THE EFFECT OF MUSCLE FATIGUE ON LOWER EXTREMITY KINEMATICS IN PHYSICALLY ACTIVE FEMALES

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

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San Marcos, TX
May 2009

What lies behind us and what lies before us are
small matters compared to what lies within us.
- Ralph Waldo Emerson

Show me the right path, O Lord;
point out the road for me to follow.
Lead me by your truth and teach me,
for you are the God who saves me.
All day long I put my hope in you.
~Psalm 27:4

ACKNOWLEDGEMENTS

First I would like to thank my husband Casey, the one person that has endured the most with me throughout the past two years. I would like to thank you for always listening even when I rambled on and on about my procedures and the problems I encountered. Casey thank you for being a shoulder or a hug I could count on when I felt overwhelmed and not quite like myself. Thank you for understanding when I would laugh or cry hysterically for no apparent reason. Most of all, thank you for believing in me and being there to celebrate my small victories throughout the whole Thesis process. I love you with all my heart, you're the best! Thanks are due to my committee members, including Dr. Jack Ransone, Dr. Luzita Vela, and Dr. Robert Pankey. Dr. Ransone, thank you for always keeping me on my toes and providing constructive feedback throughout my Thesis process. Dr. Vela, your door was always open for my questions or concerns and I greatly appreciate the personal stories we shared this semester, it was very helpful through the couple of mental breakdowns I had. Thank you, Dr. Pankey. I have retained the vital points you taught me in Biomechanics and have used them throughout my Thesis data collection and analysis; thank you for all of your recommendations. This Thesis would not have been possible without all of the subjects that volunteered. I cannot thank you all enough for enduring the fatiguing task that caused most of you a bit of muscle soreness in the days following testing. I would also like to acknowledge the volunteers that assisted me throughout the data collection, including Mike Guerrero, Nate Byerley, Lauren De La Torre, and Shannon Grattan. Last but not least, I would like to thank my Mom, John, Dad and Janet for guiding me to this point in my life. I couldn't have accomplished this milestone and all the others without all of you by my side. Thank you, with love Heather.

This manuscript was submitted on April 8, 2009.

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF ILLUSTRATIONS

Illustrations **Page**

ABSTRACT

THE EFFECT OF MUSCLE FATIGUE ON LOWER EXTREMITY KINEMATICS IN PHYSICALLY ACTIVE FEMALES

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Objective: To investigate the effect of fatigue on dynamic knee valgus and hip joint movement during a single leg squat in physically active females. **Design and Setting**: All data were collected in Jowers Athletic Training Research Laboratory, Texas State University-San Marcos. **Subjects**: Thirty healthy, physically active females (age = 21 ± 2.13 years, mass = 61.02 ± 7.33 kg, height = 167.34 ± 6.08 cm, Q angle = 17.75 ± 2.21 degrees) with no reports of injuries, impairments or surgeries to the low back or lower extremities within the past two years. **Measurements**: All subjects stood on a box (height specified and adjusted according to leg length) and then completed two single leg squats to approximately 70 degrees of knee flexion prior to isokinetic strength testing and after the fatigue protocol. Frontal plane knee motion and sagittal plane hip motion was evaluated and recorded using two 2-D SportsCam High Speed Cameras. Isokinetic (60 deg/sec) concentric knee (flexion/extension) strength was measured and evaluated, followed by an immediate isokinetic (60 deg/sec) concentric knee (flexion/extension) fatigue protocol. Subjects were evaluated as fatigued once they fell below 50% of the previously recorded knee (flexion/extension) peak torque. **Results**: Two paired t-tests for pre and post dynamic knee valgus and hip flexion angles were calculated. A significant difference was found with hip flexion. The mean score on the posttest (136.48 $\pm$ 10.98) showed an increase in hip flexion angle when compared to the pretest (140.43 $\pm$ 10.03); t (29) = 4.05, $p < .01$, accounting for 95% of the variance in the difference between the scores. Paired t-tests for the pre and post mean dynamic valgum revealed no significant difference during the single leg squat as hypothesized. Effect size for the difference between pre and post fatigue dynamic valgum ranged from -1.29 to 3.20 and hip flexion from -3.22 to 4.31 respectively. **Conclusion**: Frontal plane dynamic knee movement showed no significant difference between pre and post fatigue assessments. However, the sagittal plane mean hip flexion angle did report a significant difference between the pre and post fatigue measurements. These results demonstrate the need for further investigation of the role that the knee musculature plays in hip flexion angles during dynamic movement, pre and post fatigue.

CHAPTER I

THE EFFECT OF MUSCLE FATIGUE ON LOWER EXTREMITY KINEMATICS IN PHYSICALLY ACTIVE FEMALES

Introduction

Female athletes, statistically, have a higher incidence rate of knee injuries than their male counter parts.[1] Several studies have focused on the possible causes of the increased risk of injury including anatomical factors include larger Q angle, knee joint laxity, narrower femoral notch, and biomechanical differences such as neuromuscular deficits, knee valgus movement, leg dominance and muscular strength deficits.[2-7] It has been estimated that the majority of athletic injuries occur in the lower extremity at the end of physical activity when most athletes are fatigued.[8-9] These injuries likely result from instability of the hip, knee, and ankle joints due to muscular fatigue.[10] Furthermore, researchers have investigated the effects of fatigue on knee proprioception,[7,11] muscular co-activation,[8] decreased balance,[9] and musculature[12] of the lower extremity.

Purpose

The purpose of this study was to determine the effect of a fatigue protocol of hamstring and quadriceps muscle groups on dynamic knee valgus movement and hip flexion angles, in physically active females, during a single leg squat.

Research Hypothesis

It is hypothesized that dynamic knee valgus movement and hip flexion angle, in physically active females, will increase during a single leg squat when the hamstring and quadriceps muscles are fatigued to at least 50% of the maximum strength.

Operational Definitions

1. Dynamic valgus – Bodily position in which the knee collapses medially from excessive valgus or internal-external rotation or both.[13]
2. Genu valgum – Typically used to describe the knee position in a static pose, also known as knock knee or an inward slant of the femur. Characterized by an abnormal outward turning of the bone, usually seen in the hip, knee and/or foot.
3. Single leg squat – Also known as a unilateral leg squat. Balance is maintained on the weight bearing leg while the non-weight bearing leg is placed in front of the body with the hip flexed, knee in full extension and the ankle dorsiflexed.
4. Physically active – Maintaining exercise at least 3 times a week for 30 minute sessions.

Delimitations

This experiment has certain delimitations or boundaries that could affect the collection and interpretation of data.

1. The subjects were physically active college students between the ages of 18 and 25 years old.

2. Only females were included in this study due to the higher incidence of knee injuries when compared to males.
3. Subjects were asymptomatic, for any lower extremity injuries or trauma, at the time of testing.
4. The precision of physical activity, as reported by the subjects, will not be verified due to time restraints.

Limitations

This experiment has certain inherent limitations that may have an effect on the collection and interpretation of the data. Generalizations made from the results are compromised by the following limitations:

1. The results of this study cannot be applied to those that are not physically active (as defined in the study at least 3 times per week).
2. The results of this study cannot be applied to physically active males.
3. The results of this study cannot be applied to symptomatic males or females.
4. The results of this study are limited to the direct fatigue of the hamstring and quadriceps muscles; therefore, overall fatigue seen in athletic activity may produce a different outcome.

Assumptions

The basic assumptions for this study include:

1. The subjects that agree to participate in this study will be randomly selected.
2. It is assumed that all subjects will perform the tests and exercises with maximum effort.

3. The subjects will complete the medical health questionnaire and questions regarding physical activity level accurately.
4. It is assumed subjects completed the physical fitness and health questionnaire form accurately.

Significance of the Study

This study will attempt to determine the relationship, if any, between exercise and fatigue related biomechanical changes in the frontal (dynamic valgus) and sagittal (hip flexion) planes during a single leg squat in physically active females In addition, the investigation will examine demographics of the Hamstring: Quadricep ratio to uncover any strength imbalances that may play a role in the faulty biomechanics in the lower extremity, as literature previously advocates.[8,14-15] The results of this study will assist healthcare professionals in identifying athletes with biomechanical and strength deficits; therefore, assisting in decreasing the high incident rate of lower extremity injuries in physically active females.

CHAPTER II

REVIEW OF RELATED LITERATURE

Lower extremity kinematic research has focused on determining the anatomical and mechanical differences that may be linked to increase injury rate in female athletes. At the intercollegiate level, one in ten female athletes are unable to complete their season due to knee injuries.[1] This incidence of injuries for females is a 6 fold increase over males.[16] This is an alarming statistic and is evidence enough for additional research to attempt to identify predisposing factors of knee injuries in females and the techniques healthcare professionals can use to decrease this incidence. Normal biomechanics, differences between sexes, muscular strength and fatigue of the lower extremity are all factors that warrant further investigation.

Normal Biomechanics

All the joints of the lower extremity are viewed as a system linked together forming one functional unit.[5] If one joint is injured or displays abnormal biomechanics then the entire limb is affected. When analyzing biomechanics of the lower extremity it is important to determine how one's joint position may influence other joints' biomechanics during physical activities.

Cadaveric knees have been used in research to collect data regarding the amount and direction of strain required to damage the knee joint. When the knee was placed in a valgus moment with slight flexion, the strain on the anterior cruciate ligament (ACL) increased significantly.[17] Females exhibit a larger degree of valgus load during functional sport activities than males, resulting in possible increased strain on the anterior cruciate ligament.[3,18-19] Females are more likely prone to a genu valgum position statically because of the larger Q angle. This dynamic valgus movement tends to cause more strain than any other combination of movement of the femur on the tibia.[17]

Knee injuries can occur, in various sports, either by direct contact or non-contact. Direct contact injuries are typically seen in football, lacrosse, basketball, soccer and occasionally in softball or baseball. On the other hand, females exhibit a greater risk for non-contact knee injuries which commonly occur due to faulty lower extremity biomechanics. The abnormal biomechanics are either learned through the activity, caused by previous injuries or are flawed unintentional techniques, possibly causing injury. Proper lower extremity biomechanics are the foundation to a sound posture, starting from the plantar surface of the feet, and is extremely important to analyze.

Gender

In past research there has been a great deal of debate on the differences in lower extremity biomechanics between males and females.[2-3,5-7] Males and females have anatomical differences that possibly explain the increased risk of knee injuries in females. Possible anatomical causes of this increased risk in females are a larger Q angle, which causes an increase in the dynamic knee valgus angle, narrower femoral notch, and hypermobility of joints.[20] Despite these inherent differences, no significant difference were seen between genders when viewing the hip, knee, and ankle movements during a single legged squat, in the frontal plane.[21] The analysis of the single leg squat is applicable to most sport activities,[21] therefore, the investigation of functional activities may provide more insight on knee injuries.

Krosshaug[13] found that female players, during a jump landing, presented with significantly more knee and hip flexion angles and demonstrated more frequent dynamic valgus knee collapse than their counterpart. Initiating the proper foot landing technique from a jump landing activity, seen in various sports, may influence knee valgus, hip, and knee flexion angles. For example, Cortes et al.[2] observed three different landing techniques, the self-preferred, forefoot, and rear foot, when jumping from a 30 centimeter box and then immediately initiating a vertical jump. At initial contact, hip flexion and knee flexion angles were less with the forefoot landing technique and knee valgus angles were smaller with the self-preferred landing.[2] Both of the above experimental tests used adherent reflective markers which were placed over certain anatomical landmarks and then the subjects were filmed while performing the particular activity. One limitation seen with the use of reflective markers is that they may not accurately reflect bone transitions or rotation that is occurring due to the overlying soft tissue movement.

Joint Mechanics

For screening purposes biomechanists, athletic trainers, and physical therapist must find the most efficient apparatus for recognizing female athletes at risk. There are many ways to accomplish the latter including visual inspection of posture, still pictures, two dimensional, and three dimensional analyses. To effectively examine lower extremity biomechanics, a high-speed motion analysis of a three dimensional activity is needed.[3,22]

Other less costly and observable methods can also be used to help detect potential high risk biomechanical movements of the lower extremity. For example, the use of standard video cameras is a simpler and equally reliable method as the high speed motion analysis system.[3] McLean et al.[6] observed a standard two dimensional video analysis method can successfully identify people that have large valgus knee movement which may increase the risk of future knee injury. The two dimensional video analysis is not only a reliable method to employ it is also less expensive, resulting in more clinical settings being able to use this effective screening tool on their athletes.

Muscular Strength

Muscular strength plays an important role in all joints throughout the body, especially at the knee; the hamstrings, quadriceps, and gastrocnemius resist excessive motion. It has been suggested that, in females and males, as muscular strength increased for the hip abductors, hip internal rotators, knee flexors and knee extensors valgus movement at the knee decreased.[21] McLean et al.[6] observed neuromuscular control of the hip joint and correlations with the knee joint kinematics in the frontal and transverse planes. Furthermore, Jacobs and Mattacola[20] observed higher hip internal rotation and hip flexion angles in women than in men. Women demonstrated 7 degrees more hip flexion and 3.58 degrees greater hip internal rotation when compared to males. The changes in hip motion may be a result of strength deficits in the hip muscular or poor neuromuscular control. The resulting effect of men's hip flexion angles being less than women is that the man's gluteus medius muscle may assist as a hip external rotator and hip abductor limiting the amount of knee valgus movement.[20] In another study by Jacobs,[4] strength and fatigability of the dominant and non-dominant hip abductors was investigated in 42 healthy subjects (23 males, 19 females), it was concluded that hip abductor strength differences do exist between the dominant and non-dominant legs. These strength imbalances may increase the incidence of injury by causing flawed biomechanics throughout the lower extremity kinetic chain.

Reliability of Isokinetic Testing

Muscular strength testing is normally performed with an Isokinetic dynamometer, which has been shown to be reliable. Isokinetic testing with the Biodex System has been evaluated for level of reliability and for subject learning effect over time. Lund et al [23] witnessed that by instructing the subject through the various tests on the Biodex System 3 PRO the data were highly reliable and the learning curve effect was nonexistent. This work is supported by previous research that observed the equivalent reliability in a clinical setting.[8] Reliability increased when the subjects were on the device for brief periods of time instead of frequent testing.[23] It appears that Biodex Isokinetic testing is an efficient tool to utilize for testing muscular strength on patients or athletes.

Hamstring: Quadriceps Ratio

The hamstrings and quadriceps muscles cross at the knee joint helping to resist anterior and posterior translation of the tibia on the femur. It has been shown that if the strength of the hamstring muscles is 60–70% of the strength of the quadriceps muscles this will assist in increasing the proper tension needed at the knee joint to avoid potential injury. The ratio between the two muscles should be 2 to 3 respectively; however, most individuals have less strength than normal in either the hamstring or quadriceps.[14,24] Hamstring: quadriceps ratios are assessed prior to surgery or in postsurgical cases to identify deficits and improvements throughout the rehabilitation process. This ratio may also be used as a tool to predetermine an increased risk of possible knee injury in athletes or patients. There is contradicting results in past research, one study found that the hamstring: quadriceps ratio is the same between sexes and various sports; therefore, specific sports were not at an increased risk of injury due to an abnormal ratio[25] and another study observed no significant interactions for men and women throughout various sports.[26] Further research is needed to come to a more definite conclusion regarding the connection between hamstring: quadricep ratios, gender and various sports.

Hip Abductors

Not only is the hamstring: quadriceps ratio important to knee stability but it has also been shown that overall hip musculature plays an important role in normal knee kinematics.[20-21] A study by Jacobs[20] found that a decrease in hip abductor strength increased the knee valgus angles at the knee, in women, when landing from a jump. In the same study women displayed larger hip flexion and knee valgus angles than men. This may be due to a lack of neuromuscular control during the eccentric contraction of the hip external rotators and abductors.[6] Neuromuscular control involves the communication of nerves and the skeletal muscles in conjunction with feedback from the muscular tissue to maintain stability and normal function of the joints throughout the body. The valgus movement at the knee is one of the leading causes in non-contact knee injuries and could lead to an increased chance of future mechanical knee breakdown.[21] The overall consensus in the literature is by increasing and maintaining hip strength the knee stability will likely be increased during static posture and dynamic lower extremity activities. In another study, Hewett[27] investigated the effects of lower extremity plyometric drills, strength and flexibility exercises and found that there was a significantly lower incidence of knee ligament injury in those female athletes that participated than in those that did not participate in the same training protocol. Accordingly, it is of high importance to maintain hip eccentric strength to reduce the dynamic knee valgus angle resulting in decreased stress placed on the knee.[20-21] Hip abductor, hamstring, and quadriceps strength is essential during the single leg squat to assist in decreasing movement of the femur on the tibia.[21] Although most previous research has concluded that knee valgus angles increase due to strength deficits in the hip abductor muscles,[20-21] at least one study reported no correlation between hip abductor strength and varus or valgus movement at the knee.[39]

Fatigue

In general, fatigue is categorized as a form of physical breakdown or decrease in muscular strength. When muscles are fatigued through physical activity the muscular contractions and neuromuscular control of the joint begins to decrease. One probable cause may be due to the sarcoplasmic reticulum calcium release and calcium uptake. Hill et al.[28] looked at the changes in calcium release and uptake at rest and immediately after a lower extremity fatiguing exercise. The results showed a 35% decrease in calcium release following exercise when compared to calcium release at rest.[28] There is a minute amount of literature on the functions of the sarcoplasmic reticulum and the effects on muscle force production; however, this may be one of the underlying causes of injury. Overall, research has identified that muscular fatigue is a leading factor in causing mechanical failure at the knee joint in physically active females.[8,11,18,29,30-32]

Muscular Fatigue

Previous studies have focused on the differences between sexes on lower extremity biomechanics. Rozzi et al.[7] found that during EMG peak amplitude testing of the lateral hamstrings during a landing activity, females lateral hamstrings displayed a greater peak amplitude and area of the muscles being used than the male counterpart. Therefore, Rozzi[7] suggests that females may be subconsciously compensating with other synergist muscles to stabilize the knee during functional activities.

Muscle co-activation is the coordinated movement of two opposing muscles which enable stability at a specific joint. The hamstring and quadricep muscles have shown an increase in muscular activation during closed kinetic chain activity. Once the hamstring and quadriceps were placed under a fatigued condition the EMG data showed a significant increase in vastus medialis, vastus lateralis and biceps fermoris contraction. This study concluded that co-activation does occur during a forward lunge because both muscles fatigued as a unit during the exercise.[8]

Once muscles are fatigued, position matching of the joint is disrupted resulting in proprioception inaccuracy which might be a contributing factor to lower extremity injury.[11] Rozzi et al.[7] examined the lower extremity and found that both eccentric and concentric exercise of the quadricep muscle resulted in disruption of proprioception. Subjects identified that their exercised muscle was actually longer resulting in matching errors.[11] Position sense at the knee joint was also examined in a study by Skinner[12] which determined that there was a worsening in knee joint positioning post fatigue. This study identified a significant correlation between joint repositioning and fatigue of the muscle receptors at the knee joint. Fatigued muscles have also shown an increased shear force at the tibia in physically active females when performing a quick stop followed by an immediate jumping task.[18,29] EMG testing has documented that the hamstrings and quadriceps activation increased during the forward lunge causing co-activation resulting in more stability at the knee.[8] Fatigue is also a cause for faulty biomechanics due to slower nerve conduction to muscles being used for the activity. Marks's[33] study found no significant changes when looking at the effect of fatigue on muscular contraction in accuracy of knee positioning post quadriceps fatigue. These varying results could be due to the small sample size in Marks's[33] study or to not fatiguing multiple muscles in the lower extremity.

Single Leg Squat

The single leg squat has been utilized throughout research literature as a dynamic exercise that mimics a variety of sport activities commonly seen in athletics. Strength of the hip and knee musculature, neuromuscular control, balance and coordination are variables needed to perform the single leg squat with proper form and to the accurate level to achieve a certain amount of knee flexion, dependent on the study methods. Previous research has set the amount of knee flexion needed during the single leg squat between 60 – 90 degrees.[16,21] It is at this point in which researchers have observed a breakdown in the dynamic knee movement during a single leg squat.

Summary and Conclusions

Lower extremity injuries are perhaps associated with several anatomical and biomechanical factors that can be altered through proper training. In one study by

Hewett,[34] female athletes were prescreened for ACL injury to determine if there was a decrease in neuromuscular control or increase in valgus loading, it was concluded that knee motion and loading during a landing task were clinically significant predictors of ACL injury risk in female athletes. Future research should focus on prescreening female athletes for lower extremity neuromuscular control, faulty biomechanics, strength, and fatigue, which will assist healthcare professionals in identifying high risk athletes prior to sports participation,[7,11] therefore, biomechanical functions or muscular deficits can be addressed and altered through training to prevent pre and post fatigue injuries.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine the effect of a fatigue protocol (hamstring and quadricep muscle groups) on frontal plane, dynamic valgus movement, and sagittal plane, hip flexion angles, in physically active females during a single leg squat.

Subjects

The subjects (n=30), that completed the study, were healthy and physically active females between the ages of 18–25. Recruitment was open to undergraduate and graduate students at the Texas State University-San Marcos campus in the Department of Health, Physical Education and Recreation. For inclusion subjects participated in physical activity for 30 or more minutes per day at least 3 to 5 times per week for at least the past 6 months. The principle investigator reviewed the general reasons for conducting the study, the step by step procedures, and requirements to maintain physical activity until the subject had completed testing and then answered any questions regarding the study. The main incentives for participation in this study, was to be informed on biomechanical and potential deficits at the knee joint and the fatigue level for the hamstrings and quadriceps. Each participant was required to complete their informed written consent and a medical history questionnaire (Appendix A-B). Subjects were excluded from the study if they had any previous low back, knee, or ankle injuries. These injuries included disk herniation, sciatica, ACL sprains or complete tears, rupture of the achilles tendon or surgeries involving the low back, knee, or ankle in the past 2 years. All subjects were required to perform range of motion (ROM) testing including: hip flexion, flexion and extension of the knee, plantarflexion and dorsiflexion of the ankle and a body squat to verify normal ROM at the hip and knee joints. Leg dominance was identified by asking the subject which leg they would use to kick a soccer ball. In addition, Q angle measurements were used to assess the resting knee genu valgum angle of the subject's dominant leg. Q angle was evaluated by having the subject lay supine and marking the anterior sacroiliac spine (ASIS), the midpoint of the patella and the tibial tuberosity (Illustration 1). The foot was then placed in a neutral position, which was determined by the principle investigator and has been shown to be reliable, according to Livingston.[35] A goniometer was then positioned so that the axis was located over the midpoint of the patella, the stationary arm over the line from the ASIS to the patella and the moving arm was placed over the line from the patella to the tibial tuberosity.[36-37] Q angle measurements were taken 3 times and then averaged, subjects that had a Q angle measurement that was greater than 20 degrees were excluded from participating in this study[36-37] (Table 1). Each subject was issued a number to differentiate the results found between subjects and to maintain the confidentiality of the subject's data collection which was recorded on the Subject Information Sheet (Appendix C). All subjects provided written informed consent in accordance with the Institutional Review Board at Texas State University-San Marcos.

<u>Instrumentation</u>

The testing for each subject was performed in one session at Texas State University-San Marcos in the Athletic Training Research Laboratory and Rehabilitation Room. The research laboratory had the required equipment including a Biodex 4 Isokinetic Dynamometer (Biodex Medical Systems Inc., Shirley, NY), two SportsCam High-Speed Digital Camera with 17 mm .95 lens (Fastec Imaging Corp., San Diego, CA), and two steps with several ½ inch plywood sheets, to vary the step height, and two clamps to secure the box. The warm-up and cool-down was completed on an Precor EFX 544 Elliptical Fitness Crosstrainer (Precor Inc., Bothell, WA) located in the Athletic Training Rehabilitation Room. Box height was varied to accommodate for subject's leg length differences to ensure that each subject reached at least 70 degrees of knee flexion once the heel of the non dominant leg touches the floor during the single leg squat. The primary investigator was present for all data collection and conducted every data collection session according to the step by step procedures (Appendix D).

PROCEDURES

Pre Fatigue Single Leg Squat

The principle investigator placed reflectors on the subject's ASIS, tibial tuberosity, lateral joint line of the knee, lateral edge of the acromion process, anterior distal tibia between malleoli and the lateral malleolus on the dominant leg. Subject's leg length of the dominant leg was measured to determine the box height that was used for each subject to reach at least 70 degrees of knee flexion once their heel touched the floor during the single leg squat. The leg length and box height chart was composed during the pilot study at that time it was determined that a 33 inch leg length required a box height of a small step (4 inches) plus 2 sheets of plywood (1 inch) equally a total of a 5 inch box height. The pilot study was used as the base for determining box height throughout the data collection for every ½ inch increase or decrease, in leg length, added on 1 plywood sheet (½ inch). The leg length and box height chart was referenced for each subject during data collection (Appendix E). Once all reflectors were secure the subjects warmed up on an elliptical for 10 minutes and stretched the muscles of the lower extremity. Subjects were then given instructions on how to perform a single leg squat correctly. All subjects were instructed to squat down on one leg, the dominant leg, while stabilizing the non-weight bearing leg out in front of the body, keeping the hip flexed, knee extended and the ankle in dorsiflexion. The subject was then instructed to touch the heel of their non-weight bearing leg onto the floor without transferring their weight as the primary investigator verifies that the subject kept their head up and continued to maintain their body weight through the heel of the dominant leg during the single leg squat. The primary investigator made sure that the subject squatted straight down through the heel of the weight bearing leg and that the subject only touched the ground with the heel of their non weight-bearing leg. All subjects then completed a practice single leg squat exercise on a box and the principle investigator assured that their form was acceptable. Each subject then executed three single leg squats on a box with their dominant leg, while being recorded from the frontal and sagittal view. Due to incomplete data collection only two repetitions of the single leg squat were accepted for statistical analysis.

Hamstring: Quadriceps Strength Testing

Once subjects completed the single leg squat exercise they were then instructed through testing of their hamstring: quadricep muscles peak torque measurements with the Biodex 4 Isokinetic Dynamometer. Subjects were set up on the Biodex machine by the primary investigator using manufacturer suggested testing position. The subject was then seated upright and the chair was adjusted (forward or backward and up or down) to assure that the lateral joint line of the knee was aligned with the axis of the isokinetic moving arm. The reference numbers for chair position, on the Biodex machine, was documented for each subject. The subject was secured into the seat with a seat belt across the waist and another strap across the thigh of the leg being tested. There was another set of restraints placed across the subject's torso. Once the subject was secured in the chair, the ROM limits were set for the limb being tested. Each subject then performed 5 repetitions of concentric knee flexion/extension at the preset angular speed of 60 degrees per second.

<u>Fatigue Protocol</u>

After strength testing was completed the subjects then completed the fatigue protocol on the Biodex machine. Each subject remained seated on the Biodex machine and performed a maximal effort contraction of the quadriceps and the hamstrings at 60 degrees per second. Subjects were given verbal encouragement by the principle investigator and research assistant to motivate them throughout the exercise. Once the subject completes three consecutive repetitions that fall below 50% of the maximum peak torque recorded from the strength testing protocol, it was determined that the subject had reached a fatigued state.[15] The number of repetitions was recorded and identified as the fatigued state for the subject.

<u>Post Fatigue Single Leg Squat</u>

Immediately following the fatigue protocol, subjects completed the single leg squat exercise on the fatigued leg. Subjects were recorded from the frontal and sagittal view with the SportsCam High Speed Cameras. The SportsCam High Speed Cameras captured the single leg squat prior to the initial movement and continued recording for 5 seconds after the 3 repetitions were completed. During the post fatigue single leg squat subjects were given verbal instructions throughout the repetitions and were supervised by the principle investigator to prevent possible injury. Following the last set of single leg squats subjects were instructed to cool down on the elliptical machine for 5 to 10 minutes and then stretch the lower extremity muscles. The principle investigator educated each subject about delayed onset muscle soreness (DOMS) and how to alleviate potential discomfort following testing. This included suggesting that the subject stretch the hamstrings and quadriceps frequently in the next few hours and to complete a cool down activity. Furthermore, subjects were instructed that they could take over the counter (OTC) medication, either Aleve or Ibuprofen, the day of testing and one to two days following testing to help avoid minor muscular edema and pain. It was suggested that the subject make sure to take the OTC with food to avoid an upset stomach which is occasionally seen when taken on an empty stomach with Aleve and Ibuprofen.

Statistical Analysis

This study attempted to identify the effects of fatigue on the frontal plane (dynamic knee valgum) and sagittal plane (hip flexion) movement during a single leg squat. The frontal and sagittal plane single leg squat angles were calculated with Dart Fish Data Analysis computer software. The Dart Fish software was used to assess the frontal plane dynamic valgum by drawing a plumb line through the tibial tuberosity and measuring the angle from the mid patella to the ASIS to the plumb line. An initial measurement of dynamic knee valgus angle was taken prior to the downward motion of the single leg squat and then was taken once the subject's heel touched the floor. The dynamic knee valgus angle was taken for the initial and max knee flexion for all single leg squat reps. The mean was then calculated for the frontal plane dynamic knee valgus angle for the initial and max knee flexion difference, pre and post fatigue. Sagittal plane hip flexion was assessed when the subject reached max knee flexion by measuring the angle from the lateral shoulder, hip and knee joint markers. The mean hip flexion difference angle was calculated from all of the single leg squat repetitions, pre and post fatigue.

CHAPTER IV

MANUSCRIPT

Key Words: single leg squat, static knee valgum, dynamic knee valgum, Q angle

Introduction

The incidence of lower extremity injuries has been shown to be six fold higher in female athletes than their male counterparts.[1,3] Research has focused on several factors that could lead to this increased rate including anatomical factors such as quadriceps angle (Q angle), biomechanical deficits, Hamstring: Quadricep ratio (H:Q ratio), and hormonal levels.[3,5-8,18,20-21,39] Q angle is a clinical measure of the static posture of the quadricep muscle as it is related to the anterior sacroiliac spine (ASIS), mid patella and tibial tuberosity and ranges between 15 to 20 degrees in females.[36] A larger Q angle indicate a more static knee valgum position, known as knock knee. Whereas smaller Q angle measurements place the knee in more of a static knee varum position, known as bow legged. This study is examining dynamic knee valgum by measuring the Q angle during the single leg squat. Dynamic knee valgum describes the position of the knee during activity wherein the knee collapses medially from excessive valgus or internal-external rotation or both.[13]

Fatigue is one underlying factor that may also contribute to lower extremity injuries which are most commonly observed in athletes toward the end of practices or competitions when the musculature that supports the joints is exhausted.[10] Fatigued muscles cause a decrease in neuromuscular control, motor control strategies, postural control, decreased muscle activity, decrease in overall strength and effectiveness of the muscle to support the joints that they surround leading to potential knee injuries.[7,9,11,18,25,31,40-44] Chapell[18] observed 20 subjects (10 males and 10 females) during a stop jump task that resulted in a significant increase in peak proximal tibial anterior shear forces, decreased knee flexion angles and an increase in valgus moments in male and female subjects when fatigued. Johnston[10] reported a significant decrease in motor control seen in 20 subjects during static balance testing following a fatiguing task. Other studies by Skinner[12] and Rozzi[7] thoroughly investigated the effects of fatigue on knee joint position sense which resulted in a statistical decrease in knee joint kinesthesia and kinesthetic awareness after lower extremity fatigue. These studies identified strength as a prominent factor in the stability of joints during exercise which may play a role in the breakdown seen after fatigue. In support of this theory, Claiborne[21] examined the strength of the hip abductors, knee flexors and knee extensors and found a negative correlation between peak torque and the amount of knee valgus movement observed during a single leg squat without fatigue. In response to previous evidence proper screening of athletes to identify and improve lower extremity faulty biomechanics and strength deficits could lead to a decrease in the lower extremity injury rate in females. Previous research has focused on the outcomes of fatigue on lower extremity position sense, neuromuscular control and biomechanics during various activities; however, there is a lack of evidence regarding the effects of complete fatigue of opposing muscles on the frontal and sagittal plane movement during a single leg squat. Therefore, the purpose of this study was to investigate the effects that fatigue has on the frontal (knee valgus) and sagittal plane (hip flexion) in physically active females during a single leg squat.

METHODS

Subjects

Thirty healthy and physically active females (age = 21 $\pm$ 2.13 yrs, mass = 61.02 $\pm$ 7.33 kg, height = 167.34 $\pm$ 6.08 cm) volunteered to participate in this investigation. The inclusion criterion included females, between the ages 18 to 25, that were physically active for at least the past 6 months. This study targeted the female population due to a higher incidence of knee injuries when compared to males. Physical activity in this investigation was defined as at least 3 to 5 times per week for at least 30 minute sessions each. Each subject self reported the types of physical activity they were involved in. This included one or more of the following activities: cardio (walking, running, stair stepper, elliptical, biking, swimming, basic aerobics, step aerobics, UBE), resistance training (free weights, weight machines, abdominal exercises, yoga) and extracurricular activities (ballet, dance, basketball, cheerleading, hiking, soccer, racquetball, tennis, volleyball). Subjects were not accepted to participate if they had surgery or an injury to their low back, thigh, lower leg, ankle or foot within the past two years. Subject's Q angle (Q angle = 17.75 $\pm$ 2.21 degrees) was assessed by measuring the angle from the ASIS, mid patella and tibial tuberosity on the dominant limb three times then averaged (Illustration 1). The dominant leg was identified by asking the subject which leg they would use to kick a soccer ball and Q angle was determined. Subject's with a mean Q angle greater than 20 were excluded from the study (Table 1).

Illustration 1. Q angle Measurement

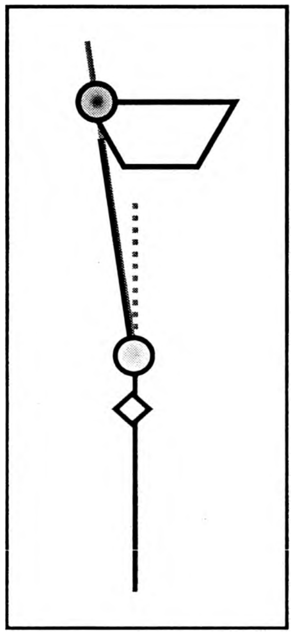


Table 1. Q angle Demographics (n=30)

MEAN	17.75
SD	2.25
MIN	11
MAX	20

Before participating subjects were warned about the possible risks, including delayed onset muscle soreness (DOMS) due to the fatigue protocol. All subjects completed a consent form and medical health questionnaire prior to participation. This study was approved by Texas State University-San Marcos Intuitional Review Board.

<u>Instrumentation</u>

A Biodex 4 Isokinetic Dynamometer (Biodex Medical Systems Inc, Shirley, NY) was used to perform concentric knee flexion and extension strength testing and the fatiguing task at the knee joint. During the single leg squat two SportsCam High-Speed Digital Cameras with a 17 mm .95 lens (Fastec Imaging Corp, San Diego, CA) were used to capture the frontal plane (dynamic knee movement) and the sagittal plane (hip flexion angle) following a muscle fatigue protocol. For a consistent downward and upward motion, during the assessment of a single leg squat, a metronome was set at 46 beats per minute (www.metronomeonline.com). Box height varied according to the subject's leg length; ensuring subjects reached approximately 70 degrees of knee flexion once their heel of the non-dominant leg touched the floor during the single leg squat. The leg length and box height chart was composed during the pilot study. The pilot study was used as the base for determining box height throughout the data collection. For every ½ inch increase or decrease, in leg length, added on 1 plywood sheet (½ inch) to the box height (Appendix E).

Procedures

Prior to the testing session, the primary investigator measured the subject's dominant leg length, from the ASIS to the medial malleolus, the Q angle, (Illustration 1) the angle between the mid-patella, tibial tuberosity and ASIS, and completed an orthopedic screen, looking for normal ROM at the hip, knee and ankle. Subjects self reported their age, height, weight and physical activity level which were documented on the Subject Information Sheet (Appendix C). Once the screening was complete each subject began a warm-up on an elliptical machine for about 5 to 10 minutes. Following the warm up subjects were instructed to lightly stretch their dominant leg muscles. The investigator placed reflectors on the following landmarks: ASIS, just inferior to the acromion process, greater trochanter, tibial tuberosity, lateral knee joint line, lateral malleolus, and the distal tibia half way between the malleoli. Once all reflectors were in place the primary investigator demonstrated the proper form and technique to use for the single leg squat. Subjects were instructed to stand on their dominant leg on a box with their non-weight bearing leg fully extended in front of the box. The hip of the non-weight bearing leg was slightly flexed thus positioning the leg in front of the box allowing the foot to clear the box on the downward motion of the single leg squat. A metronome, set at 46 beats per minute, was used to consistently guide the subject through the downward motion, one beat, and the upward motion, one beat. Subjects were instructed to squat down to the rhythm and touch the heel of the opposite foot on the floor in front of the box. Subjects were allotted 3 repetitions of the single leg squat to practice and the principle investigator assured that their form was correct. Both the pre and post single leg squat repetitions were recorded at 125 frames/second from the frontal and sagittal view with the SportsCam High Speed Cameras. For the pre fatigue single leg squat the subjects performed three single leg squats on the box with the dominant leg. Due to incomplete data collection only two repetitions of the single leg squat were used for statistical analysis. Biodex set-up followed the knee protocol provided by the manufacturer. Subjects were oriented with the machine by the principle investigator. The strength protocol was set at 60 degrees per second for 5 concentric flexion and extension repetitions. The fatiguing protocol was set at 60 degrees per second and was not limited by repetitions. Subjects continued concentric knee flexion and extension until both the hamstrings and quadricep muscles were unable to reach at least 50% of their strength from the previously recorded peak torque testing for both the quadriceps and hamstring muscles. During the strength testing and fatigue protocol subjects were verbally encouraged and cheered on throughout the exercise.

Directly after the fatiguing task the subjects repeated the step-down task procedures to determine the post fatigue values. Subjects were told to do a cool down exercise, stretch the hamstring and quadricep muscles of the test leg and encouraged to take over the counter (OTC) non steroidal anti-inflammatory drugs (NSAIDS), either Ibuprofen or Aleve with food, starting immediately to help decrease any discomforts they may experience from the testing procedures.

This study attempted to identify the effects of fatigue on the frontal plane (dynamic knee valgum) and sagittal plane (hip flexion) movement during a single leg squat. The frontal and sagittal plane single leg squat angles were calculated with Dart Fish Data Analysis computer software. The Dart Fish software was used to assess the frontal plane dynamic valgum by drawing a plumb line through the tibial tuberosity and measuring the angle from the mid patella to the ASIS to the plumb line. An initial measurement of dynamic knee valgus angle was taken prior to the downward motion of the single leg squat and then was taken once the subject's heel touched the floor. The dynamic knee valgus angle was taken for the initial and max knee flexion for all single leg squat reps. The mean was then calculated for the frontal plane dynamic knee valgus angle for the initial and max knee flexion difference, pre and post fatigue. Sagittal plane hip flexion was assessed when the subject reached max knee flexion by measuring the angle from the lateral shoulder, hip and knee joint markers. The mean hip flexion difference angle was calculated from all of the single leg squat repetitions, pre and post fatigue.

Statistical Analysis

Data analysis was performed using paired t-test for pre and post fatigue mean valgum and hip flexion angles. SPSS software (version 15.0: SPSS Inc, Chicago, IL) was used to calculate the statistical analyses. Cohen's d was calculated to determine size of effect on the difference between pre and post fatigue for dynamic valgum and hip flexion with

95% confidence intervals (CIs). The effect size (ES) strength was assessed based on the following guidelines given from Cohen values less than 0.4 were weak; from 0.41 to 0.7 are moderate and more than 0.7 as strong.[38]

Results

Demographics were completed on the hamstring and quadricep peak torque strength testing, H:Q ratio, total work output during the fatigue protocol, and for the repetitions to fatigue for the fatigue protocol (Table 3). Specifically the H:Q ratio (53.5 ± 1 91) demonstrated that subjects did not meet the ratio of 2 to 3 that has been previously suggested to maintain stability at the knee joint.[8,14-15]

Table 2. Data Collection Variables

Variable (x)	Mean ± SD	Min	Max
Q-Peak Torque	94.47 ± 18.05	66.9	149.3
H-Peak Torque	53.5 ± 1.91	36.5	82
Q:H Ratio	0.57 ± 0.07	0.45	0.73
Total Work (fatigue)	3712 ± 1559.98	1733	7918
Q-Reps to Fatigue	45 ± 23.55	17	100
H-Reps to Fatigue	40.3 ± 23	12	100

A significant difference was found in the pre and post fatigue hip flexion angle. The mean score on the posttest (136.48 ± 10.98) showed an increase in hip flexion angle when compared to the pretest (140.43 ± 10.03); $t(29) = 4.05$, $p < .01$. A smaller hip flexion angle indicates an increase in hip flexion while a larger angle signifies an upright position. These results demonstrate that the mean hip flexion angle increased after the fatigue protocol. It was also hypothesized that there would be an increase in the frontal plane post fatigue; however, no significant differences were observed in the dynamic knee valgum movement between pre (1.07 + 2.82) and post (2.81 ± 9.72) single leg squat t-test values. The ES analyses for pre and post dynamic knee valgum range was d=0.28 (95% CI -1.29 to 3.20) and hip flexion was d=0.38 (95% CI -3.22 to 4.31) indicating a weak level of clinical significance for both variables (Table 4).

Table 3. Cohen's d

X	Mean	SD	
Pre DV	1.07	2.82	-.028 (95% CI -1.29 to 3.20)
Post DV	2.81	9.72	
Pre HF	140.43	10.04	0.38 (95% CI -3.22 to 4.31)
Post HF	136.48	10.98	

Discussion

The purpose of this study was to identify the effects of fatigue on the frontal plane (dynamic knee valgum) and sagittal plane (hip flexion) during the single leg squat in physically active females. It was hypothesized that fatiguing the hamstrings and quadricep muscles to at least 50% of their peak torque would show an increase in the frontal plane, knee valgus movement, and sagittal plane, hip flexion angle. This study did not result in a significant difference in the frontal plane dynamic knee valgum movement during the single leg squat between pre (1.07 ± 2.82) and post (2.81 ± 9.72) fatigue. These findings oppose a study that looked at 20 subjects and concluded that after fatigue of the hip-abductor muscle participants landed in a greater valgus orientation than compared to pre fatigue testing.[33] Another study demonstrated a significant increase in valgus moments in 20 subjects during a stop-jump task following a fatigue exercise.[18] These differences seen between this study and previous research may be due to the need for three-dimensional videography. This study was limited to a two-dimensional analysis of the frontal plane resulting in the inability to assess rotation at the hip and knee joint during the single leg squat. On the other hand, this study found significant differences in pre and post mean hip flexion angles consistent with previous research in regards to increased hip angles due to fatigue.[13,30] The mean score on the posttest (136.48 $\pm$ 10.98) showed an increase in hip flexion angle when compared to the pretest (140.43 $\pm$ 10.03); $t(29) = 4.05$, $p < .01$. A study that evaluated 10 subjects for changes between shock attenuation during a single-leg landing found no significant difference; however, there was an increase observed in hip joint work which is thought to be a compensatory response seen occasionally after a fatiguing bout of exercise.[30] Various mechanisms of knee injury have been researched one such study looked at the mechanism of ACL injury in 39 basketball players (17 male and 22 female) and found that female players had a significant increase in knee and hip flexion when landing from a jump than males. Furthermore it was found that females are at a 5.3 times higher risk of injury due to valgus collapse.[13] Conversely, 11 subjects were observed after fatigue during a single leg hop test and demonstrated adapted hip strategies of less hip flexion and knee flexion post quadricep muscle fatigue.[45] The results of this study may possibly be altered by fatiguing multiple muscles instead of the quadriceps muscle alone.

Research has shown that once muscles in the lower extremity are fatigued there is a compensatory response, either increased or decreased hip flexion, possibly caused by the center of gravity shifting due to a decrease in motor control. As the center of gravity shifts the body will compensate either by increasing or decreasing the angle at various joints to maintain balance and avoid a fall. When hip flexion is increased the hamstring muscles are placed in a lengthened position.[37] The hamstrings might assist as a stabilizer at the knee joint to help resist anterior translation of the tibia and once this muscle is lengthened this function may be less effective increasing the chances of knee injury. Further research is necessary to determine the primary muscles involved in this compensatory response and other common activities that may alter lower extremity kinematics during activity.

As indicated in the results there was no significant difference found regarding our previous hypothesis on the effects of fatigue on the frontal plane knee movement. The mean dynamic knee valgus angle measurement did not produce enough evidence for a significant finding. This lack of statistical evidence may be due to limitations of this study.

Conclusion

Hamstring and quadricep isokinetic induced fatigue resulted in a significant increase in hip flexion angles during a single leg squat in physically active females, when compared to pre fatigue. Mean pre fatigue hip flexion angles were larger, due to a more erect position, but once the muscles were fatigued the mean post fatigue hip flexion angles decreased signifying an increase in hip flexion. It has been concluded that by incorporating decline single leg squat exercises can help to increase the performance at the hip, knee and ankle joints by stimulating various muscles around the joint depending on the set angle of decline.[46] Future investigations should analyze various sport and rehabilitation exercises and integrate fatigue into the training programs to help prepare the lower extremity for non-laboratory setting activities.

CHAPTER V

CONCLUSIONS, APPLICATIONS AND RECOMMENDATIONS

Conclusions and Applications

The following study investigated the effects of fatigue on the mechanical breakdown at the knee and hip joint during a single leg squat in physically active females. It was concluded that there was a significant difference between the pre and post hip flexion angles during the dynamic exercise. Research has shown that females tend to use compensatory muscular activity to assist in dynamic movements once the muscles around the joint are at a fatigued state.[13,30,35] No significant difference was observed, as previously hypothesized, with dynamic knee valgum movement pre and post the fatiguing task of the hamstring and quadriceps. Healthcare providers should account for the effects of fatigue in lower extremity kinematics when incorporating dynamic exercise into training and rehabilitation programs. Athletic Trainers and coaches can screen for incorrect biomechanics during exercise when the lower extremity is fatigued and then assist in reestablishing motor control and strength to the lower extremity kinematic chain.

Recommendations

The data collection of this study encountered some limitations due to technical error when using the SportsCam High Speed Cameras. Originally, three repetitions of the single leg squat were going to be completed pre and post fatigue; however, the cameras only captured 2 or less repetitions on 10 of the subject's single leg squat exercises.

Resulting in the remaining subjects (n = 30) having at least 2 repetitions of pre and post fatigue single leg squats from the frontal and sagittal view, still enabling a mean to be calculated and analyzed. The lack of a significant finding for the frontal plane, dynamic knee valgus, could be a result of the low statistical power due to the camera malfunction which caused 10 subjects to be dropped from the study. A larger sample size was needed because of the effect size for the study. Future studies, should obtain more than 3 repetitions; therefore, making certain they collect all necessary data. Another limitation for the analyses of the frontal plane data was the lack of a reflector marker over the mid patella for proper dynamic knee valgum angle measurement When analyzing the data with Dart Fish the patella was identified by marking midway between the medial and lateral femoral condyles just above the tibial tuberosity. Last but not least, even though the reflective markers were placed on the subjects in a consistent manner, the markers inherently move with the skin not giving a definitive depiction of the underlying bony anatomy.

The present study did not investigate the relationship between hamstring and quadricep muscle strength and pre and post frontal plane knee and sagittal plane hip motion; however, other relevant studies[30,39] have evaluated further hip musculature which resulted in no correlation to overall movement in either the frontal or sagittal plane, during dynamic exercise, following a fatigue protocol of the lower extremity. Only H:Q ratio demographics (53.5 $\pm$ 1.91) were completed in this study and demonstrated that subjects did not meet the ratio of 2 to 3 that has been previously suggested to maintain stability at the knee joint.[8,14-15] Further research is warranted to investigate if there is a correlation between strength (H:Q ratio) and lower extremity breakdown during dynamic exercise. It is recommended that future studies assess physical activity level with physical fitness testing (i.e., 3 minute step test, Cooper 1.5 mile test, body fat analyses, etc). Therefore, verifying that the activity level of the subject is accurate for the testing protocol. Research should establish a more intensive bout of physical activity to accurately assess the amplitude of stress that the lower extremity joints are under during specific sport activities. Additional research is needed to investigate the effects of fatigue to multiple muscles in the lower extremity during dynamic exercises commonly done in training and rehabilitation programs. By identifying lower extremity kinematic breakdown, due to fatigue, Athletic Trainers, coaches and strength and conditioning coaches, can incorporate certain training protocols to decrease the faulty biomechanics thus reducing the injury rate in physically active females.

APPENDIX

APPENDIX A

Consent Form for Participation in Neuromuscular Contributions to Knee Instability
Department of Health, Physical Education, and Recreation, Texas State University

The principle investigator is Heather Wedding. The researcher can be contacted by email, hm1110@txstate.edu, or phone, 210-240-3636.

INTRODUCTION AND PURPOSE OF STUDY

You have been asked to participate in a research to assess your lower extremity mechanics, including forces exerted by muscles and gravity on the skeletal system, and strength deficits. The investigation will help to determine if strength of the thigh muscles can help to limit abnormal lower extremity movement while the subject completes a single leg lowering exercise. The study will also establish the effects of fatigue on the body movement during a single leg lowering exercise.

You will be evaluated in the Athletic Training Research Lab at Texas State University in the Jowers building, room D108. The following form includes more details regarding the research if you have any questions or concerns about the study please ask before you decide to participate.

PROCEDURES

Each subject will be instructed to wear athletic clothing including a t-shirt, tight fitting shots (i.e. biker shorts, spandex), and tennis shoes. Workout clothing is necessary for locating specific areas on the body and attaching reflective markers for body movement analysis. The following are the procedures for the study which will take about 30 minutes to complete:

1. Subjects will first be instructed, by the principle investigator, on how to complete a single leg lowering exercise off of a box and how to use the strength testing machine.

2. The principle investigator will locate the hip, knee and ankle joints and attach reflective markers on each of the specific areas of the body.

3. Each subject will then practice doing a single leg lowering exercise on the box provided and will be corrected on form if necessary. Once the subject's form is perfected, the subject will complete three single leg lowering exercises on their favorite leg while being recorded from a side view and frontal view.

4. Prior to testing, subjects will complete a 5 – 10 minute warm-up on a stationary bicycle and complete a stretching program.

5. The subject's thigh strength will then be tested, on their favorite leg, with the strength testing machine.

6. After strength testing, subjects will be instructed, by the principle investigator, on how to use the strength testing machine for muscle fatigue.

7. The thigh muscles, on the favorite leg, will be slightly fatigued from previous maximum strength recorded.

8. Immediately after fatigue subject will complete three single leg lowering exercises, on the favorite leg, and be recorded from the side view and frontal view.

9. Once completed each subject will cool down on a stationary bicycle and will be instructed to stretch their thigh muscles.

POTENTIAL RISKS AND DISCOMFORTS

Subjects will be informed about the nature of what is involved as a participant, including particularly a description of anything they might consider to be unpleasant or a risk. The potential risks for this experiment are minimal because the subjects will be supervised by the principle investigator during the duration of the study; however, with any exercise there are potential risks for injury. Minor discomforts may be experienced due to the fatigue phase of the experiment. Risks will be minimized by warming up prior to strength testing and cooling down post fatigue protocol and testing.

If an emergency occurs during testing the subjects will be instructed to exit the building immediately. If it is a medical emergency then emergency services will be contacted. The primary investigator is Professional Rescuer Certified and will assist with all emergency situations until EMS arrives on the scene.

POSSIBLE BENEFITS

The benefits from this investigation hopefully will provide information for the athletic and medical community. Also, the results from this investigation may help you learn about:

- Your thigh strength
- Body movement deficits
- Fatigue level of the lower extremity

CONFIDENTIALITY

Each subject in this study will be issued a number to differentiate the results found between subjects and to maintain the confidentiality of the subject's information and results. Name, social security numbers, telephone numbers, age, etc. are not required for testing; however, name and telephone number are needed for the following form. Results from the study may be shared for future research except for the consent forms. If consent form material is needed for research purposes then the subjects will be contacted for additional written consent for release of their information. All recorded data will be kept for 2 years total and will maintain confidentiality of the subject's identity by blurring the subject's faces in the video. All data from the research will be kept in the primary investigator's office.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed you data will be returned to you or destroyed. If you have any other questions regarding the research, research participants' rights, and/or research-related injuries to participants please contact the IRB chair, Dr. Jon Lasser, (512) 245- 3413, lasser@txstate.edu or to Ms. Becky Northcut, Compliance Specialist, (512) 245 2102.

AUTHORIZATION

The Athletic Training Program supports the practice of protection for human subjects participating in research and related activities. The consent form is provided so that you can decide whether you wish to participate in the present study.

"I have read the above statement and have been fully advised of the procedures to be used in this project. I have been given sufficient opportunity to ask any questions I had concerning the procedures and know that I am free to ask questions as they may arise. I likewise understand that I can withdraw from the study at any time without being subjected to reproach."

Contact Heather Wedding, Principal Investigator at (210) 240-3636 or email at hm1110@txstate.edu if you have any questions.

____________________________________ __________________

Participant Name Printed (18 years or older) Phone #

____

Signature

____

Principle Investigator Signature

APPENDIX B

Medical Health Questionnaire – Athletic Training Research Laboratory

Yes	No	Current Activity Level
❍	❍	Are you physically active (i.e., do you get at leasat 30 minutes of physical activity on at least 3 days per week)? Please list the activities that you do for physical activity (i.e. aerobic exercise, weights, sport activities, etc)
❍	❍	Have you been doing the above activities for the past 6 months to year?
Yes	**No**	**Symptoms – Do you:**
❍	❍	Experience chest discomfort with exertion?
❍	❍	Experience unreasonable breathlessness or unusual fatigue at rest, with mild exertion, or during usual activities?
❍	❍	Experience dizziness, fainting, or blackouts?
❍	❍	Experience difficulty breathing when lying flat or when asleep?
❍	❍	Experience ankle swelling?
❍	❍	Experience forceful or rapid heart beats?
❍	❍	Experience numbness in legs or arms from time to time?
Yes	**No**	**Other health issues that may warrant physician approval before engaging in physical activity.**
❍	❍	Have you ever been told not to exercise by a health care provider?
❍	❍	Do you have problems with your muscles, bones, or joints?

Emergency Contact: **Name:** ____________________ **Phone Number:** __________

I certify that the information included on this form is correct.

_________ ____

Date **Signature of Participant**

_________ ____

Date **Signature of Primary Investigator**

APPENDIX C

SUBJECT INFORMATION SHEET

Date: ____________

Subject #: _____

Q angle: 1st _____ 2nd _____ 3rd _____ Average = _____

Ortho-screen Lower Extremity: PASS or FAIL

Height: _____

Weight: _____ lb

Dominant Leg: RIGHT or LEFT

Leg Length: _____ in

Physical Activity: ____

____

____

Camera EVT Number: **Frontal:** Pre-fatigue ______ Post-fatigue ______

Sagittal: Pre-fatigue ______ Post-fatigue ______

Peak Torque: **Quadriceps** ______ **50%** ______

Hamstring ______ **50%** ______

Fatigue: **Quadriceps** – Avg Peak Torque ______ x Reps ______ = Work ______

Hamstrings– Avg Peak Torque ______ x Reps ______ = Work ______

APPENDIX D

Step by Step Procedures for DATA COLLECTION

1. **Go over consent form & health questionnaire & sign**
    a. Verify that the subject has not had any low back, hip, pelvis, knee or ankle injuries in the past two years.
    b. Notify the subject that they will most likely experience DOMS in the next couple days from the strength testing and fatigue protocol
    c. Answer any questions subject may have and sign document
    d. Ask subject the following questions and document on "Subject Information Sheet"
        i. Issue Subject # to keep track of data and keep information confidential
        ii. Height
        iii. Weight
        iv. Which leg would you kick a soccer ball with to determine leg dominance?
2. **Quick Ortho-screen**
    a. Ask subject to do a body squat
    b. Have subject sit on exam table and complete assessment of ROM of plantarflexion, dorsiflexion, knee extension & flexion and hip flexion.
    c. Mark PASS or FAIL on "Subject Information Sheet"
3. **Measure Q angle**
    a. Mark tibial tuberosity and mid patella with a permanent marker
    b. Ask subject to hold tape measure at the ASIS to visualize line from ASIS thru mid patella

4. Take three measurements with goniometer and record on "Subject Information Sheet" and calculate average
5. **Measure Leg Length of the Dominant Leg**
    a. Measure from ASIS to medial malleolus (measured in inches) & note on "Subject Information Sheet"
    b. Check Leg Length on the Step Height Chart and Set up step while subject is warming up
6. **Warm-up 5 – 10 minutes on Cybex Stationary Bicycle**
7. **Light Stretching**
    a. Of the hamstrings, quadriceps, adductors, and calf muscles instructed by the primary investigator
8. **Clean areas for reflectors & apply QDA**
    a. Clean over the ASIS, inferior to the acromion process on the lateral aspect of the arm, greater trochanter, lateral knee joint line, tibial tuberosity, anterior distal aspect of the tibia midway between malleoli, lateral malleolus.
9. **Place markers on:**
    a. ASIS, Tibial tuberosity, lateral knee joint line, greater trochanter, anterior tibia between malleoli, lateral malleolus & inferior lateral acromion process
10. **Set METRONOME at 46 for Single Leg Squat**
11. **Demonstrate single leg squat & then have subject practice single leg squat no more than 3 times**
12. **Ask subject if they have any questions????**
13. **Verify that subject's reflectors and scale are visible in both cameras**
14. **Verify that both cameras are set to:**
    a. 125 speed, master, event number 1
15. **Press record on both cameras**

16. **Instruct subject to complete three single leg squats to the beat of the metronome**
    a. Instruct subject to barely touch their non weight bearing heel to the ground and then immediately come back up
17. **Once 3 single leg squats are done stop recording then select BEGIN SAVING ON**
    BOTH CAMERAS for PRE-FATIGUE SLS
18. **Instruct subject to sit on the Biodex machine**
19. **Hook subject up on Biodex & explain procedures**
    a. Now we will measure you hamstring and quadriceps strength on the Biodex machine
    b. You will complete five reps of knee extension and knee flexion as fast and as hard as you can
    c. You can go ahead and do a test run to get a feel for the machine
    d. Ready to begin…set….GO !!! 5 REPS AS FAST AND HARD AS YOU CAN!!!!!
20. **Check with subject and make sure they are doing alright??**
21. **Print out Results**
    a. Record peak torque for the Quadriceps and Hamstrings on the "Subject Information Sheet"
    b. Divide by 2 to determine 50% peak torque for Fatigue protocol and record on "Subject Information Sheet"
22. **Mark line on Biodex screen for 50% peak torque for quadriceps and hamstrings**
23. **Explain Fatigue Protocol procedures**
    a. Now you will complete the fatigue protocol, you will complete as many reps as you possibly can as fast and as hard as you can until your peak torque falls below 50% for both your quadriceps and hamstrings
    b. Are you ready to begin….set…..GO!!! Go AS FAST AND AS HARD AS YOU CAN!! KEEP IT UP!!!!

24. **HAVE ASSISTANT TAKE OVER of motivating the subject while the primary investigator, Verifies that the PRE-FATIGUE VIDEOS saved and Note EVT # on "Subject Information Sheet" for PRE-FATIGUE EVT #s**
25. **Once Fatigue Protocol is completed Help Subject off of the Biodex machine and Verify Reflectors have NOT shifted**
26. **Turn on Metronome**
27. **Press record on both cameras**
28. **Instruct subject to complete three single leg squats to the beat of the metronome**
    a. Instruct subject to barely touch their non weight bearing heel to the ground and then immediately come back up
29. **Select BEGIN SAVING on BOTH cameras for POST-FATIGUE SLS**
    a. Make sure to write down Fatigue Results and Record AVERAGE PEAK TORQUE, REPS to FATIGUE, and calculate WORK on "Subject Information Sheet"
30. **Verify that the POST-FATIGUE VIDEOS saved and Note EVT # on "Subject Information Sheet" for POST-FATIGUE EVT #s**
31. **Begin 5 to 10 minute cool down & stretching**
    a. Notify subject that they will probably experience Delayed Onset Muscle Soreness with the next couple of days, they can take OTC Aleve or Ibuprofen for soreness but make sure to take with food to avoid an upset stomach.
32. **Thank you very much for your participation in my Thesis Study.**

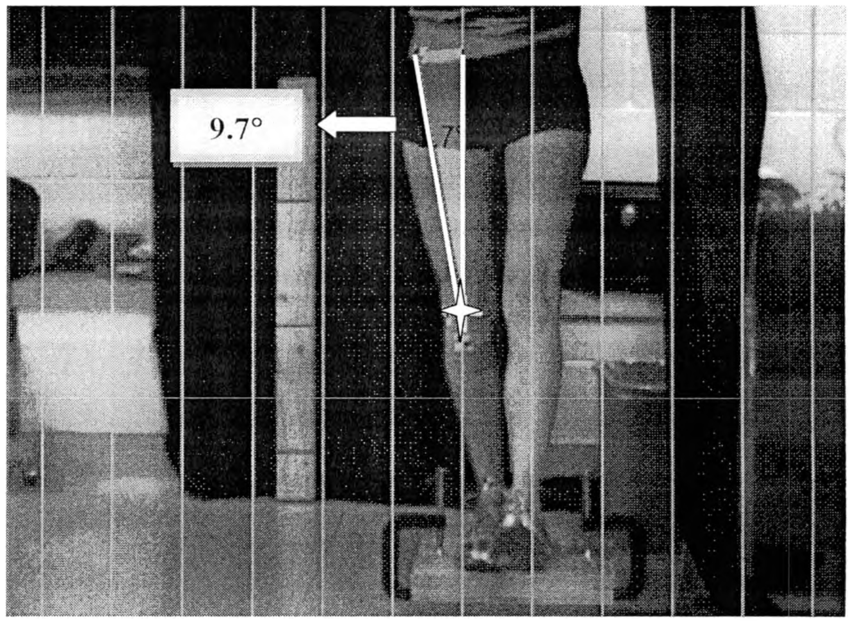
APPENDIX E

Leg Length and Box Height Table

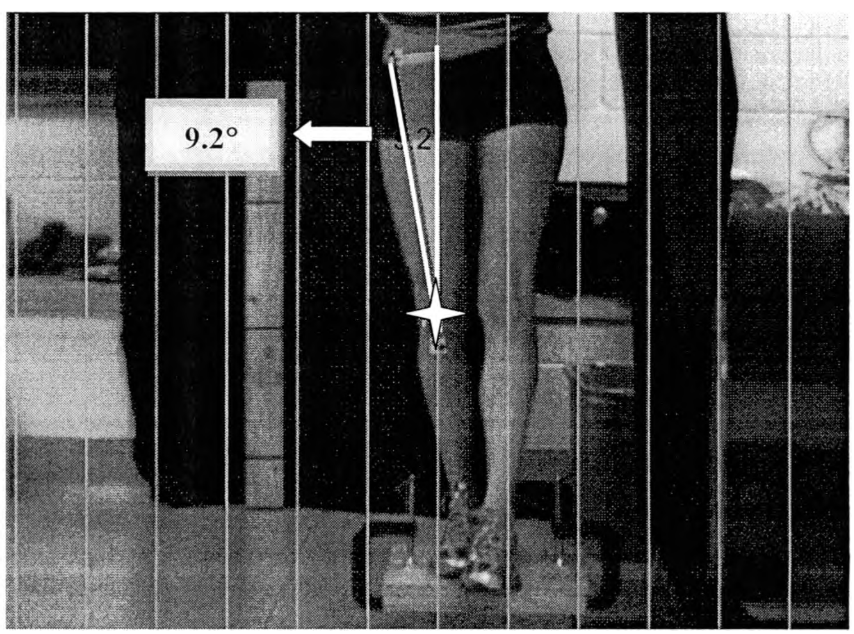
LEG LENGTH	STEP HEIGHT
28.5	1/2 in on ground (1 sheet)
29	1 in on ground (2 sheets)
29 5	1 ½ in on ground (3 sheets)
30	2 in on ground (4 sheets)
30 5	2 ½ in on ground (5 sheets)
31	3 in on ground (6 sheets)
31 5	3 ½ in on ground (7 sheets)
32	4 in – sm Step Only
32 5	4 ½ in – sm Step + 1 sheet
33	5 in – sm Step + 2 sheets
33.5	5 ½ in – sm Step + 3 sheets
34	6 in – sm Step + 4 sheets
34 5	6 ½ in – sm Step + 5 sheets
35	7 in – sm Step + 6 sheets
35.5	7 ½ in – sm Step + 7 sheets
36	8 in – sm Step + 8 sheets
36 5	8 ½ in – sm Step + 9 sheets
37	9 in – lg Step Only
37 5	9 ½ in – lg Step + 1 sheet
38	10 in – lg Step + 2 sheets
38.5	10 ½ in – lg Step + 3 sheets
39	11 in – lg Step + 4 sheets
39.5	11 ½ in – lg Step + 5 sheets
40	12 in – lg Step + 6 sheets

APPENDIX F: Pre and Post Fatigue Max Initial Frontal View

Pre Fatigue Max Initial

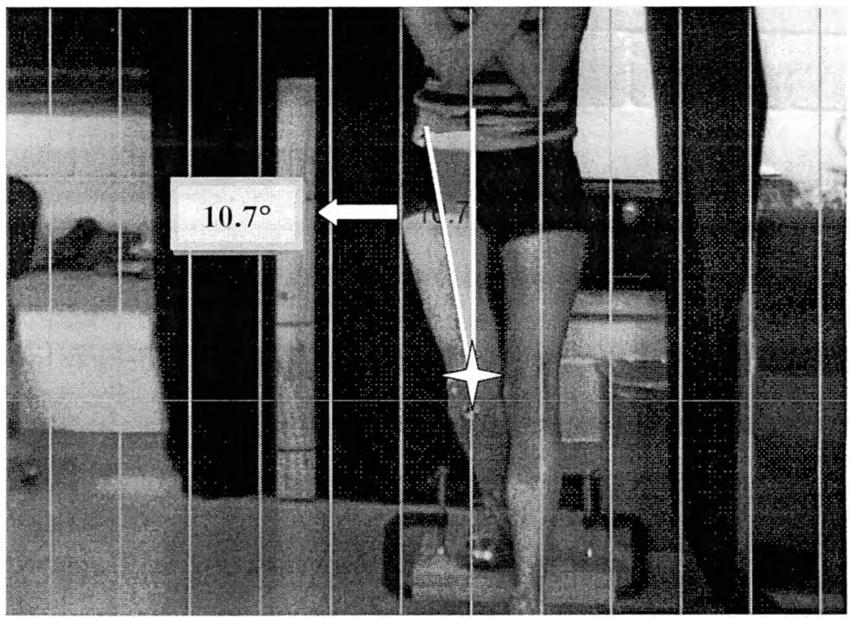


Post Fatigue Initial Valgus

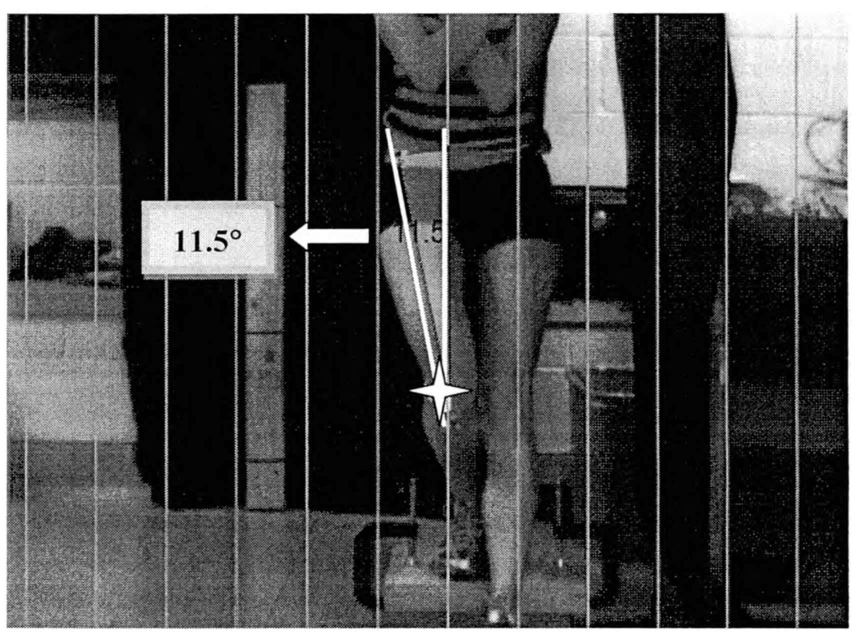


APPENDIX G: Pre and Post Fatigue Max Valgus Frontal View

Pre Fatigue Max Valgus



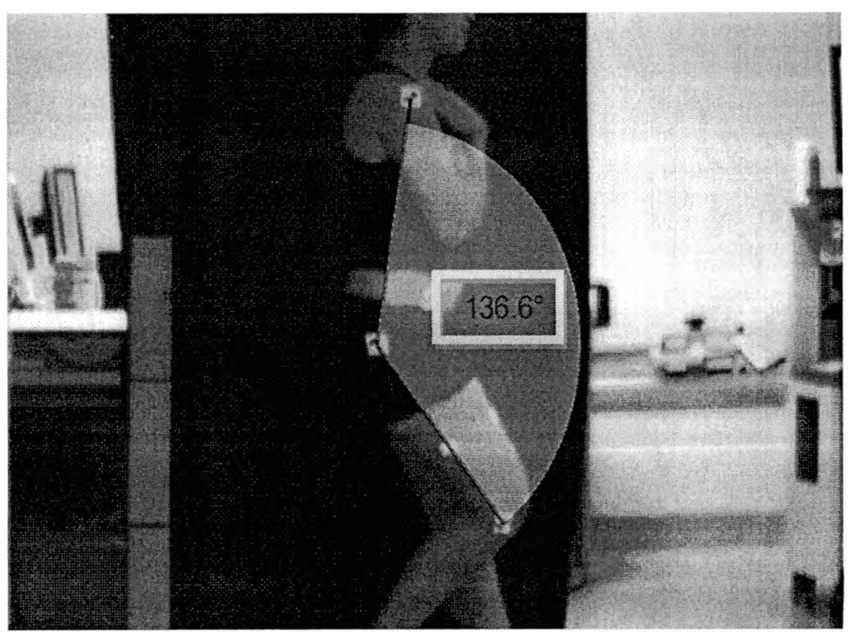
Post Fatigue Max Valgus



APPENDIX H: Pre and Post Fatigue Hip Flexion Sagittal View

Pre Fatigue Hip Flexion

Post Fatigue Hip Flexion



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VITA

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