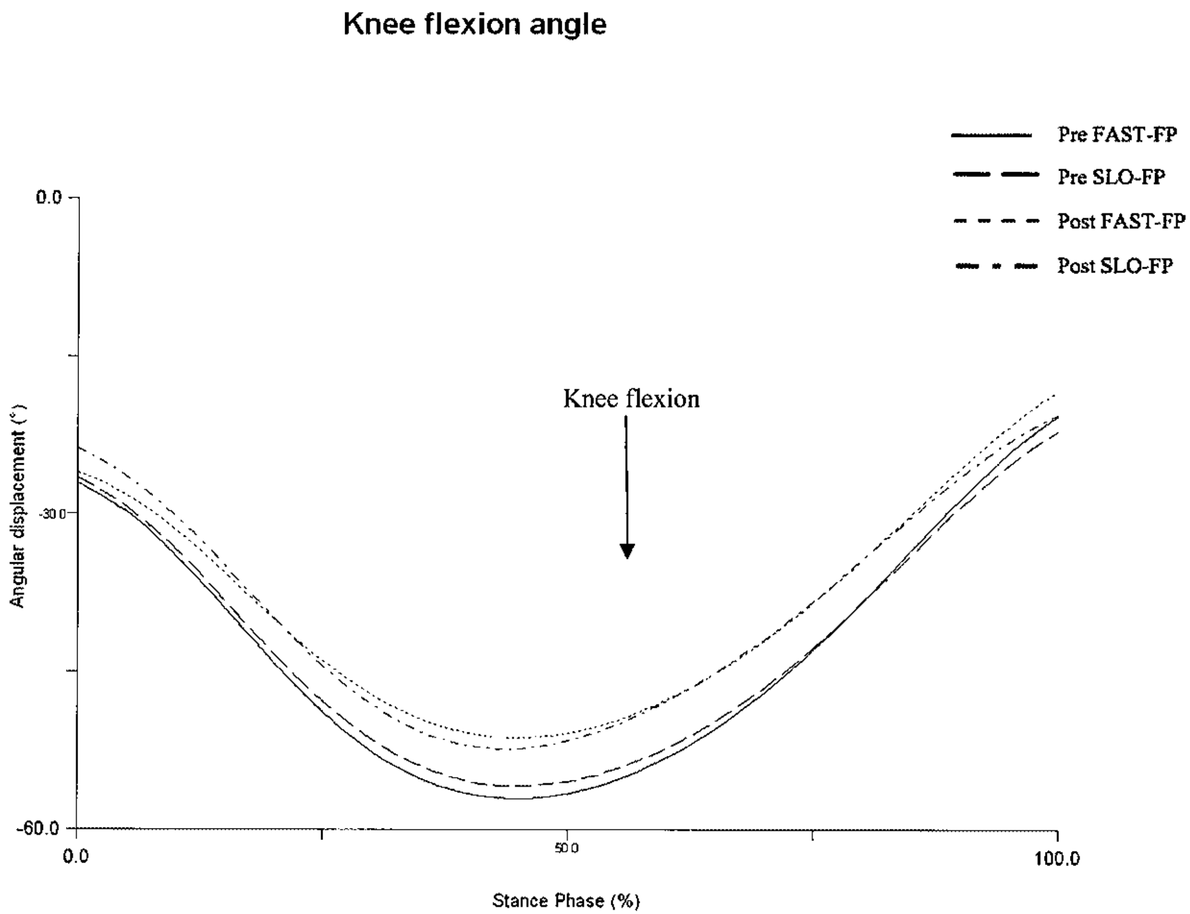
Peak Vertical Ground Reaction Force

There was a statistically significant main effect between fatigue conditions for hip flexion ($F_{1, 14}$=17.026, *p*=0.001). Pairwise comparison determine that the subjects were in significantly lower hip flexion at peak vertical ground reaction force post fatigue (44.7±8.4°) when compared with pre fatigue (50.4±10.3°), *p*=0.001, *d*=.55 (Figure 3). There were no statistically significant main effects for protocol ($F_{1, 14}$ =.934, *p*=.350) and no significant interaction ($F_{1, 14}$ =2.448, *p*=.140) for hip flexion at peak vertical ground reaction force.

There was a statistically significant main effect between fatigue conditions for knee flexion ($F_{1, 14}$=11.537, p=.004). Pairwise comparison determine that the subjects were in significantly lower knee flexion at peak vertical ground reaction force post fatigue (-35.7±6.5°) when compared with pre fatigue (-38.8±5.03°), *p*=0.001, *d*=.48. There were no statistically significant main effects for protocol ($F_{1, 14}$ =.160, *p*=.695) and no significant interaction ($F_{1, 14}$ =.033, *p*=.859) for knee flexion at peak vertical ground reaction force.

There were no statistically significant main effects for protocol ($F_{1, 14}$ =1.260, p=. 280), time ($F_{1, 14}$ =2.430, p=.141) and no significant interaction ($F_{1, 14}$ =.631, p=.440) for vertical ground reaction force at peak vertical ground reaction force; and no statistically significant main effects for protocol ($F_{1, 14}$ =1.877, p=.192), time ($F_{1, 14}$ =.523, p=.482) and no significant interaction ($F_{1, 14}$ =.360, p=.558) for knee abduction at peak vertical ground reaction force.

Figure 4 – Knee flexion angle during SLO-FP and FAST-FP (pre and post fatigue conditions) while performing a running-stop jump task



Peak Posterior Ground Reaction Force

There was a statistically significant main effect between fatigue conditions for knee flexion ($F_{1,14}$=9.300, p=.009). Pairwise comparison determined that the subjects were in significantly lower knee flexion at peak posterior ground reaction force post fatigue (-35.6±7.2°) when compared with pre fatigue (-38.4±5.6°), *p*=0.009, *d*=.39. There were no statistically significant main effects for protocol ($F_{1,14}$ =.314, *p*=.584) and no significant interaction ($F_{1,14}$ =.766, *p*=.396) for knee flexion at peak posterior ground reaction force.

There was a statistically significant main effect between fatigue conditions for hip flexion ($F_{1,14}$=18.533, p=.001). Pairwise comparison determine that the subjects were in significantly lower hip flexion at peak posterior ground reaction force post fatigue (45.2±8.6°) when compared with pre fatigue (51.1±10.8°), *p*=0.001, *d*=.55 (Figure 4). There were no statistically significant main effects for protocol ($F_{1,14}$ =.657, *p*=.431) and no significant interaction ($F_{1,14}$ =.816, *p*=.382) for hip flexion at peak posterior ground reaction force.

There were no statistically significant main effects for protocol ($F_{1,14}$ =.269, p=.612), time ($F_{1,14}$ =.135, p=.718) and no significant interaction ($F_{1,14}$ =.384, p=.546) for posterior ground reaction force at peak posterior ground reaction force (Figure 5).

Figure 5 – Hip flexion angle during SLO-FP and FAST-FP (pre and post fatigue conditions) while performing a running-stop jump task

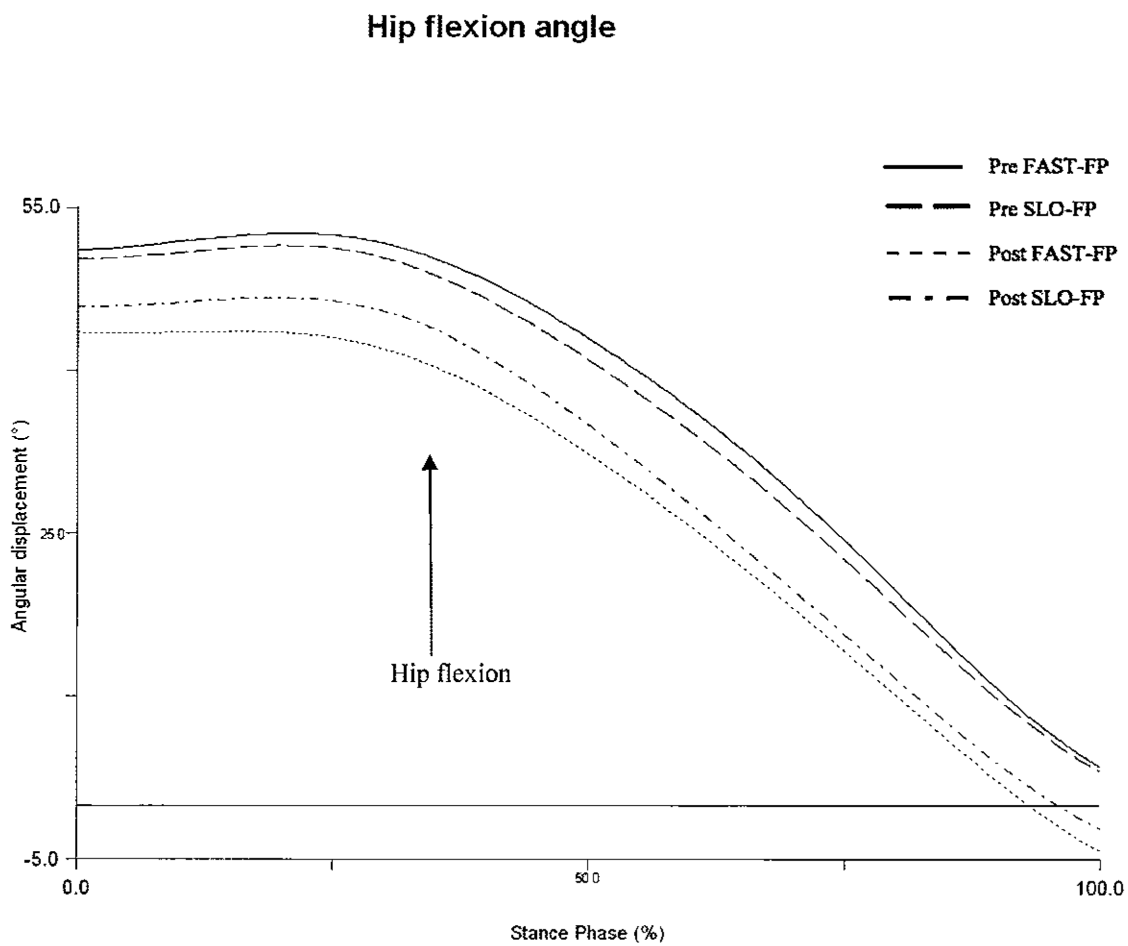
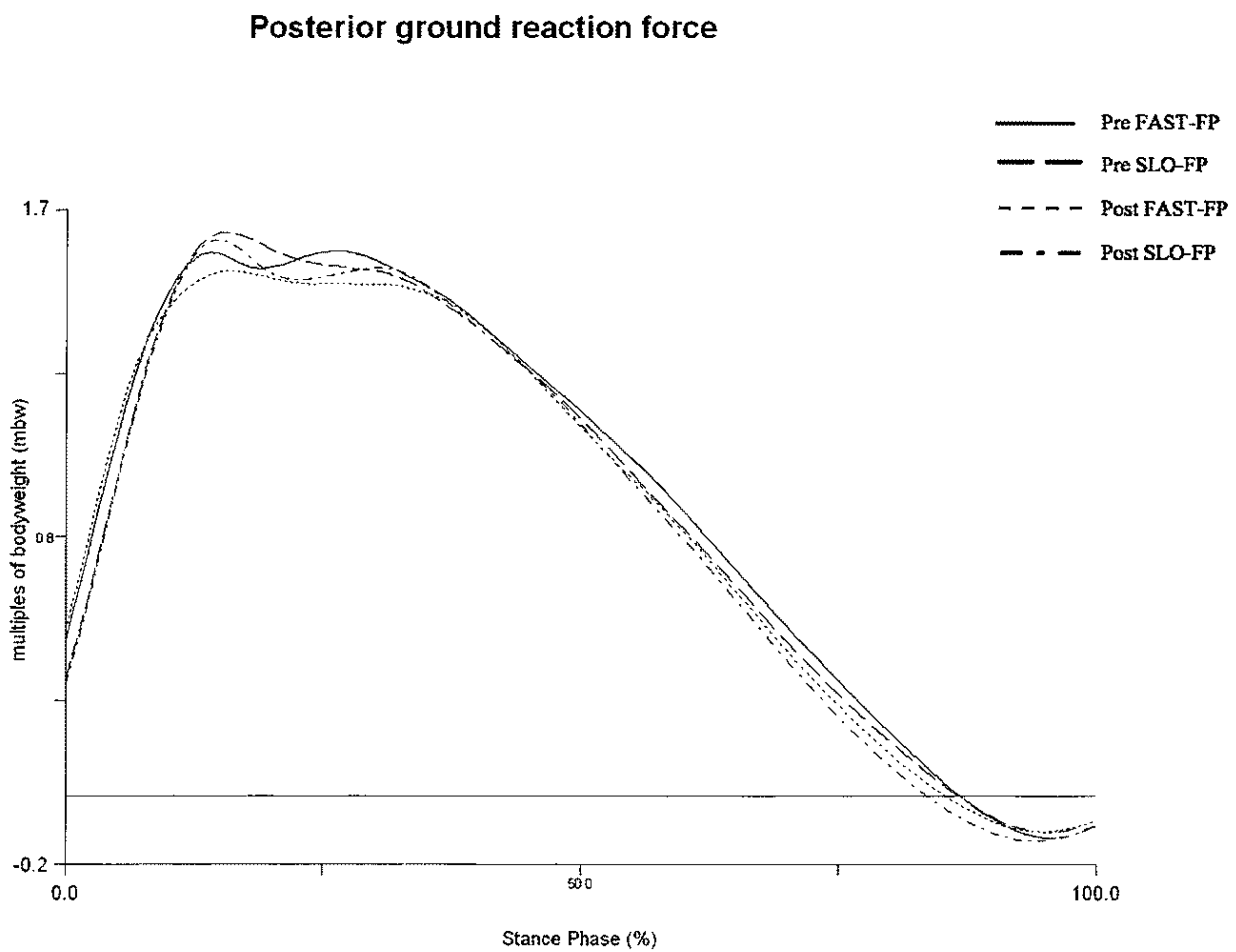


Figure 6 – Posterior ground reaction force during SLO-FP and FAST-FP (pre and post fatigue conditions) while performing a running-stop jump task



Peak Knee Flexion

There was a statistically significant main effect between fatigue conditions for knee flexion ($F_{1, 14}$=24.346, p=.000). Pairwise comparison determine that the subjects were in significantly lower knee flexion at peak knee flexion post fatigue (52.5±7.9°) when compared with pre fatigue (56.8±8.3°), *p*=0.000, *d*=.52. There were no statistically significant main effects for protocol ($F_{1, 14}$ =.000, *p*=.994) and no significant interaction ($F_{1, 14}$ =2.181, *p*=.162) for knee flexion at peak knee flexion.

There was a statistically significant main effect between fatigue conditions for hip flexion ($F_{1, 14}$=17.331, p=.001). Pairwise comparison determine that the subjects were in significantly lower hip flexion at peak knee flexion post fatigue (38.7±8.7°) when compared with pre fatigue (45.1±11.6°), *p*=0.001, *d*=.55. There were no statistically significant main effects for protocol ($F_{1, 14}$ =.280, *p*=.605), and no significant interaction ($F_{1, 14}$ =1.795, *p*=.202) for hip flexion at peak knee flexion.

There was a statistically significant main effect between protocols for hip abduction ($F_{1,14}$=13.086, p=.003). During the FAST-FP subjects had increased hip abduction (-3.7±4.6°) when compared with the SLO-FP (-1.8±3.9°), *p*=0.003, *d*=.41. There were no statistically significant main effects for time ($F_{1, 14}$ =.824, *p*=.379) and no significant interaction ($F_{1, 14}$ =.873, *p*=.366) for hip abduction at peak knee flexion.

There were no statistically significant main effects for protocol ($F_{1, 14}$ =.335, p=.572), time ($F_{1, 14}$ =.430, p=.523) and no significant interaction ($F_{1, 14}$ =.124, p=.730) for posterior ground reaction force at peak knee flexion; no statistically significant main effects for protocol ($F_{1, 14}$ =2.939, p=.108), time ($F_{1, 14}$ =1.133, p=.305) and no significant interaction ($F_{1, 14}$ =.378, p=.549) for knee abduction at peak knee flexion.

Peak Stance - Maximum Values

There was a statistically significant main effect between fatigue conditions for hip flexion ($F_{1,14}$=16.616, p=.001). Pairwise comparison determine that the subjects were in significantly lower hip flexion at maximum hip flexion post fatigue (47.3±8.2°) when compared with pre fatigue (53.3±10.95°), *p*=0.001, *d*=.55. There were no statistically significant main effects for protocol ($F_{1,14}$ =.531, *p*=.478), and no significant interaction ($F_{1,14}$ =1.300, *p*=.273) for hip flexion at maximum hip flexion.

There was a statistically significant main effect between protocols for knee extension moment ($F_{1,14}$=6.486, p=.023). During the SLO-FP subjects had increased knee extension moments (2.01±.32Nm/Kgm) when compared with the FAST-FP (1.9±.36Nm/Kgm), *p*=0.023, *d*=.31. There were no statistically significant main effects for protocol ($F_{1,14}$ =.6.486, *p*=.023), and no significant interaction ($F_{1,14}$ =.177, *p*=.680) for maximum knee extension moment.

There were no statistically significant main effects for protocol ($F_{1,14}$ =.078, p=.785), time ($F_{1,14}$ =1.565, p=.232) and no significant interaction ($F_{1,14}$ =2.918, p=.110) for knee adduction moment at maximum knee adduction moment; and no statistically significant main effects for protocol ($F_{1,14}$ =1.976, p=.182), time ($F_{1,14}$ =1.326, p=.269) and no significant interaction ($F_{1,14}$ =.000, p=.990) for knee abduction at peak knee abduction.

Figure 6: Average percentage of maximum heart rate for subjects during the SLO-FP.

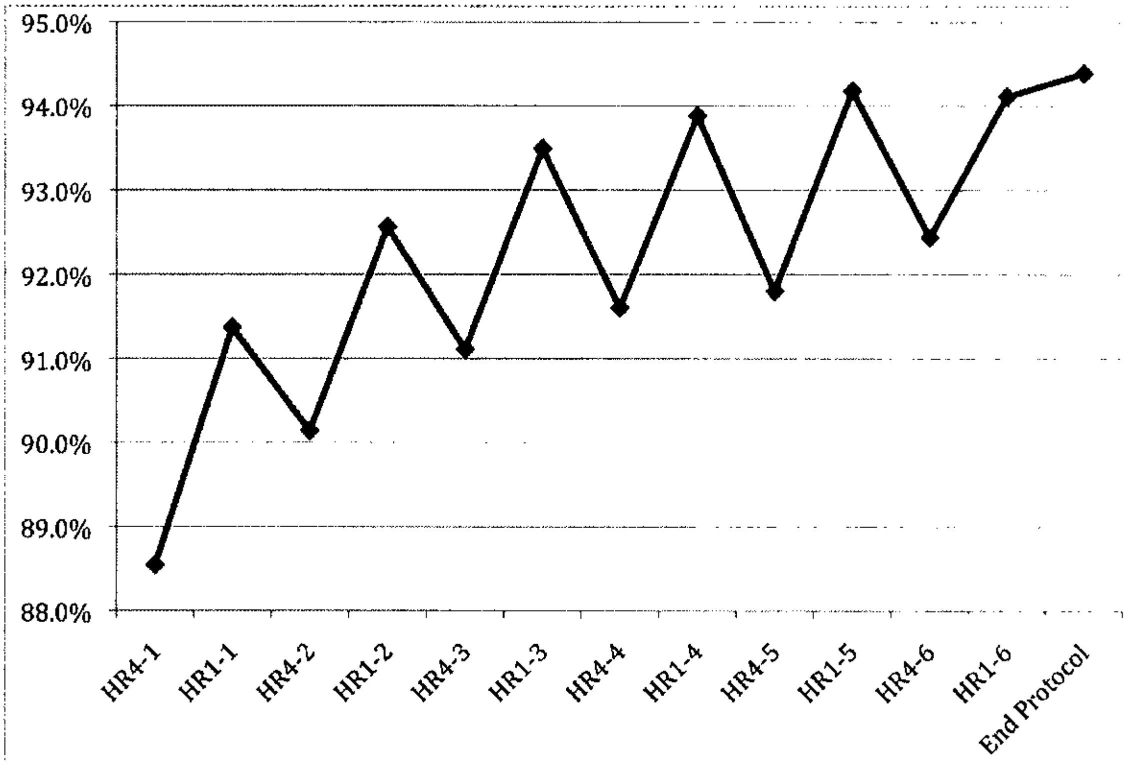
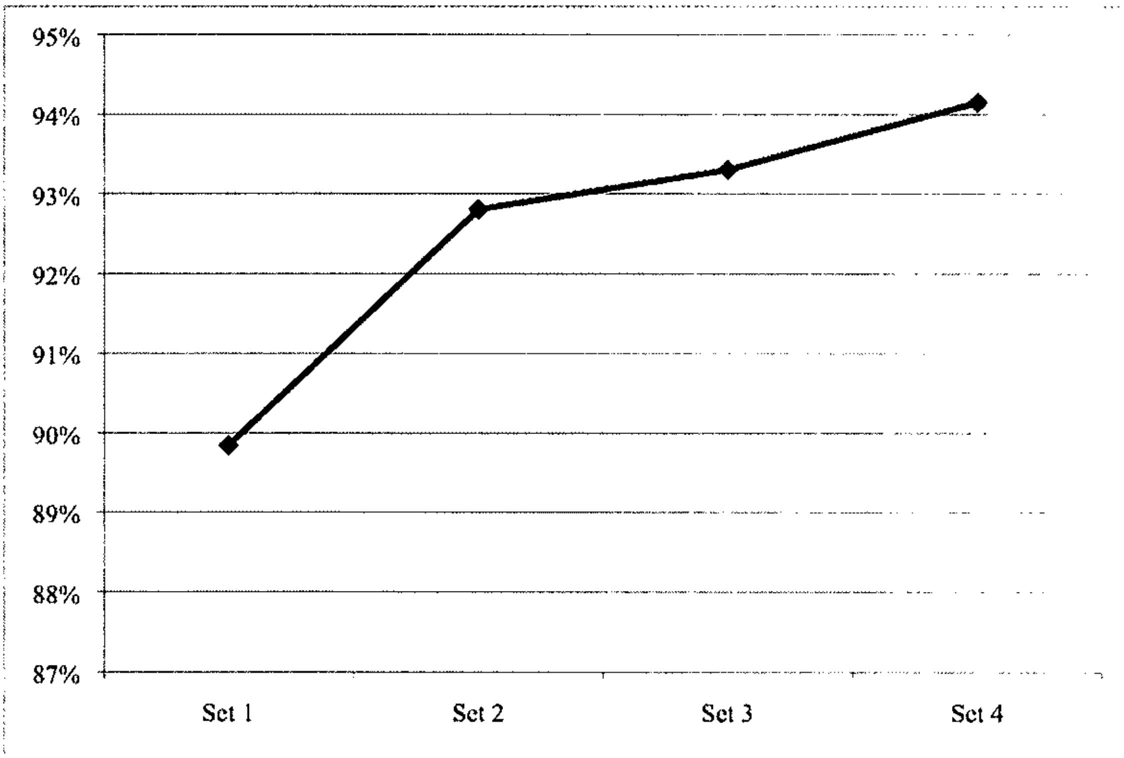


Figure 7: Average percentage of maximum heart rate during the 4 sets of the FAST-FP.



CHAPTER V

DISCUSSION AND CONCLUSIONS

DISCUSSION

The current study evaluated the effects of two fatigue protocols on lower extremity biomechanics. We hypothesized fatigue would induce lower extremity biomechanical alterations in the hip and knee during the landing phase of the running stop task. One of our main results was a significant decrease in knee and hip flexion (sagittal plane) following two types of fatigue protocols (SLO-FP and FAST-FP). The participants presented a more erect/extended position after being fatigued. Landing with the hip and knee in a more extended position has been shown to increase anterior shear force on the proximal end of the tibia, via an increased patellar tendon-tibia shaft angle (Hughes et al. 2006). Previous research has suggested that increased tibial anterior shear force results in increased loads being placed on the ACL (Chappell et al. 2005, Kernozek et al. 2008). It can be theorized that our subjects might have increased the strain placed on the ACL, and consequently increased ACL loading due to their erect position. These decreased joint angles are thought to produce a mechanical disadvantage for the hamstring muscles by shortening their angle of pull and decreasing the amount of posterior force that can be applied to the tibia. This decreased posterior force allows for increased anterior translation, which could increase the load placed on the ACL (Pandy & Shelburne, 1997). The combination of lower extremity knee and hip joint angles while performing an unanticipated task (decision-making process) under a fatigued condition may increase the likelihood of injury.

Fatigue has previously been identified to alter hip and knee kinematics when performing various athletic tasks (Kernozek, et al., 2008; MacDonald, Hultsch, & Dixon, 2003; McLean, et al., 2007; McLean & Samorezov, 2009). Our results, which show fatigue changes neuromechanics during a landing task, are similar to those of previous studies (Borotikar, et al., 2008; Chappell, et al., 2005; McLean & Samorezov, 2009). Chappell, et al., (2005, 2007) utilized a stop-jump task similar to the one used in the current study. The authors found significant decreases in knee flexion angle at peak proximal tibial anterior shear force; specifically, they found that subjects had a knee flexion angle at pre fatigue of 26.3 degrees and at post fatigue of 23.1 degrees, representing a 12% decrease between fatigue states. Previous research has found peak proximal tibial anterior shear force to be significantly correlated to corresponding peak posterior ground reaction force and peak vertical ground reaction force during a stop-jump (Yu, Lin, & Garrett, 2006).

The current study analyzed knee flexion at peak posterior ground reaction force and peak vertical ground reaction force, and found a decrease of 6.9% (pre=38.4, and post=35.8) and 7.4% (pre=38.8, and post =35.9), respectively. The percentage change for the current study was smaller than the change seen in the study done by Chappell et al., (2005). A possible reason for the smaller change in knee flexion angle seen in our subjects is due to the use of recreational athletes by Chappell et al., (2005), whereas the athletes in the current study were division one soccer players. The smaller decrease in knee flexion angle in our study could potentially be a result of the increased level of conditioning and athletic ability present in our subjects. However, the reduced knee angle at peak posterior ground reaction may still be increasing the load on the ACL and thereby its likelihood of rupture.

Cerulli, et al., (2003) analyzed the strain placed on the ACL during rapid deceleration and found ACL strain to be highest during peak ground reaction force (Cerulli, Benoit, Lamontagne, Caraffa, & Liti, 2003). Anterior displacement of the tibia via the quadriceps is most pronounced between 15 and 45 degrees of knee flexion, with the peak anterior translation occurring at 30 degrees of knee flexion (Hirokawa, Solomonow, Lu, Lou, & D'Ambrosia, 1992). In the presence of fatigue knee flexion at peak vertical ground reaction force went from -38.76 to -35.88, and decreased from -38.40 to -35.75 at peak posterior ground reaction force. Fatigue is in effect moving the knee closer to 30 degrees knee flexion where peak anterior translation of the tibia is thought to occur.

The sagittal plane hip joint kinematics was significantly affected at all time instances analyzed. We found fatigue to induce statistically significant decreases in hip flexion at initial contact (10.7% change), peak vertical ground reaction force (12.7%), peak posterior ground reaction force (11.5%), peak knee flexion (14.4%), and peak stance (11.2%). Previous research has found fatigue to induce similar findings during unanticipated landings, with hip flexion decreasing 15.1% pre to post fatigue (Borotikar, et al., 2008). An alteration in sagittal plane hip biomechanics is of interest due to its relationship with anterior and posterior tibial shear forces (Kernozek, et al., 2008). These forces are theorized to increase the load in the knee ligaments and the probability of injury. However, other authors have reported that fatigue mainly produces changes in the frontal plane kinematics and kinetics (Borotikar, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009).

The current study along with the previously mentioned research all analyzed lower extremity biomechanics during the performance of various unanticipated tasks. Each task performed was unanticipated in nature, however, in every case the subject knew the task had to be one of two or at maximum three options, and in no case more then that, nor were the subjects ever exposed to repeated unanticipated movements. Therefore, in order to complete a successful trial the subject was only required to complete one unanticipated movement, without being concerned with what would happen next. In real life game situations athletes are exposed to a constantly evolving environment, in which they are required to perform multiple unanticipated movements in conjunction with each other. This collection of unanticipated movements along with a combination of motion in the sagittal, frontal, and transverse planes is what results in abnormal out of plane motion, commonly seen during an ACL injury. Future research should examine the effects multiple unanticipated movements have on lower extremity biomechanics.

It is possible that landing in a more extended position decreases the capabilities of the lower extremity to effectively absorb shock, through decreased flexion of the joints (Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003). This increased force on the knee joint could potentially decrease the stability of the joint making it more susceptible to out of plane motions, and increasing the likelihood of ACL injury. Previous researchers have analyzed the landing phase of single leg jumps, both pre and post fatigue, the authors found the following frontal plane changes: increased knee abduction and internal rotation (Borotikar, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009; McNair, Hewson, Dombroski, & Stanley, 2002), increased hip internal rotation (Baca, 1999; Borotikar, et al., 2008; McLean & Samorezov, 2009), and increased hip internal rotation moment (McLean & Samorezov, 2009) from pre to post fatigue. It is worth noting that the task used in those studies differed from the running stop used in our study. The lower extremity neuromechanical adaptation for the demands of different tasks might partially explain the difference in results. The running stop is a task where the demands occur primarily in the sagittal plane with full deceleration to perform a vertical jump, whereas the sidestep cutting is a task that combines a deceleration with acceleration phase, as well as a change in direction (45 degree angle). Characteristics of both tasks have been observed during ACL tear events; however, the difference between these tasks makes comparison challenging. It is therefore, illogical to make generalized comparisons across different tasks, involving different neuromuscular demands. How each task (running stop, sidestep cut, single and double leg landing) modifies, by enhancing or diminishing, the lower extremity neuromechanical parameters is of importance, and should be the focus of future research.

Although the differences between the two fatigue protocols were minimal, we found the FAST-FP to induce significant changes in frontal plane hip and knee biomechanics when compared to the SLO-FP. Hip abduction at peak knee flexion significantly increased during the FAST-FP when compared with the SLO-FP. It is possible that the multidirectional movements associated with the FAST-FP induced greater amounts of fatigue to our subjects hip musculature resulting in increases in hip abduction post FAST-FP. The multidirectional functional protocol recruited a variety of muscle groups (e.g., flexors/extensors, abductors/adductors, etc.), whereas the SLO-FP primarily affected the flexors and extensors. This increased hip abduction angle during landing have been associated with excessive knee valgus/abduction moments (Sigward & Powers, 2007). Furthermore, the FAST-FP induced significant increases in knee adduction moment at initial contact when compared with the SLO-FP. In the transverse plane our subjects knee internal rotation significantly increased from pre to post fatigue in the FAST-FP. Fatigue has previously been shown to alter knee abduction/adduction moments (McLean & Samorezov, 2009) and knee internal rotation (Mclean et al. 2007; (Borotikar, et al., 2008; Sanna & O'Connor, 2008) during landing tasks. It is reasonable to assume that there is a relationship between the significant increase in knee adduction moment induced by the FAST-FP and the increased knee internal rotation present post fatigue during the FAST-FP. The increased internal knee adduction moment is most likely a response to an increased external valgus load attempting to force the knee into an abducted position.

The increase in knee rotation post FAST-FP could have been due to the increased external valgus load. As the knee moved into increased amounts of rotation post fatigue the compensatory effect would be to pull the knee back into its original position, which would result in the increased knee adduction moment. Knee motion resulting in increased amounts of internal tibial rotation have been shown to increase the load placed on the ACL (Markolf, et al., 1995). It appears the FAST-FP resulted in neuromuscular changes that induced increases in external valgus loading of the knee, which is in agreement with previous research (McLean, et al., 2007; McLean & Samorezov, 2009).

Increased valgus loading during landing has previously been shown to increase risk for sustaining an ACL injury (Hewett, Myer, Ford, et al., 2005).

An increase in knee extension moment at peak stance was observed/attained during the SLO-FP when compared to the FAST-FP. Fatigue has previously been shown to modify knee flexion/extension moments during landing (McLean & Samorezov, 2009). An increased knee extension moment resists the knee from going into flexion by activating the quadricep muscle group. The quadriceps muscle group is the major contributor to anterior shear force at the proximal end of the tibia (Yu & Garrett, 2007). An increase in anterior shear force on the tibia has previously been suggested to increase the load placed on the ACL, thus increasing the likelihood of injury (Chappell, et al., 2005; Kernozek, et al., 2008).

The results of this study indicate that both slow linear oxidative fatigue protocol (SLO-FP) and functional agility short-term fatigue protocol (FAST-FP) induced similar kinematic and kinetic changes to the lower extremity during the running stop task. The fatigue protocols elicited the largest variations in sagittal plane lower extremity kinematics. Specifically, subjects landed with less hip flexion at all of the time instances analyzed. Sagittal plane knee mechanics were significantly altered in the presence of fatigue, specifically a decrease in knee flexion was seen at peak vertical ground reaction force, and peak posterior ground reaction force and peak knee flexion. Previous research, in which the author's did not completely utilize a SLO-FP or FAST-FP but induced lower extremity fatigue found similar results for the kinematic variables stated above (Borotikar, et al., 2008; Chappell, et al., 2005; McLean & Samorezov, 2009).

An interesting result to note is the lack of difference between fatigue protocols (SLO-FP vs. FAST-FP). The majority of pre to post fatigue changes were observed regardless of the fatigue protocol used, with minimal difference noted between the two protocols. We initially hypothesized that the FAST-FP would create greater changes on the lower extremity biomechanics due to its functional drills performed at high intensity. However, a slow linear oxidative fatigue protocol, with medium to moderate intensity, has produced similar neuromechanical adaptations in our subjects. For the purposes of this study, the only objective physiological measure of fatigue available is heart rate. As shown in graphs 1 & 2 our subjects average heart rate progressed in a similar linear fashion in both the SLO-FP and FAST-FP.

Of particular interest is the fact that similar neuromuscular changes are present whether immediately after high intensity short duration exercise (FAST-FP) or after low intensity long duration exercise (SLO-FP). Short high intensity exercise (FAST-FP) done for as little as five minutes creates the same and in some cases greater neuromuscular changes as long duration low intensity exercise (SLO-FP) done for approximately forty-five minutes. Therefore, it should be known that when athletes engage in high intensity exercise their biomechanics could become negatively altered in as little as five minutes. When developing ACL prevention programs, feedback on proper mechanics should be stressed early on due to fatigue related lower extremity modifications occurring in as little as five minutes of intense multi-directional movements. It appears both fatigue protocols turned out to be anaerobic in nature, that is to say both ended with the subjects at or above their anaerobic threshold.

The fact that the most severe neuromuscular changes occurred after 5 minutes of exercise (FAST-FP) when compared with 45 minutes of exercise (SLO-FP) is clinically relevant. A five-minute fatigue protocol similar to the FAST-FP could be utilized to induce fatigue. A quick and effective screening process, similar to the Landing Error Scoring System (Padua, et al., 2009), could be developed to analyze lower extremity biomechanics while in a fatigued state. This tool could be used to identify individuals that utilized lower extremity movement patterns placing them at high (or low) risk for ACL injury. This would be a relatively inexpensive and efficient process to determine which risk factors are modified during fatigue conditions, and therefore which areas need to be focused during an ACL injury prevention program. Individualized prevention programs that take into account specific neuromechanical characteristics with and without fatigue should be developed. This would allow individuals to modify and adjust their specific risk factors in an ideal (un-fatigued) situation. The same prevention program would again be completed near the end of practice when subjects are in a fatigued state. Each subject would be given proper feedback on how to improve his or her previously identified neuromechanical risk factors. Thus, this instruction could potentially carry over to game situations that take place during fatigued status.

For the purposes of this study, the only objective physiological measure of fatigue available is heart rate. As shown in figures 7 & 8 our subjects average heart rate progressed in a similar linear fashion throughout both the SLO-FP and FAST-FP. It is not possible to quantify the amount of fatigue our subjects experienced throughout the fatigue protocols. However, our subject's heart rate increased after each set of the FAST-FP, and after each stage during the SLO-FP. It is therefore reasonable to assume that both the FAST-FP and SLO-FP induced adequate amounts of central and peripheral fatigue similar to what would be experienced during a game situation. We did not assess any objective measure of blood lactate levels, however, we speculate that the increased levels of lactic acid during the later stages of both fatigue protocols altered the landing mechanics. Lactic acid accumulation associated with muscular fatigue has been reported to impair balance, proprioception and reduce the ability of the muscle to perform work (Surenkok, Kin-Isler, Aytar, Gultekin, & Akman, 2006). Koutedakis & Sharp, (1985) analyzed lactic acid levels and heart rate in subjects engaging in athletic activity at or above their anaerobic threshold (Koutedakis & Sharp, 1985). The authors found when the subjects were working at an intensity of 86% of their maximum heart rate, they were considered to be at or above their anaerobic threshold. Subjects in our study averaged 180 bpm for both the FAST-FP and SLO-FP. Our subjects' age calculated maximum heart average was 200.8 bpm, meaning our subjects were working at an average intensity of 89.6% of their maximum heart rate. Therefore, it appears that our subjects were working at an intensity at or above their anaerobic threshold for both the FAST-FP and SLO-FP. It is plausible to assume that during both fatigue protocols the accumulation of lactic acid in our subjects' muscles may have resulted in impaired balance and reduction in the muscles ability to perform work.

One possible reason for the similarities between the SLO-FP and FAST-FP is our subject population is accustom to a wide range of activity including short-term high intensity exercise as well as low intensity long duration exercise. During a competitive game, elite female soccer athletes on average change activity 1459 times, the activity changes range from standing, walking, running at low intensity, and high intensity running (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005). Krustrup, et al., (2005) analyzed elite female soccer players and found the average HR during a competitive match to be 87% of their max heart rate. The average heart rate for our subjects during both fatigue protocols was 89.6% of their max, similar to what is experienced during a competitive game. Therefore, it appears our subject population of elite soccer athletes was able to adjust accordingly to both the SLO-FP and FAST-FP, because both protocols are similar to what is experienced during a game.

CONCLUSIONS

One of the main outcomes of the current study is the similarity of the two fatigue protocols. Similar lower extremity biomechanical modifications occurred after five minutes of fatigue (SLO-FP) when compared with forty-five minutes of fatigue (FAST-FP). Altered lower extremity biomechanical movement patterns are known risk factors for ACL injury. The results of this study indicate fatigue, regardless of type, makes these biomechanical risk factors more pronounced. Therefore, ACL prevention programs should be designed to prevent the detrimental effects of fatigue. In order to accomplish this, individuals need to be trained and instructed on proper mechanics while in a fatigued state. During this fatigued state feedback on proper mechanics should be given early on and often, and continued throughout the entire prevention program. We found fatigue induced decreases in hip and knee flexion, resulting in a more extended landing posture. Landing in a more extended position is thought to increase anterior tibial translation and thus increase the strain placed on the ACL. The FAST-FP produced significant increases in hip abduction, knee adduction moment, and knee rotation, all of which are either a cause or result of increased valgus loading on the knee joint.

The unanticipated running stop task was utilized in the current study, and significant biomechanical alterations occurred in the sagittal, frontal, and transverse planes. Previous research in which a side step cutting task was utilized found the majority of biomechanical alterations to occur in the frontal plane (Borotikar, et al., 2008; McLean, et al., 2007; McLean & Samorezov, 2009). A variety of unanticipated tasks have been utilized in previous research, each task in itself creates a modification in the lower extremity movement pattern that is directly related to the specific demands of the task. Taking into consideration that the exact mechanism of ACL injury is yet to be identified. Presumptions of which task will result in the desired out of plane motions they may or may not cause an ACL injury seems unwise. Future research should focus on the effects of multiple unanticipated tasks completed in succession of one another. The motions produced from this "unanticipated movement pattern" would be comparable to what is constantly occurring in a game environment. Furthermore, future research should examine the effects multiple unanticipated tasks have on each other, specifically what modifications are present when the task is performed on its own and in sequence with another.

REFERENCES

Agel, J., Arendt, E. A., & Bershadsky, B. (2005). Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *Am J Sports Med, 33*(4), 524-530.

Arendt, E., & Dick, R. (1995). Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med, 23*(6), 694-701.

Baca, A. (1999). A comparison of methods for analyzing drop jump performance. *Med Sci Sports Exerc, 31*(3), 437-442.

Beasley, L. S. (2005). Anterior Cruciate Ligament Reconstruction: A Literature Review of the Anatomy, Biomechanics, Surgical Considerations, and Clinical Outcomes. *Oper Tech Orthop, 15*, 5-19.

Begon, M., Monnet, T., & Lacouture, P. (2007). Effects of movement for estimating the hip joint centre. *Gait Posture, 25*(3), 353-359.

Besier, T. F., Lloyd, D. G., Ackland, T. R., & Cochrane, J. L. (2001). Anticipatory effects on knee joint loading during running and cutting maneuvers. *Med Sci Sports Exerc, 33*(7), 1176-1181.

Bjordal, J. M., Arnly, F., Hannestad, B., & Strand, T. (1997). Epidemiology of anterior cruciate ligament injuries in soccer. *Am J Sports Med, 25*(3), 341-345.

Boden, B. P., Dean, G. S., Feagin, J. A., Jr., & Garrett, W. E., Jr. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics, 23*(6), 573-578.

Borotikar, B. S., Newcomer, R., Koppes, R., & McLean, S. G. (2008). Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. *Clin Biomech (Bristol, Avon), 23*(1), 81-92.

Cerulli, G., Benoit, D. L., Lamontagne, M., Caraffa, A., & Liti, A. (2003). In vivo anterior cruciate ligament strain behaviour during a rapid deceleration movement: case report. *Knee Surg Sports Traumatol Arthrosc, 11*(5), 307-311.

Chandrashekar, N., Slauterbeck, J., & Hashemi, J. (2005). Sex-based differences in the anthropometric characteristics of the anterior cruciate ligament and its relation to intercondylar notch geometry: a cadaveric study. *Am J Sports Med, 33*(10), 1492-1498.

Chappell, J. D., Creighton, R. A., Giuliani, C., Yu, B., & Garrett, W. E. (2007). Kinematics and electromyography of landing preparation in vertical stop-jump: risks for noncontact anterior cruciate ligament injury. *Am J Sports Med, 35*(2), 235-241.

Chappell, J. D., Herman, D. C., Knight, B. S., Kirkendall, D. T., Garrett, W. E., & Yu, B. (2005). Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. *Am J Sports Med, 33*(7), 1022-1029.

Decker, M. J., Torry, M. R., Wyland, D. J., Sterett, W. I., & Richard Steadman, J. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clin Biomech (Bristol, Avon), 18*(7), 662-669.

Ferretti, M., Ekdahl, M., Shen, W., & Fu, F. H. (2007). Osseous landmarks of the femoral attachment of the anterior cruciate ligament: an anatomic study. *Arthroscopy, 23*(11), 1218-1225.

Flouris, A. D., Koutedakis, Y., Nevill, A., Metsios, G. S., Tsiotra, G., & Parasiris, Y. (2004). Enhancing specificity in proxy-design for the assessment of bioenergetics. *J Sci Med Sport, 7*(2), 197-204.

Ford, K. R., Myer, G. D., & Hewett, T. E. (2003). Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc, 35*(10), 1745-1750.

Gandevia, S. C. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiol Rev, 81*(4), 1725-1789.

Gandevia, S. C., Allen, G. M., Butler, J. E., & Taylor, J. L. (1996). Supraspinal factors in human muscle fatigue: evidence for suboptimal output from the motor cortex. *J Physiol, 490 (Pt 2)*, 529-536.

Gehring, D., Melnyk, M., & Gollhofer, A. (2009). Gender and fatigue have influence on knee joint control strategies during landing. *Clin Biomech (Bristol, Avon), 24*(1), 82-87.

Gilchrist, J., Mandelbaum, B. R., Melancon, H., Ryan, G. W., Silvers, H. J., Griffin, L. Y., et al. (2008). A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. *Am J Sports Med, 36*(8), 1476-1483.

Giron, F., Cuomo, P., Aglietti, P., Bull, A. M., & Amis, A. A. (2006). Femoral attachment of the anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc, 14*(3), 250-256.

Griffin, L. Y., Agel, J., Albohm, M. J., Arendt, E. A., Dick, R. W., Garrett, W. E., et al. (2000). Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg, 8*(3), 141-150.

Griffin, L. Y., Albohm, M. J., Arendt, E. A., Bahr, R., Beynnon, B. D., Demaio, M., et al. (2006). Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *Am J Sports Med, 34*(9), 1512-1532.

Harner, C. D., Baek, G. H., Vogrin, T. M., Carlin, G. J., Kashiwaguchi, S., & Woo, S. L. (1999). Quantitative analysis of human cruciate ligament insertions. *Arthroscopy, 15*(7), 741-749.

Hewett, T. E., Ford, K. R., & Myer, G. D. (2006). Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med, 34*(3), 490-498.

Hewett, T. E., Lindenfeld, T. N., Riccobene, J. V., & Noyes, F. R. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med, 27*(6), 699-706.

Hewett, T. E., Myer, G. D., & Ford, K. R. (2005). Reducing knee and anterior cruciate ligament injuries among female athletes: a systematic review of neuromuscular training interventions. *J Knee Surg, 18*(1), 82-88.

Hewett, T. E., Myer, G. D., & Ford, K. R. (2006). Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med, 34*(2), 299-311.

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Jr., Colosimo, A. J., McLean, S. G., et al. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med, 33*(4), 492-501.

Hirokawa, S., Solomonow, M., Lu, Y., Lou, Z. P., & D'Ambrosia, R. (1992). Anterior-posterior and rotational displacement of the tibia elicited by quadriceps contraction. *Am J Sports Med, 20*(3), 299-306.

Hogervorst, T., & Brand, R. A. (1998). Mechanoreceptors in joint function. *J Bone Joint Surg Am, 80*(9), 1365-1378.

Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train, 42*(2), 311-319.

Hughes, G., & Watkins, J. (2006). A risk-factor model for anterior cruciate ligament injury. *Sports Med, 36*(5), 411-428.

Kernozek, T. W., Torry, M. R., & Iwasaki, M. (2008). Gender differences in lower extremity landing mechanics caused by neuromuscular fatigue. *Am J Sports Med, 36*(3), 554-565.

Kirkendall, D. T., & Garrett, W. E., Jr. (2000). The anterior cruciate ligament enigma. Injury mechanisms and prevention. *Clin Orthop Relat Res*(372), 64-68.

Koutedakis, Y., & Sharp, N. C. (1985). Lactic acid removal and heart rate frequencies during recovery after strenuous rowing exercise. *Br J Sports Med, 19*(4), 199-202.

Krosshaug, T., Nakamae, A., Boden, B. P., Engebretsen, L., Smith, G., Slauterbeck, J. R., et al. (2007). Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *Am J Sports Med, 35*(3), 359-367.

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: importance of training status. *Med Sci Sports Exerc, 37*(7), 1242-1248.

Luites, J. W., Wymenga, A. B., Blankevoort, L., & Kooloos, J. G. (2007). Description of the attachment geometry of the anteromedial and posterolateral bundles of the ACL from arthroscopic perspective for anatomical tunnel placement. *Knee Surg Sports Traumatol Arthrosc, 15*(12), 1422-1431.

MacDonald, S. W., Hultsch, D. F., & Dixon, R. A. (2003). Performance variability is related to change in cognition: evidence from the Victoria Longitudinal Study. *Psychol Aging, 18*(3), 510-523.

Maletius, W., & Messner, K. (1999). Eighteen- to twenty-four-year follow-up after complete rupture of the anterior cruciate ligament. *Am J Sports Med, 27*(6), 711-717.

Malinzak, R. A., Colby, S. M., Kirkendall, D. T., Yu, B., & Garrett, W. E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech (Bristol, Avon), 16*(5), 438-445.

Markolf, K. L., Burchfield, D. M., Shapiro, M. M., Shepard, M. F., Finerman, G. A., & Slauterbeck, J. L. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. *J Orthop Res, 13*(6), 930-935.

McLean, S. G., Felin, R. E., Suedekum, N., Calabrese, G., Passerallo, A., & Joy, S. (2007). Impact of fatigue on gender-based high-risk landing strategies. *Med Sci Sports Exerc, 39*(3), 502-514.

McLean, S. G., Huang, X., & van den Bogert, A. J. (2008). Investigating isolated neuromuscular control contributions to non-contact anterior cruciate ligament injury risk via computer simulation methods. *Clin Biomech (Bristol, Avon), 23*(7), 926-936.

McLean, S. G., & Samorezov, J. E. (2009). Fatigue-induced ACL injury risk stems from a degradation in central control. *Med Sci Sports Exerc, 41*(8), 1661-1672.

McNair, P. J., Hewson, D. J., Dombroski, E., & Stanley, S. N. (2002). Stiffness and passive peak force changes at the ankle joint: the effect of different joint angular velocities. *Clin Biomech (Bristol, Avon), 17*(7), 536-540.

Melnyk, M., & Gollhofer, A. (2007). Submaximal fatigue of the hamstrings impairs specific reflex components and knee stability. *Knee Surg Sports Traumatol Arthrosc, 15*(5), 525-532.

Metsios, G. S., Flouris, A. D., Koutedakis, Y., & Theodorakis, Y. (2006). The effect of performance feedback on cardiorespiratory fitness field tests. *J Sci Med Sport, 9*(3), 263-266.

Mihata, L. C., Beutler, A. I., & Boden, B. P. (2006). Comparing the incidence of anterior cruciate ligament injury in collegiate lacrosse, soccer, and basketball players: implications for anterior cruciate ligament mechanism and prevention. *Am J Sports Med, 34*(6), 899-904.

Mountcastle, S. B., Posner, M., Kragh, J. F., Jr., & Taylor, D. C. (2007). Gender differences in anterior cruciate ligament injury vary with activity: epidemiology of anterior cruciate ligament injuries in a young, athletic population. *Am J Sports Med, 35*(10), 1635-1642.

Olsen, O. E., Myklebust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med, 32*(4), 1002-1012.

Olsen, O. E., Myklebust, G., Engebretsen, L., Holme, I., & Bahr, R. (2003). Relationship between floor type and risk of ACL injury in team handball. *Scand J Med Sci Sports, 13*(5), 299-304.

Padua, D. A., Marshall, S. W., Boling, M. C., Thigpen, C. A., Garrett, W. E., & Beutler, A. I. (2009). The Landing Error Scoring System (LESS) Is a Valid and Reliable Clinical Assessment Tool of Jump-Landing Biomechanics. *Am J Sports Med, 37*(10), 1996-2002.

Pandy, M. G., & Shelburne, K. B. (1997). Dependence of cruciate-ligament loading on muscle forces and external load. *J Biomech, 30*(10), 1015-1024.

Petersen, W., & Hansen, U. (1997). Blood and lymph supply of the anterior cruciate ligament: cadaver study by immunohistochemical methods. *J Orthop Sci, 2*, 313-318.

Sanna, G., & O'Connor, K. M. (2008). Fatigue-related changes in stance leg mechanics during sidestep cutting maneuvers. *Clin Biomech (Bristol, Avon), 23*(7), 946-954.

Schulz, B. W., Ashton-Miller, J. A., & Alexander, N. B. (2008). The effects of age and step length on joint kinematics and kinetics of large out-and-back steps. *Clin Biomech (Bristol, Avon)*.

Schwartz, M. H., & Rozumalski, A. (2005). A new method for estimating joint parameters from motion data. *J Biomech, 38*(1), 107-116.

Sigward, S. M., & Powers, C. M. (2007). Loading characteristics of females exhibiting excessive valgus moments during cutting. *Clin Biomech (Bristol, Avon), 22*(7), 827-833.

Surenkok, O., Kin-Isler, A., Aytar, A., Gultekin, Z., & Akman, M. (2006). Effect of knee muscle fatigue and lactic accumulation on balance in healthy subjects. *Isokinetics and Exercise Science, 14*, 301-306.

Taylor, J. L., & Gandevia, S. C. (2008). A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions. *J Appl Physiol, 104*(2), 542-550.

Uhorchak, J. M., Scoville, C. R., Williams, G. N., Arciero, R. A., St Pierre, P., & Taylor, D. C. (2003). Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med, 31*(6), 831-842.

Yu, B., & Garrett, W. E. (2007). Mechanisms of non-contact ACL injuries. *Br J Sports Med, 41 Suppl 1*, i47-51.

Yu, B., Lin, C. F., & Garrett, W. E. (2006). Lower extremity biomechanics during the landing of a stop-jump task. *Clin Biomech (Bristol, Avon), 21*(3), 297-305.

Zantop, T., Petersen, W., & Fu, F. H. (2005). Anatomy of the Anterior Cruciate Ligament. *Oper Tech Orthop, 15*, 20-28.

Zantop, T., Petersen, W., Sekiya, J. K., Musahl, V., & Fu, F. H. (2006). Anterior cruciate ligament anatomy and function relating to anatomical reconstruction. *Knee Surg Sports Traumatol Arthrosc, 14*(10), 982-992.

APPENDICES

Appendix 1

INFORMED CONSENT DOCUMENT
OLD DOMINION UNIVERSITY

PROJECT TITLE: Lower Extremity Biomechanical Evaluation During Various Foot Landing Patterns and Athletic Tasks – A Gender Comparison

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. The name of research project is "Lower Extremity Biomechanical Evaluation During Various Foot Landing Patterns and Athletic Tasks in Collegiate Soccer Athletes". The data collection will take place in the Motion Analysis Laboratory, Room 1007, in Student Recreation Center on the Old Dominion University campus.

RESEARCHERS

Dr. James Oñate, Ph.D., ATC Assistant Professor, Responsible Project Investigator
Nelson Cortes, M.S. Ed, Doctoral Student, Human Movement Sciences Department
Roger Kollock, M.S. Ed., Doctoral Student, Human Movement Sciences Department
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DESCRIPTION OF RESEARCH STUDY

There have been numerous studies that have analyzed the high occurrence of anterior cruciate ligament tears in non-contact sports. Most studies have looked at the knee joint and how it contributes to this type of injury. There is still a lack of knowledge on how these injuries occur in relation to the knee joint. Although there are numerous studies on anterior cruciate ligament tears, there is little evidence that shows how different foot positions while performing specific unanticipated athletic tasks affects the knee joint. There have been studies that have added other contributing factors while still analyzing the knee joint. Therefore there is a need to explain the effects of gender and how it affects hip and ankle motions in three athletic tasks based on different landing techniques, self-preferred, forefoot, and rearfoot. The purpose of this study is to analyze hip and ankle kinematics while performing three different athletic tasks.

If you decide to participate, then you will join a study involving research of different landing techniques that are related to hip and ankle kinematics during the stop-jump phase. The study will be collected in two sessions separated by one week. You will report to the Sports Medicine Research Lab, wearing spandex shorts, t-shirt or sports bra, and running shoes. You will fill out a questionnaire with questions about your history of injury and soccer experience.

- You will have a 10-minute warm-up period that will consist of cycling and/or self-directed stretching. After the warm-up period and stretching, thirty-seven (37) reflective markers will be placed on specific body landmarks. You will be requested to step on a scale in order for us to measure your weight and height. A caliper will be used to measure knee width, ankle width, elbow width, wrist width and hand thickness. A measurement tape will be used to measure your leg length. The measurement will be taken from your hip to your ankle.

- There will be a short period of time to familiarize yourself with the athletic tasks.
- The four athletic tasks that will be performed consist of a drop jump task, running pivoting task, a running side-step cutting task, and a running crossover-cutting task.
- To perform the drop jump task, you will be standing on a box, 30 cm height and 30 cm from the force plates, shift your weight forward to drop from the box and land on the force plates, followed by a jump straight back into the air and landing back on the force plates.
- When performing the running pivoting you will stand on the beginning of the platform, start running and planting onto the force plate with the dominant foot and pivoting 180 degrees and run to the opposite direction. You will use the designated landing technique by the researcher.
- The running side-step cutting task consists of you running towards the force plates and once you reach the force plate you will cut at an angle between 35°-55° either to the left or right as directed by image that will prompt on the screen depending on which leg is your dominant leg.
- The running-crossover-step cutting task consists of you running towards the force plates and once you reach the force plate you will plant and perform a crossover step while cutting at an angle between 35°-55° either to the left or right as directed by image that will prompt on the screen depending on which leg is your dominant leg.
- In both running tasks, you will be directed on which landing technique to perform as well. The landing techniques are forefoot (toes), rearfoot (heel), and self-preferred. The forefoot landing technique is performed by initially landing with your forefoot and then your rearfoot. The rearfoot landing technique is performed by initially landing with you rearfoot and then your forefoot.
- The self-preferred landing technique is how you would normally land whenever landing from a jump. If at any time while performing each task, you touch the ground with your hands or lose your balance and fall, the trial will not be analyzed.
- All athletic tasks will be randomly performed and 5 times each. The self preferred landing technique will be performed first in each task while the forefoot and rearfoot landing technique will be performed in a counterbalanced order.
- After performing the previous tasks you will perform one of two fatigue protocols (aerobic and anaerobic), with the other fatigue protocol being performed one week after the first session.
- The aerobic fatigue will consist of a VO2 maximal protocol, where you will run at 9 km/h with 1 km/h increments every two minutes until you cannot keep going. You will rest for five minutes followed by 30 minutes jogging, running, and sprinting. At the end of the protocol you will feel as if you have just finished a 5-kilometer race.
- The anaerobic fatigue will consist of performing a series of step-up and down movements on a 20-cm box for 30 seconds. Following you will perform a three-

cone drill, with the cones placed on an L shape separated by 5 yards. You will sprint 5 yards to one cone, sprint back to the starting cone, and head back to the second cone where you run around it and cut right to the third cone. You will then run in a circle around the third cone from the inside to the outside and run around the second cone before running to the first cone. Immediately following the three-cone drill, you will perform 5 consecutive counter-movement jumps staying within 25% of their max vertical jump. Immediately after, you will perform two different types of agility drills. On the 1st and 3rd set of the anaerobic fatigue protocol, the subjects will run over the ladder touching both feet in each ladder space. During the 2nd and 4th set of the fatigue protocol the subjects will face perpendicular to the ladder moving sideways along the ladder touching both foot in each space. You will repeat 4 times the entire protocol. At the end of the protocol, it will feel like as if you have just got done playing an intense game of basketball.

All athletic tasks will be videotaped, this will allow the investigator to insure the landing techniques and athletic tasks are performed correctly. If you do not consent to be videotaped you will be excluded from the test. You will also perform strength testing. The strength test involves using a load cell, which is a device similar to a dynamometer (strength measuring device) strength tester to measure hip, knee, and ankle strength. Two practice repetitions and three test trials will be conducted for each strength test. If you say YES, then your participation will last for approximately 60 minutes at the Sports Medicine Research Lab, Room 113, in Spong hall. Approximately 50 females and 50 males will be participating in this study.

EXCLUSIONARY CRITERIA

You will be excluded from the study in case you do not consent to be videotaped/photographed.

RISKS AND BENEFITS

RISKS: If you decide to participate in this study, then you may face a risk of ankle sprain, knee injury, muscle pain, and muscle soreness. Ankle sprains can be compared as stepping off the curb, muscle pain and muscle soreness can be compared as the same sensation you might have after workout. The researcher tried to reduce these risks by provided clear directions on how to perform each athletic task and landing technique. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: There are no direct benefits for the subject for participating in this study.

COSTS AND PAYMENTS

The researchers want your decision about participating in this study to be absolutely voluntary. Yet they recognize that your participation may pose some inconvenience with travel time to and from the testing site. Unfortunately at this time, the researchers are unable to give you any payment for participating in this study.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

All information obtained about you in this study is strictly confidential unless disclosure is required by law. The researchers will take reasonable steps to insure confidentiality is upheld. The researchers will store all questionnaires, videotapes, and laboratory findings in a locked file cabinet prior to processing. The results of this study may be used in reports, presentations and publications, but the researcher will not identify you.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of harm and/or injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in this research project, you may contact Dr. James Oñate at 757-683-4351, Nelson Cortes at 757-683-5676, or Dr. George Maihafer, the current IRB chair, at 757- 683-4520 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them: Dr. James Oñate at 757-683-4351 or Nelson Cortes at 757-683-5676.

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer, the current IRB chair, at 757- 683-4520, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	**Date**

INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	**Date**

Appendix 2

Name____ Subject ID: ______________

Data Collection Sheet: FAST-FP

Resting Heart Rate: _______________ MAX Heart Rate: _______________

Steps Ups (220 bpm on metronome)

1.______________

2.______________

3.______________

4.______________

L Drill (three-cone drill)

1.__________________seconds

2.__________________seconds

3.__________________seconds

4.__________________seconds

Agility Ladder (220 bpm on metronome)

Forward

Set 1.________________seconds

Set 3.________________seconds

Lateral

Set 2.________________seconds

Set 4.________________seconds

Vertical Jump Max Vertical Jump________inches
All jumps need be within 18-22% of subjects max vertical jump.

1.______inches 1.______inches 1.______inches 1.______inches 1.______inches

2.______inches 2.______inches 2.______inches 2.______inches 2.______inches

3.______inches 3.______inches 3.______inches 3.______inches 3.______inches

4.______inches 4.______inches 4.______inches 4.______inches 4.______inches

5.______inches 5.______inches 5.______inches 5.______inches 5.______inches

Within 18-22% of max vertical (yes or no)

Set 1______ Set 2______ Set 3______ Set 4______ Set 5______

Appendix 3

Name______________________________ Subject ID: __________

Data Collection Sheet – SLO-FP

Resting Heart Rate: ________ **MAX Heart Rate (age calculated):** ________

Height (meters): __________ **Mass** (kg): ________ **Age** (years): __________

VO_2 MAX:

Time Stopped: ________________ Speed Stopped: _________________

Minutes	Km/h	Mph	HR
1-5	9	5.6	
6-7	10	6.2	
8-9	11	6.8	
10-11	12	7.5	
12-13	13	8.1	
14-15	14	8.7	
16-17	15	9.3	
18-19	16	10	
20-21	17	10.6	
22-23	18	11.2	

Met which criteria (circle two):

1. Heart rate reached 90% of age-calculated max
2. Respiratory quotient greater than 1.1
3. Plateau in VO_2 max curve
4. Subject was unable to continue

30-minute run:

Jog Speed (70%): _____________ Sprint Speed (80%): _____________

Did they complete entire treadmill test (circle):
Yes
No - Time stopped: ________________

Jog Speed 70%		Sprint Speed 80%	
Mph	**HR**	**Mph**	**HR**

Appendix 4

Jump-Landing Participation Questionnaire – Soccer Athletes

Age: ____ Gender: Male Female

Weight: _____ Height: _____ To be filled out by investigator

Dominant Leg: Left or Right

** This is the leg in which you would kick a soccer ball as far as possible with.**

Are you a:

Freshman Sophmore Junior Senior

How many years have you been playing soccer? _______

Have you had any ankle sprains?

☐ Yes ☐ No

If yes, which leg? Right Left Both

If yes, when? ____________

Have you had any ACL injury?

☐ Yes ☐ No

If yes, which leg? Right Left Both

If yes, when? ___________

Have you had any surgeries (ankle and/or knee)?

☐ Yes ☐ No

If yes, which leg? Right Left Both

If yes, when? ________________

Do you presently have any physical impairment that would limit you from performing a jump-landing task?

☐ Yes ☐ No

Have you been exercising at least 30 minutes per day, 3 times per week, for the past 6-months?

☐ Yes ☐ No

To your knowledge are you presently pregnant?

☐ Yes ☐ No

Appendix 5

Data Collection Sheet

Height (meters): __________ **Mass** (kg): ______ **Age** (yrs): ___ **Dominant Leg**: Left Right (Circle one)

FATIGUE PROTOCOL: AEROBIC ANAEROBIC (circle one) **Date of Testing:** ___/___/____

Body Fat (skinfolds): Tricep ____ Suprailiac ____ Thigh _____ **Body Fat (Bodpod):** ______

PRE-FATIGUE

(2) Simple Reaction Time
(√ - valid trial; x – not valid trial)

Right	Left
Trial 1: _____	Trial 1: _____
Trial 2: _____	Trial 2: _____
Trial 3: _____	Trial 3: _____
Trial 4: _____	Trial 4: _____
Trial 5: _____	Trial 5: _____
Trial 6: _____	Trial 6: _____
Trial 7: _____	Trial 7: _____
Trial 8: _____	Trial 8: _____
Trial 9: _____	Trial 9: _____
Trial 10: _____	Trial 10: _____

(3) Choice Reaction Time
(√ - valid trial; x – not valid trial)

Trial 1:	Right	Left	___
Trial 2:	Right	Left	___
Trial 3:	Right	Left	___
Trial 4:	Right	Left	___
Trial 5:	Right	Left	___
Trial 6:	Right	Left	___
Trial 7:	Right	Left	___
Trial 8:	Right	Left	___
Trial 9:	Right	Left	___
Trial 10:	Right	Left	___
Trial 11:	Right	Left	___
Trial 12:	Right	Left	___
Trial 13:	Right	Left	___
Trial 14:	Right	Left	___
Trial 15:	Right	Left	___

(1) Box-Drop
(√ - valid trial; x – not valid trial)

Trial 1: ___________
Trial 2: ___________
Trial 3: ___________
Trial 4: ___________
Trial 5: ___________
Trial 6: ___________
Trial 7: ___________
Trial 8: ___________
Trial 9: ___________
Trial 10: ___________

(4) Dynamic Tasks
(√ - valid trial; x – not valid trial)

	(Circle task)		Speed	(√ or x)
Trial 1:	Side Step	Pivoting	________	___
Trial 2:	Side Step	Pivoting	________	___
Trial 3:	Side Step	Pivoting	________	___
Trial 4:	Side Step	Pivoting	________	___
Trial 5:	Side Step	Pivoting	________	___
Trial 6:	Side Step	Pivoting	________	___
Trial 7:	Side Step	Pivoting	________	___
Trial 8:	Side Step	Pivoting	________	___
Trial 9:	Side Step	Pivoting	________	___
Trial 10:	Side Step	Pivoting	________	___
Trial 11:	Side Step	Pivoting	________	___
Trial 12:	Side Step	Pivoting	________	___
Trial 13:	Side Step	Pivoting	________	___
Trial 14:	Side Step	Pivoting	________	___
Trial 15:	Side Step	Pivoting	________	___
Trial 16:	Side Step	Pivoting	________	___
Trial 17:	Side Step	Pivoting	________	___
Trial 18:	Side Step	Pivoting	________	___
Trial 19:	Side Step	Pivoting	________	___
Trial 20:	Side Step	Pivoting	________	___

POST-FATIGUE

(4) Simple Reaction Time
(√ - valid trial; x – not valid trial)

Right	Left
Trial 1: _____	Trial 1: _____
Trial 2: _____	Trial 2: _____
Trial 3: _____	Trial 3: _____
Trial 4: _____	Trial 4: _____
Trial 5: _____	Trial 5: _____
Trial 6: _____	Trial 6: _____
Trial 7: _____	Trial 7: _____
Trial 8: _____	Trial 8: _____
Trial 9: _____	Trial 9: _____
Trial 10: _____	Trial 10: _____

(2) Choice Reaction Time
(√ - valid trial; x – not valid trial)

Trial 1:	Right	Left	____
Trial 2:	Right	Left	____
Trial 3:	Right	Left	____
Trial 4:	Right	Left	____
Trial 5:	Right	Left	____
Trial 6:	Right	Left	____
Trial 7:	Right	Left	____
Trial 8:	Right	Left	____
Trial 9:	Right	Left	____
Trial 10:	Right	Left	____
Trial 11:	Right	Left	____
Trial 12:	Right	Left	____
Trial 13:	Right	Left	____
Trial 14:	Right	Left	____
Trial 15:	Right	Left	____

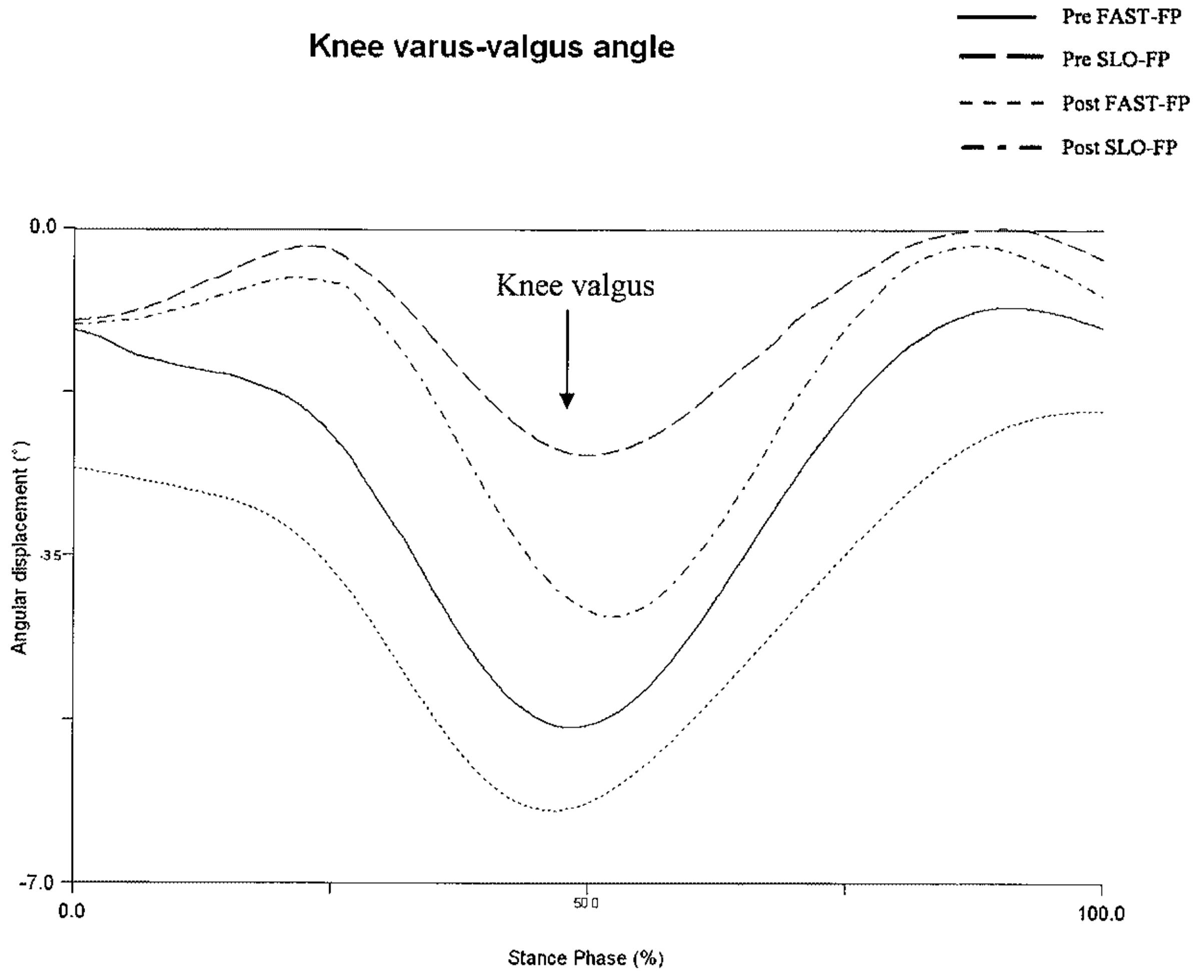
(3) Box-Drop
(√ - valid trial; x – not valid trial)

Trial 1: __________
Trial 2: __________
Trial 3: __________
Trial 4: __________
Trial 5: __________
Trial 6: __________
Trial 7: __________
Trial 8: __________
Trial 9: __________
Trial 10: __________

(1) Dynamic Tasks
(√ - valid trial; x – not valid trial)

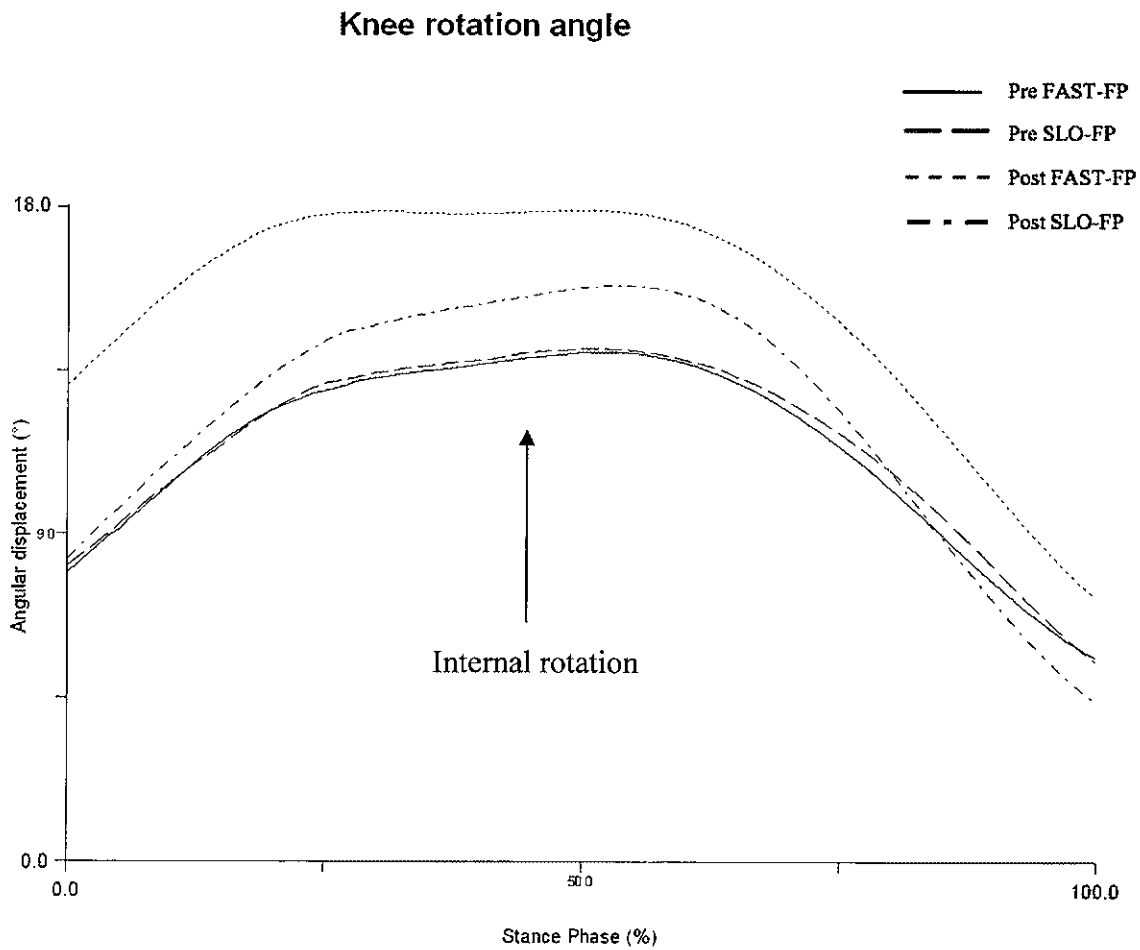
	(Circle task)		Speed	(√ or x)
Trial 1:	Side Step	Pivoting	________	____
Trial 2:	Side Step	Pivoting	________	____
Trial 3:	Side Step	Pivoting	________	____
Trial 4:	Side Step	Pivoting	________	____
Trial 5:	Side Step	Pivoting	________	____
Trial 6:	Side Step	Pivoting	________	____
Trial 7:	Side Step	Pivoting	________	____
Trial 8:	Side Step	Pivoting	________	____
Trial 9:	Side Step	Pivoting	________	____
Trial 10:	Side Step	Pivoting	________	____
Trial 11:	Side Step	Pivoting	________	____
Trial 12:	Side Step	Pivoting	________	____
Trial 13:	Side Step	Pivoting	________	____
Trial 14:	Side Step	Pivoting	________	____
Trial 15:	Side Step	Pivoting	________	____
Trial 16:	Side Step	Pivoting	________	____
Trial 17:	Side Step	Pivoting	________	____
Trial 18:	Side Step	Pivoting	________	____
Trial 19:	Side Step	Pivoting	________	____
Trial 20:	Side Step	Pivoting	________	____

Appendix 6A



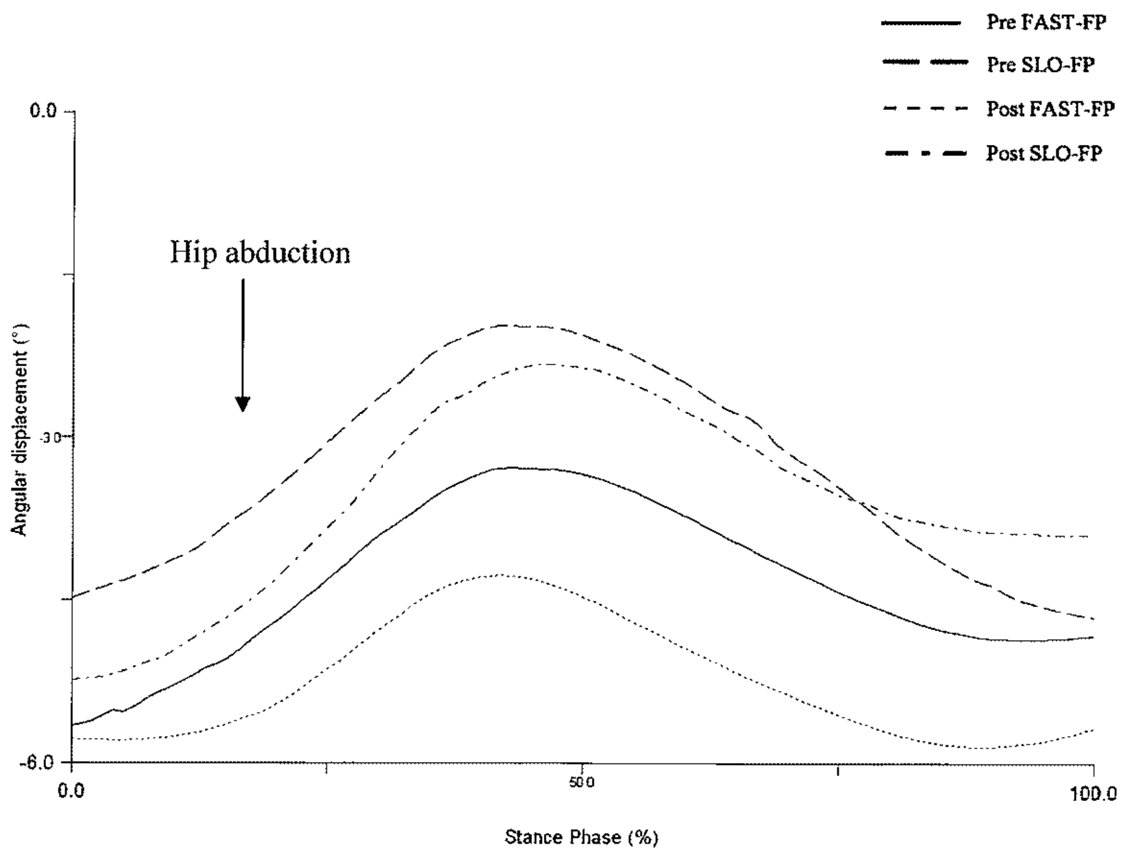
Knee varus-valgus angle
Pre FAST-FP
Pre SLO-FP
Post FAST-FP
Post SLO-FP
Knee valgus
0.0
-3.5
-7.0
Angular displacement (°)
0.0
50.0
100.0
Stance Phase (%)

Appendix 6B


Knee rotation angle
Pre FAST-FP
Pre SLO-FP
Post FAST-FP
Post SLO-FP
18.0
9.0
0.0
Angular displacement (°)
Internal rotation
0.0
50.0
100.0
Stance Phase (%)

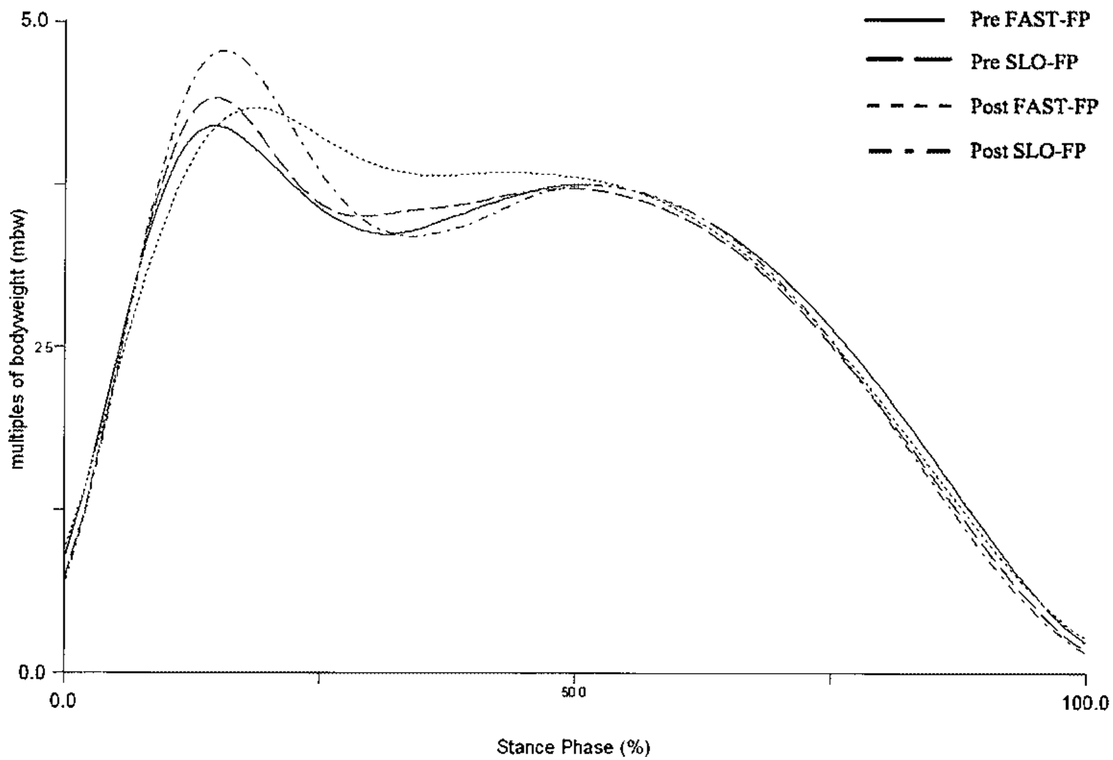
Appendix 6C

Hip abduction angle



Appendix 6D

Vertical ground reaction force



VITA

David L. Quammen

Education

May 2010 Old Dominion University
NATA Accredited Post Professional Athletic Training Education Program
Master of Science in Education
Norfolk, Virginia

May 2008 Minnesota State University, Mankato
Bachelor of Science in Athletic Training
Mankato, Minnesota

Professional Experience

Graduate Assistant Athletic Trainer *August 2008-Current*

Virginia Wesleyan College, Norfolk, VA
Virginia Wesleyan College competes in 16 intercollegiate sports in NCAA Division III Athletics. The Athletic Training department at VWC has two full times ATC's and two graduate assistant ATC's. My responsibilities included primary sports coverage including travel to the following sport teams.

- Men's Lacrosse
- Women's Soccer
- Men's Basketball
- Women's Lacrosse
- Field Hockey

Research Assistant – Old Dominion University *August 2008-Current*

Athletic Training Student – Minnesota State University, Mankato *August 2006-May 2008*

Teaching Experience

Old Dominion University

Co-Instructor *August 2009-Decemeber 2009*
Advanced Prevention and Care of Athletic Injuries (EXSC 340)

Lab Instructor *January 2010-May 2010*
Anatomical Kinesiology (EXSC 322)

CPR-AED Instructor *September 2009*