# The Effects of Hip Musculature on Knee Valgus During a Squat Task With and Without a 2-inch Heel Block

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ABSTRACT
Brian Vesci: The Effects of Hip Musculature on Knee Valgus During a Squat Task With and Without a 2-inch Heel Block
(Under the direction of Dr. Darin A. Padua)

**Objective:** To compare hip ROM, strength, muscle activity, and ankle dorsiflexion ROM between groups that demonstrate knee valgus during a squat task and those that do not (control). Also, determine if muscle activity changes after knee valgus is corrected by a two-inch heel block. **Design:** A single-session experimental research design was used to compare the control group and the valgus group. **Participants:** Seventeen (10 Females, 7 Males) control subjects (age[yr] = 23.82 ± 5.76, height[cm] = 166.12 ± 31.13, weight[kg] = 69.59 ± 15.37) and fourteen (12 Female, 2 Male) valgus subjects (age[yr] = 22.36 ± 3.08, height[cm] = 167.21 ± 9.3, weight[kg] = 65.93 ± 9.9) without lower extremity injury. **Dependent Variables:** Supine hip abduction and external rotation ROM. Ankle dorsiflexion ROM (straight and bent knee). Hip internal rotation, external rotation, extension, and abduction eccentric and concentric peak torque and time to peak torque. EMG mean amplitude of the gluteus maximus, gluteus medius and adductor complex during a squat with and without a two inch heel block. **Data Analysis:** Mixed model analysis of variance tested for difference both between and within groups. **Results:** A significant group by phase interaction effect ($p = 0.02$) existed for mean adductor amplitude between the valgus and the control group. A significant difference ($p < .001$) in straight knee ankle dorsiflexion ROM existed between the control and the valgus group. A significant difference ($p = 0.034$) existed between the internal rotation concentric time to peak torque between the two groups. **Conclusion:** The

adductor complex plays a significant role in hip extension. Increased activity of the adductor during extension could pull the knees into valgus. Gastrocnemius tightness might contribute to knee valgus during a squat. There appears to be three distinct populations when considering this knee valgus squatting position. 1. Normal individuals who do not have valgus. 2. Ankle dysfunction individuals who's valgus position corrects with a heel block. 3. Hip dysfunction individuals who's valgus position does not correct with a heel block.
**Keywords:** Knee valgus, double leg squat, hip adductor activity, gastrocnemius flexibility

TABLE OF CONTENTS


| | Page |
|---|---|
| LIST OF TABLES | viii |
| LIST OF FIGURES | ix |
| Chapter | |
| 1. INTRODUCTION | 1 |
| Introduction | 1 |
| Statement of Purpose | 5 |
| Research Questions | 6 |
| Research Hypotheses | 7 |
| Null Hypotheses | 9 |
| Variables | 10 |
| Independent Variable | 10 |
| Dependent Variable | 11 |
| Definition of Terms | 11 |
| Operational Definitions | 12 |
| Assumptions | 13 |
| Limitations | 13 |
| Delimitations | 13 |

Significance of Study 14

2. REVIEW OF THE LITERATURE 15

Introduction 15

Muscular Tightness –Anatomy 17

Adductor Complex 17

Gastrocnemius/Soleus Complex 19

Muscular Tightness – Assessment 19

Hip Abduction 20

Hip Internal Rotation 20

Ankle Dorsiflexion 21

Muscular Strength – Anatomy 21

Gluteus Medius 22

Gluteus Maximus 23

Muscular Strength – Assessment 24

Gluteus Medius 24

Gluteus Maximus 25

Proper Double-Legged Squat Technique 25

Isokinetic Testing 26

Electromyography (EMG) 27

3. METHODS 28

Subjects 28

Measurement and Instrumentation 29

Procedures 30

ROM Measurements 31

Electromyography 32

Strength Measurements 33

Double-Legged Squat Task 35

Data Analysis 36

4. RESULTS 37

ROM Measurements 37

Hip External Rotation Concentric/Eccentric Peak Torque 37

Hip Internal Rotation Concentric/Eccentric Peak Torque 37

Hip Extension Concentric/Eccentric Peak Torque 38

Hip Abduction Concentric/Eccentric Peak Torque 38

Hip External Rotation Concentric/Eccentric Time to Peak Torque 38

Hip Internal Rotation Concentric/Eccentric Time to Peak Torque 38

Hip Extension Concentric/Eccentric Time to Peak Torque 39

Hip Abduction Concentric/Eccentric Time to Peak Torque 39

Gluteus Maximus EMG Mean Amplitude During a Squatting Task 39

Gluteus Medius EMG Mean Amplitude During a Squatting Task 40

Adductor Mean EMG Amplitude During Squatting 40

Gluteus Maximus EMG Mean Amplitude During Squatting with Heel Block 41

Gluteus Medius Mean EMG Amplitude During Squatting with a Heel Block 41

Adductor EMG Mean Amplitude During Squatting with and without a Heel Block 41

5. DISCUSSION 43

Muscle Activity During Squatting 43

Straight and Bent Knee Ankle Dorsiflexion ROM 46

Internal Rotation Time to Peak Torque 48

Abduction Concentric Peak Torque and Time to Peak Torque 49

Hip Abduction and Internal Rotation ROM 49

Hip Extension and External Rotation Concentric and Eccentric Peak Torque 50

Limitations 50

Future Research 51

APPENDICIES 53

Appendix A: Tables 53

Appendix B: Figures 60

Appendix C: Manuscript 79

Appendix D: IRB Materials 106

Appendix E: Data Collection Materials 139

Appendix F: Raw Data 141

Appendix G: SPSS Outputs 172

REFERENCES 203

LIST OF TABLES

1. Subject Demographics; Mean and Standard Deviation 54

2. Ranges of Motion; Means and Standard Deviations 55

3. Isokinetic Peak Torque Normalized to Body Weight (ft * lbs/kg); Means and Standard Deviations 56

4. Isokinetic Time to Peak Torque (seconds); Means and Standard Deviations 57

5. Mean EMG Amplitude (Normalized to MVIC) During a Squat Task; Means and Standard Deviations 58

6. Mean EMG Amplitude (Normalized to MVIC) During a Squat Task with Heel Block; Means and Standard Deviations 59

LIST OF FIGURES

1. Ankle Dorsiflexion ROM 61

2. Hip Abduction Isokinetic Strength (Normalized to Body Weight) 62

3. Internal Rotation Time to Peak Torque 63

4. Abduction Concentric Time to Peak Torque 64

5. Adductor Mean EMG Amplitudes 65

6. Hip Abduction ROM Measurement Positioning 66

7. Hip External Rotation Measurement Positioning 67

8. Straight Knee Ankle Dorsiflexion ROM Measurement Positioning 68

9. Bent Knee Ankle Dorsiflexion ROM Measurement Positioning 69

10. Gluteus Medius Electrode Placement 70

11. Gluteus Maximus Electrode Placement 71

12. Adductor Electrode Placement 72

13. Hip External Rotation Strength Measurement Positioning 73

14. Hip Internal Rotation Strength Measurement Positioning 74

15. Hip Extension Strength Measurement Positioning 75

16. Hip Abduction Strength Measurement Positioning 76

17. Squat Task Positioning 77

18. Squat Task Positioning – Heel Block 78

# CHAPTER 1 – INTRODUCTION

## Introduction

Baseline screenings are commonly utilized in sports medicine as a method to assess injury status and establish return to play criteria should injury occur. More recently baseline screenings are used to develop corrective exercise programs to prevent injury from occurring. Typically baseline screenings have utilized isolated measures of flexibility, muscle strength, and functional performance; as well as identifying faulty posture. Acquiring this information serves two purposes. Initially this information is required to ensure that the athletes are not injured coming into the season. However, most often this information is important in the ongoing attempt to prevent those injuries from occurring. It is inevitable that certain injuries are going to occur during a season; however, if certain risk factors can be identified and corrected in the preseason, some of these injuries can be prevented.

Posture is a very important and often neglected part of overall health. Ideal posture maintains that structural integrity and optimum alignment of each component of the kinetic chain (Clark, 2001). The kinetic chain consists of the myofascial system, articular system, and the neural system (Clark, 2001). When one component of this system is out of alignment, then the entire system is placed at a disadvantage. Postural malalignment is thought to create predictable patterns of tissue overload and dysfunction, initiating the

cumulative injury cycle (Clark, 2001). This cumulative injury cycle begins with tissue trauma, inflammation, leading to muscle spasm, adhesions, altered neuromuscular control, and muscle imbalance. This cycle is thought to cause decreased athletic performance and eventual injury (Clark, 2001).

Functional movement analyses are becoming increasingly popular as a tool during dynamic postural assessment. Double leg and single leg squatting tasks are common during functional movement analyses. These methods can be easily implemented and are time efficient, thus are attractive measures for the clinician. During functional movement analyses the clinician observes for dysfunctional movement patterns that are believed to represent muscle imbalances caused by lack of flexibility, muscle weakness, and/or muscle activation. For example, individuals who demonstrate excessive knee valgus during a double leg squat are hypothesized to display a tight adductor muscle complex and weak gluteus medius and maximus muscles, as well as a lack of neuromuscular control in the aforementioned muscles. (Clark 2001) However, research has not been performed to validate the idea of functional movement analyses as a method to identify muscle imbalances.

Lack of muscle flexibility is one of the most common thought of risk factors for muscular injury. (van Mechelen, Hlobil et al. 1992; Garrett 1996; Gleim and McHugh 1997) It is theorized that if a muscle is unable to lengthen to a point that is considered normal ROM when stressed during activity, then it has a greater potential to fail. One study has shown that decreased flexibility in certain muscle groups can be considered an important factor in the development of injuries in soccer players. (Witvrouw, Danneels et al. 2003). In contrast, another study has shown that there was no significant difference in preseason adductor flexibility in professional ice hockey players who sustained adductor muscles injuries and

those who did not. (Tyler, Nicholas et al. 2001) The literature is inconclusive as to whether or not flexibility of a muscle is directly related to injury, but most evidence seems to suggest that it is a contributing factor to most muscular injuries. (Worrell 1994; Gleim and McHugh 1997; Thacker, Gilchrist et al. 2004)

Muscular weakness is another potential risk factor to muscular injury. Some studies have examined individual muscle strength and how it relates to injury of that specific muscle. (Worrell 1994) Although, few studies have analyzed whether or not weakness in one muscle has any relationship to injury in another area along the kinetic chain. Muscular weakness may develop secondary to changes in its antagonistic muscle. If a muscle is tight or overactive, then its antagonistic muscle may become weak or inhibited. This concept, called reciprocal inhibition, is considered to be another risk factor that contributes to athletic injury.(Clark M 2001) If a muscle is weak or inhibited, then it cannot fully function to mobilize or stabilize the structure for which is it intended. Muscle weakness can cause certain movement dysfunctions that can put certain muscles or joints in positions considered to be of high risk for injury.(Clark M 2001) This concept has yet to be fully investigated in the literature.

It is logical to assume that athletes, notably lower extremity athletes, may not have lower extremity muscular tightness or weakness. However, the idea of reciprocal inhibition brings to light another aspect of injury risk, which is muscle activation. If athletes do not posses the neuromuscular control to avoid these dysfunctional movements, then strength or flexibility would not matter. Extensive research currently explains the muscle activation patterns of the gluteus medius muscle during functional tasks. (Soderberg and Dostal 1978; Schmitz, Riemann et al. 2002; Earl 2005; Garrison, Hart et al. 2005) Also, research has

looked at the gluteus maximus activation in various functional tasks, although it is less understood. (Zeller, McCrory et al. 2003) However, research has yet to fully investigate hip musculature muscle activation, flexibility, and strength measurements during functional tasks and its relation to knee valgus.

As mentioned before, certain movement dysfunctions have been identified that are believed to be caused by the above mentioned risk factors.(Clark 2001) Knee valgus alignment during dynamic tasks (e.g. squatting) is a common postural dysfunction seen in the lower extremity. Knee valgus alignment during squatting is defined as the mid-patella moving medially and crossing over the ipsilateral great toe as the knee flexes while squatting downward. Knee valgus alignment has been described as a potentially dangerous movement pattern (Ireland 1999). Knee valgus alignment is accompanied by movement of the hip into adduction and internal rotation, which are commonly described mechanisms for anterior cruciate ligament (ACL) injury (Ireland 1999). It has also been shown that patello-femoral compressive forces increase with knee valgus alignment (Escamilla 2001) Thus, knee valgus alignment is also believed to be a contributing factor to patello-femoral pain syndrome. Furthermore, the medial collateral ligament (MCL) is stressed when the knee is exposed to a valgus moment. The MCL can become injured when that valgus stress becomes too great. Individuals who undergo excessive knee valgus motion during functional tasks may place greater stress on the MCL and be at greater risk for injury. These injuries can be detrimental to an individual's physical well-being. Therefore, it is important to understand the factors that influence knee valgus alignment as this may improve our understanding of lower extremity injury risk factor, which may lead to the development of exercise programs to correct knee valgus alignment and reduce injury risk. Currently, knee valgus alignment is

thought to occur due to weakness or inhibition in the hip abdcutor muscles (e.g. gluteus medius, gluteus maximus) and hip external rotator muscles. Meanwhile, the hip adductor and internal rotator muscles are believed to be tight or overactive (Clark 2001). However, research has not investigated if these hypothesized muscle imbalances actually exist in individuals demonstrating knee valgus alignment during a functional squatting task.

Squat tests, both single and double legged, have been used in the past as functional tests because they put the knee through common motions found in athletics.(Beutler, L.W. et al. 2002; Loudon, Wiesner et al. 2002; Zeller, McCrory et al. 2003) Moreover, studies have been done that examine knee valgus during squat tasks. (Zeller, McCrory et al. 2003) However, currently research has yet to focus on how the abovementioned risk factors associated with injury differ between subjects who experience a position of great knee valgus versus those who do not when performing a squat.]

Statement of Purpose

Closed-chain knee flexion is a very common athletic position. When this position is accompanied by knee valgus stress the risk for a knee injury is increased.(Ireland 1999) A double-legged squatting task (DLST) is a functional test that can be used clinically to mimic this closed-chain knee flexion. When someone's knee adducts during this squatting task, it is logical to assume it would do the same during an athletic activity. As of yet no concrete evidence exists to suggest what exactly causes this knee adduction during a DLST.

Research Questions

1. Do subjects who demonstrate bilateral knee adduction in a DLST have less hip abduction ROM compared to those who do not demonstrate bilateral knee adduction?
2. Do subjects who demonstrate bilateral knee adduction in a DLST have less hip external rotation compared to those who do not demonstrate bilateral knee adduction?
3. Do subjects who demonstrate bilateral knee adduction in a DLST have less straight knee ankle dorsiflexion compared to those who do not demonstrate bilateral knee adduction?
4. Do subjects who demonstrate bilateral knee adduction in a DLST have less bent knee ankle dorsiflexion compared to those who do not demonstrate bilateral knee adduction?
5. Do subjects who demonstrate bilateral knee adduction in a DLST have less gluteus medius muscle strength compared to those who do not demonstrate bilateral knee adduction?
6. Do subjects who demonstrate bilateral knee adduction in a DLST have less gluteus maximus muscle strength compared to those who do not demonstrate bilateral knee adduction?
7. Do subjects who demonstrate bilateral knee adduction in a DLST have less hip external rotator muscle strength compared to those who do not demonstrate bilateral knee adduction?

8. Do subjects who demonstrate bilateral knee adduction in a DLST have more hip internal rotator muscle strength compared to those who do not demonstrate bilateral knee adduction?
9. Do subjects who demonstrate bilateral knee adduction in a DLST have less mean gluteus medius EMG activity compared to those who do not demonstrate bilateral knee adduction?
10. Do subjects who demonstrate bilateral knee adduction in a DLST have less mean gluteus maximus EMG activity compared to those who do not demonstrate bilateral knee adduction?
11. Do subjects who demonstrate bilateral knee adduction in a DLST have more mean adductor complex EMG activity compared to those who do not demonstrate bilateral knee adduction?

Research Hypotheses

1. Subjects who demonstrate bilateral knee adduction in a DLST will have less hip abduction ROM compared to those who do not demonstrate bilateral knee adduction.
2. Subjects who demonstrate bilateral knee adduction in a DLST will have less hip external rotation ROM compared to those who do not demonstrate bilateral knee adduction.
3. Subjects who demonstrate bilateral knee adduction in a DLST will have less straight knee ankle dorsiflexion ROM compared to those who do not demonstrate bilateral knee adduction.

4. Subjects who demonstrate bilateral knee adduction in a DLST will have less bent knee ankle dorsiflexion ROM compared to those who do not demonstrate bilateral knee adduction.
5. Subjects who demonstrate bilateral knee adduction in a DLST will have less gluteus medius muscle strength compared to those who do not demonstrate bilateral knee adduction.
6. Subjects who demonstrate bilateral knee adduction in a DLST will have less gluteus maximus muscle strength compared to those who do not demonstrate bilateral knee adduction.
7. Subjects who demonstrate bilateral knee adduction in a DLST will have less hip external rotator muscle strength compared to those who do not demonstrate bilateral knee adduction.
8. Subjects who demonstrate bilateral knee adduction in a DLST will have more hip internal rotator muscle strength compared to those who do not demonstrate bilateral knee adduction.
9. Subjects who demonstrate bilateral knee adduction in a DLST will have less mean gluteus medius EMG activity compared to those who do not demonstrate bilateral knee adduction.
10. Subjects who demonstrate bilateral knee adduction in a DLST will have less mean gluteus maximus EMG activity compared to those who do not demonstrate bilateral knee adduction.

11. Subjects who demonstrate bilateral knee adduction in a DLST will have more mean adductor complex EMG activity compared to those who do not demonstrate bilateral knee adduction.

Null Hypotheses

1. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in hip abduction ROM compared to those who do not demonstrate bilateral knee adduction.
2. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in hip external rotation ROM compared to those who do not demonstrate bilateral knee adduction.
3. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in straight knee ankle dorsiflexion ROM compared to those who do not demonstrate bilateral knee adduction.
4. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in bent knee ankle dorsiflexion ROM compared to those who do not demonstrate bilateral knee adduction.
5. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in gluteus medius muscle strength compared to those who do not demonstrate bilateral knee adduction.
6. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in gluteus maximus muscle strength compared to those who do not demonstrate bilateral knee adduction.

7. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in hip external rotator muscle strength compared to those who do not demonstrate bilateral knee adduction.
8. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in hip internal rotator muscle strength compared to those who do not demonstrate bilateral knee adduction.
9. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in mean gluteus medius EMG activity compared to those who do not demonstrate bilateral knee adduction.
10. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in mean gluteus maximus EMG activity compared to those who do not demonstrate bilateral knee adduction.
11. Subjects who demonstrate bilateral knee adduction in a DLST will have no difference in mean adductor complex EMG activity compared to those who do not demonstrate bilateral knee adduction.

Variables

Independent Variable:

1. Group: Subjects will be placed into one of two groups based on their knee motion in an OHST

    a). Ankle Dysfunction Group: Demonstrates bilateral knee adduction in DLST that is corrected by placing a two-inch heel block under the calcaneous.

b). Control Group: Does not demonstrate bilateral knee adduction in DLST with or without 2-inch heel block.

Dependent Variables:

2. Flexibility as measured in degrees by a manual goniometer will be measured for the following muscles and ROMs:
    a. Adductor Complex
    b. Hip IR
    c. Gastrocnemius
    d. Soleus
3. Concentric and eccentric strength as measured in Newton-meters (N*m) by an isokinetic dynamometer for the following movements:
    a. Hip Abduction
    b. Hip Extension
    c. Hip External Rotation
    d. Hip Internal Rotation
4. Mean amplitude EMG activity during a DLST for the following muscles:
    a. Gluteus Medius
    b. Gluteus Maximus
    c. Adductor Complex

Definition of Terms

1. Reciprocal Inhibition – The process whereby a tight or overactive agonist inhibits its functional antagonist.

2. Flexibility – As measured by a goniometer in degrees.
3. Strength – As measured by an isokinetic dynamometer in Newton meters (N*m).
4. Electromyography (EMG) – A measure of the neuromuscular action potential of a muscle; typically measured as peak, average onset time, and mean amplitude.
5. Isokinetic Testing – A measure of muscle contraction in which the length of the muscle is changing while the contraction velocity remains constant.

Operational Definitions

1. Double-Legged Squat Test (DLST) – Subject stands with feet shoulder width apart, feet facing forward, and hands raised above head. Subject then proceeds to squat down as if trying to sit in a chair.
2. Knee Adduction - The subject's knees will be such that the center of their patella is medial to the ipsilateral medial maleolus when they are in a squatted position.
3. Knee Valgus – Adduction and internal rotation of the femur on the tibia.
4. EMG –
    a. Peak: The highest magnitude of EMG activity during a dynamic maneuver.
    b. Mean Amplitude: The average magnitude of EMG activity for a given time interval.
    c. Onset Time: Point in time when EMG amplitude reaches a predetermined magnitude.
5. Torque –
    a. Peak: The greatest moment produced at one point in a range of motion.

b. Mean: The average moment produced throughout a range of motion.

6. Adductor Complex – Adductor magnus, adductor longus, and adductor brevis

Assumptions

1. Subjects will be truthful in the consent form about previous and current injury status.
2. Subjects will provide maximum effort in performing strength assessments.
3. Tester is reliable in obtaining accurate measurements of strength and flexibility.
4. EMG was collected without noise affecting the signal.
5. Tester will provide each subject with exact same instructions prior to testing.

Limitations

1. EMG may measure different portions of muscles due to skin movement during the DLST.
2. Subjects' previous experience with squatting exercises could affect their form in a squatting activity.

Delimitations

1. Subjects in both groups will be asymptomatic with and without activity and during the DLST
2. Subjects in the hip dysfunction group will demonstrate bilateral knee adduction in the DLST with and without a 2-inch heel block.

3. Subjects in the control group will not demonstrate bilateral knee adduction in the DLST with or without the 2-inch heel block.
4. Subjects in both groups will have no previous history of surgery in either lower extremity.
5. Subjects in control group will be matched to subjects in hip dysfunction group based on height, weight, age, gender, and physical activity level.

## Significance of Study

The significance of this study is to ascertain what factors lead to knee valgus during a closed chain flexed knee position. If these factors can be determined, then an intervention protocol can be established to correct them. This correction could then be studied further to examine its impact on decreasing knee injuries thought to be caused by this valgus position

# CHAPTER 2 – REVIEW OF THE LITERATURE

## Introduction

Preseason screenings are used by sports medicine professionals to gain knowledge about the health of their athletes. These baseline tests are used for documentation, assessment, and prediction of performance.(Crill, Kolba et al. 2004) It is believed that findings such as muscular imbalances and postural faults, both static and dynamic, can help predict not only performance but also risk of injury. Injury has been thought to be due to two different factors, both extrinsic and intrinsic. Extrinsic factors are those thought to be environment related such as weather, playing surfaces, ect., while intrinsic are those that are related to the individual person.(Taimela, Kujala et al. 1990; van Mechelen, Hlobil et al. 1992; Inklaar 1994) Intrinsic factors can be the neuromuscular control and postural imbalances that are sought out during preseason screenings. It is thought that since these factors are related to the athlete, then they can be altered through corrective exercise.

Injuries are inherent in sport. Some injuries, such as contact related traumatic injuries, are difficult, sometimes impossible, to prevent. Other injuries, such as muscular strain injuries are considered to be preventable with proper training. It is these preventable injuries that are of utmost importance to study. If it can be determined why or how muscular strain injuries occur then, theoretically, they can be prevented. The most widely believed cause of these injuries is muscular tightness.

(van Mechelen, Hlobil et al. 1992; Garrett 1996; Gleim and McHugh 1997) It is also believed that muscular tightness can lead to injuries as well, such as sprains and overuse injuries.(Worrell 1994; Krivickas 1997)

Before examining the concept of tightness in a muscle, there are two important terms that must first be defined. These are flexibility and stiffness. Muscular flexibility has most simply been defined as the angle beyond which no further displacement is possible.(Riemann, DeMont et al. 2001) Muscular stiffness represents the amount of deformation proportional to the load applied. (Blackburn, Padua et al. 2004) It is important to keep in mind that although these two concepts are related when assessing muscular length, they are two different characteristics of muscle.

Knee valgus occurs when there is a simultaneous internal rotation and adduction of the femur on the tibia. While these are normal biomechanical motions, this valgus position has been theorized to be a mechanism of injury for the ACL and MCL when the ROM becomes extreme. (Bendjaballah, Shirazi-Adl et al. 1997; Ireland 1999; Boden, Dean et al. 2000) The knee joint ligaments are designed to provide support to the joint; however, knee joint stability is not solely dependent upon these ligaments. As soon as the weight-bearing knee is flexed surrounding musculature is activated to increase joint stability.(Rosse 1997) This surrounding musculature involves muscles that cross the knee joint as well as the hip joint. If these muscles cannot effectively increase the joint stability, then the risk of injury to the knee joint increases. Unfortunately, little research exists to explain the role this musculature has in either leading to, or preventing, injury.

Muscular Tightness – Anatomy

Adductor Complex

When examining the movement of hip adduction, there are five muscles that are typically grouped into the hip adductors. These muscles are the pectineus, adductor longus, adductor brevis, adductor magnus, and the gracilis. However, when referring to the adductor complex, the most commonly though of muscles are the adductor longus, brevis, and magnus. Although all of these muscles can contribute to hip flexion and internal rotation, together their primary role is hip adduction. Investigation of these muscles and their role in muscular injuries in athletes is limited and inconclusive. A study done by Witvrouw et al showed that there was no significant difference between the adduction flexibility of soccer players who sustained adductor muscle strains as compared to non-injured players. (Witvrouw, Danneels et al. 2003) Another study on professional ice hockey players found no significant difference in adductor flexibility between players sustaining adductor injuries and players who did not. (Tyler, Nicholas et al. 2001) In contrast, Ekstrand and Gillquist found a correlation between tightness of the adductor muscles and the presence of adductor muscle strains in their prospective study of male soccer players. (Ekstrand and Gillquist 1983) It is important to note that in the study done by Witvrouw et al, players studied as a whole did not suffer many adductor injuries. Thus, their study did not have very much statistical power in regards to adductor muscle involvement in developing muscular injury. Further attention should be devoted towards resolving this conflict, because the current literature has yet to sufficiently explain the hip adductors role in muscular injury.

The pectineus muscle lies just medial to the iliopsoas and forms the medial part of the floor of the femoral triangle. It originates from the pectin of the pubis and the bone anterior

to the pectin, and inserts on the pectineal line, the proximal extension of the linea aspera, of the femur (Rosse 1997). The pectineus receives its vascular supply from the medial femoral circumflex artery and obturator artery, and it is innervated by the femoral nerve (Rosse 1997).

The adductor longus is the most anterior member of the adductor group. It originates from the superior pubic ramus and inserts into the medial lip of the linea aspera on the femur (Rosse 1997). The adductor longus receives its vascular supply from the medial femoral circumflex and obturator arteries, and it is innervated by the anterior division of the obturator nerve (Rosse 1997).

The adductor brevis is deep to the pectineus and adductor longus. It originates from the inferior pubic ramus and inserts into the medial lip of the linea aspera, superior to the adductor longus, on the femur (Rosse 1997). The adductor brevis receives its vascular supply from the medial femoral circumflex and obturator arteries, and it is innervated by the anterior division of the obturator nerve (Rosse 1997).

The adductor magnus is a combination of two muscles with different innervations. Both parts originate from the inferior pubic ramus, the ischiopubic ramus, and the ischial tuberosity. However, the adductor head inserts into the medial lip of the linea aspera on the femur and has horizontal fibers. The ischiocondylar head inserts on the adductor tubercule of the femur (Rosse 1997). The adductor head is innervated by the posterior division of the obturator nerve; while, the ischiocondylar head is innervated by the tibial nerve. Both portions receive their vascular supply from the deep femoral, medial femoral circumflex, and obturator arteries (Rosse 1997).

The gracilis is a long slender muscle lying superficially along the medial side of the thigh. It originates from the inferior pubic ramus and the pubic symphysis, and it inserts on the anteromedial part of the medial tibial condyle, via the pes anserine insertion (Rosse 1997). The gracilis receives its vascular supply from the medial femoral circumflex and obturator arteries, and it is innervated by the anterior division of the obturator nerve (Rosse 1997).

Gastrocnemius/Soleus Complex

The gastrocnemius is the superficial muscle of the triceps surae. It has two heads, meadial and lateral, that originate just superior to the medial and lateral femoral condyles respectively. It receives its vascular supply from the posterior tibial and sural arteries and is innervated by the tibial nerve (Rosse 1997). The soleus is the deep muscle of the triceps surae. It originates from the upper part of the fibula and the soleal line on the tibia. The soleus receives its vascular supply from the posterior tibial artery (Rosse 1997). Both the gastrocnemius and soleus insert together into the calcaneus via the Achilles tendon (Rosse 1997).

Muscular Tightness – Assessment

Since it is widely thought that muscular tightness is a factor for muscular injury, it becomes important to have a way to quantify the flexibility of a muscle. Manual goniometers commonly regarded as the easiest and are the most widely used devices to measure range of motion in a joint. (Gajdosik and Bohannon 1987) However, they have their limitations. They have a single hinge and lack the ability to accurately measure movements

made by more than one joint. Furthermore, if proper anatomical landmarks are not established and adhered to for the measurement, then the measurement itself would be useless to a clinician. Despite these limitations though, they seem to be the preferred method of ROM testing. This ROM assessment is used by most studies to make inferences about muscle length and tightness.(Tyler, Nicholas et al. 2001; Witvrouw, Danneels et al. 2003; Decoster, Scanlon et al. 2004)

Hip Abduction

The proper patient positioning for ROM measurement for hip abduction is supine. The fulcrum of the goniometer is placed over the anterior superior iliac spine (ASIS) of the extremity being measured. The stationary arm is placed along an imaginary line from one ASIS to the other. The movement arm is placed along the anterior midline of the femur using the midline of the patella for reference.(Norkin 1995)

Hip Internal Rotation

The proper patient positioning for ROM measurement for hip internal rotation is seated with knees flexed to 90 degrees over the edge of the surface. The hip is in neutral abduction as well as adduction and is flexed to 90 degrees. A towel roll may be placed under the distal end if necessary to maintain the femur in a horizontal plane. The fulcrum of the goniometer is over the anterior center aspect of the patella. The stationary arm is positioned perpendicular to the floor. The movement arm is placed along the anterior midline of the

tibia pointing towards the anterior midpoint of the ankle between the two melleoli.(Norkin 1995)

Ankle Dorsiflexion

The proper patient positioning for ROM measurement of straight knee dorsiflexion was supine with the dominant knee in full extenion. The ankle is in neutral inversion/eversion. The axis of the goniometer is the distal lateral maleolus. The stationary arm is positioned with the lateral midline of the fibula, using the fibular head for reference. The movement arm is placed parallel to the lateral aspect of the fifth metatarsal (Norkin 1995).

The proper patient positioning for ROM measurement of bent knee dorsiflexion is the same as straight knee; however, a bolster is placed under the subject's dominant knee so that it is flexed to at least 30 degrees (Norkin 1995).

Muscular Strength – Anatomy

Muscular strength is another intrinsic factor believed to be associated with muscular injury. (Knapik, Bauman et al. 1991; Tyler, Nicholas et al. 2001) If a muscle has inadequate strength then it may break down due to the physical demands placed upon it during functional activities. Unfortunately, the literature fails to fully outline how muscular strength pertains to injury.

Gluteus Medius

The gluteus medius muscle originates on the lateral aspect of the ilium between the anterior and posterior gluteal lines, and it inserts on the greater trochanter of the femur. It receives its vascular supply from the superior gluteal artery and is innervated by the superior gluteal nerve (Rosse 1997). The main action of this muscle is hip abduction and internal rotation of the hip, although it functions effectively as a pelvic stabilizer during standing and as a pelvic rotator during gait. (Gottschalk, Kourosh et al. 1989; Earl 2005) The fibers of the gluteus medius muscle are arranged in such a fashion as to suggest it is capable of performing many functions in many different positions of hip flexion and extension. The muscle itself has been looked at in the past as having three separate sections divided into anterior, middle, and posterior portions.(Gottschalk, Kourosh et al. 1989; Schmitz, Riemann et al. 2002) The anterior and middle portions have been shown to be most active during hip abduction and internal rotation, while the posterior portion is most active in pulling the femoral head into the acetabulum and stabilizing the hip joint.(Earl 2005) Soderberg and Dostal examined the gluteus medius muscle's EMG activity during a variety of function tasks. They found that the three portions each had the highest amount of activity in movements that required maximum control of the femur.(Soderberg and Dostal 1978) This would suggest that the gluteus medius muscle plays an important role in controlling the femur in multiple planes during functional activities.

The common injury of concern when talking about gluteus medius weakness and poor control at the hip is the anterior cruciate ligament (ACL). (Zeller, McCrory et al. 2003) It has been reported that this lack of proper hip control leads to increased hip adduction when the hip is loaded. This increase in adduction causes the femur to internally rotate and provide a

valgus stress to the knee. (Zeller, McCrory et al. 2003) This is considered a deleterious position for the knee to be in and may predispose the ACL to injury.(Beutler, L.W. et al. 2002; Mattacola, Perrin et al. 2002; Zeller, McCrory et al. 2003) While the function of this muscle has been studied quite thoroughly during many functional tasks, such as single leg stance, closed-chain hip rotation, and single leg squat, the step has not yet been taken to fully understand what effects it has on injury. (Schmitz, Riemann et al. 2002; Zeller, McCrory et al. 2003; Earl 2005)

Gluteus Maximus

The gluteus maximus muscle originates from the posterior gluteal line of the ilium, the lateral sacrum and coccyx, and the sacrotuberous ligatment, and it inserts into the iliotibial tract and the gluteal tuberosity of the femur. It receives its vascular supply from the inferior gluteal artery and is innervated by the inferior gluteal nerve (Rosse 1997). This muscle is the prime hip extensor and is also involved in hip external rotation.

The external rotation moment arm of the gluteus maximus has been shown to decrease as the hip moves into flexion. Although the external rotation moment arm of the posterior fibers has been shown to remain even with a flexed hip.(Delp, Hess et al. 1999) This suggests that the gluteus maximus can be used to help control femoral internal rotation even when the hip if flexed. Moreover, it has been speculated that increasing strength and neuromuscular control of the gluteus maximus can help correct excessive femoral internal rotation in individuals that are believed to be at a higher risk of knee injury due to increased knee valgus in a position of hip and knee flexion.(Delp, Hess et al. 1999)

As stated before, this muscle is also believed to work in conjunction with the latissimus dorsi to aid in stabilization of the sacroiliac joint. (Clark 2001) Recently though, it has been theorized that its function as an external rotator plays a significant role in controlling functional movements. It is thought that it plays an important role in eccentrically controlling excess femoral internal rotation and avoiding the dangerous knee position previously outlined. (Clark 2001) However, its function in this capacity has currently not been researched enough to fully understand.

Muscular Strength – Assessment

Much like muscular length testing, a clinician must be able to assess and quantify muscular strength. Dynamometers make it possible to evaluate maximal muscular performance clinically. The many measurement methods that can be utilized include static, isokinetic, and, more recently, isotonic, isoinertial, and isoaccelerative. (Nadeau, Gravel et al. 1996) Each method controls one mechanical variable (angle, velocity, load inertia, or acceleration) and measures changes in some of the remaining variables. Static testing is generally considered the easiest way to test muscular strengths at certain positions in the joint's range of motion. While isokinetic testing is commonly considered the more popular method of quantifying dynamic muscular strength. (Osternig 1986; Cabri 1991)

Gluteus Medius

The proper positioning for the gluteus medius to be strength tested is to have the patient side-lying with the test leg being the uppermost. The patient starts with the test limb slightly extended beyond the midline and the pelvis rotated slightly forwards. The lowermost

knee is flexed for stability. The tester stands behind the patient. One hand is used to palpate the gluteus medius just proximal to the greater trochanter of the femur. The hand providing resistance is placed on the lateral surface of the knee joint. Resistance is given in a straight downward direction. The patient abducts the hip through the full range of motion without flexing the hip or rotating it in either direction. (Kendall 1993; Hislop 2002)

Gluteus Maximus

The proper positioning for the gluteus maximus to be strength tested is to have the patient supine with knee flexed to ninety degrees. The tester stands at the side to be tested at the level of the pelvis. One hand is place over the sacrum to stabilize the alignment of the pelvis. The hand providing resistance is placed over the posterior thigh just above the knee. Resistance is provided in a straight downward manner. The patient extends the hip through the full available range of motion while maintaining knee flexion. (Kendall 1993; Hislop 2002)

Proper Double-Legged Squat Technique

The National Strength and Conditioning Association (NSCA) has outlined the proper body mechanics for a squat. The subject is to hold the chest up and out while pulling the scapulae towards each other. The head is tilted slightly upward. The feet are positioned should-width apart, even with each other, with the toes pointed straight ahead or just slightly outward (externally rotated). The subject allows the hips and knees to slowly flex while keeping the torso-to-floor angle relatively constant during the downward movement phase. The heels of the feet are to remain on the floor and the knees stay aligned over the feet. The

torso is not to be flexed forward or the low back rounded. The subjects continues the simultaneous hip and knee flexion until the thighs are parallel to the floor.(Baechle 2000)

Isokinetic Testing

Isokinetic testing is a form of strength testing that offers an objective measure of muscular strength. Isokinetic machines allow the subject to offer a maximal contraction force throughout a range of motion at a predetermined angular velocity. The objective measures that can be obtained from an isokinetic machine are muscular strength isometrically, concentrically, and eccentrically.(Arnheim 2000)

Strength measurement on isokinetic devices are measured in torque or moment. Torque is measured in foot-pounds or Newton-meters. Peak torque is the maximum moment recorded in the range of motion. Average torque is the mean torque produced by the muscle throughout the entire range of motion. Subjects who differ in body size make it difficult to compare isokinetic data in Newton-meters. This difficulty is avoided by dividing the torque measurements by the subject's body weight.

Different hip motion isokinetic testing positions currently exist. Some studies have suggested that hip abductor/adductor strength testing should be done in the side-lying position with the hip extended, and hip external rotation should be tested with the subject supine.(Burnett, Betts et al. 1990) Kincom (Chattanooga Group Inc.) recommends in their clinical desk reference that hip flexion/extension be tested in a standing position, hip abduction/adduction be tested in a supine position, and hip external/internal rotation be tested in a seated position.

Electromyography (EMG)

In their resting state, all body cells exhibit a resting membrane potential. This potential typically ranges from –20 to –200 millivolts (mV).(Marieb 1999) This potential can be characterized as the relative charge between the inside and outside of the cell and is negative because the inside of the cell is negative as compared to the outside.(Marieb 1999)

When a muscle fiber is activated by a motor neuron, and electrical impulse is conducted along the length of the its axon. This response is call and action potential. This potential is always the same, regardless of the source or type of stimulus.(Marieb 1999) Muscles respond to these action potential by forming stable bonds between contractile myofibrils and creating force.(Marieb 1999)

Surface EMG uses electrodes placed on the skin to detect these action potentials. Typically, two electrodes are place in a parallel over the muscle 2-4 cm apart. The extracellular charge is positive before muscular contraction. As the muscle fibers depolarize under the first electrode, the action potential under that electrode becomes negative with respect to the second electrode. The EMG system can measure this difference between the electrodes.

One problem with EMG measurements is that they can vary greatly between subjects. This makes it difficult to compare the raw date between different subjects. A reference standard must first be defined before data can be interpreted across different subjects. This process is known as normalization. A common way to normalize EMG data across different subjects is through a measurement of maximal voluntary isometric contraction (MVIC). The EMG data is expressed as a percentage of the MVIC.

# CHAPTER 3 - METHODS

## Subjects

Approximately 70 subjects were screened by the principal investigator by watching them perform a double leg squat. Those subjects that were observed to exhibit a valgus motion during the squat were then observed with a two-inch heel block underneath their calcaneus. These subjects were recruited through volunteers from emails, fliers, and personal recruiting in classes. Subjects were divided into two groups based upon their results on the double leg squat task (DLST). The valgus group consisted of subjects who demonstrated bilateral knee adduction during the DLST that was corrected by placing a two-inch heel block under their calcaneus. The control group consisted of subjects who did not demonstrate knee adduction on either leg during the DLST. Subjects in the control group were matched to subjects in the hip dysfunction group by age, height, and weight. The control group consisted of 17 subjects while the valgus group consisted of 14 subjects whose ages ranged from 18-26 years. Subject demographics are located in Table 1. Subjects were otherwise healthy individuals that had no current musculoskeletal injuries or had not sustained an injury to either lower extremity in the past six months. Subjects were also excluded if they had surgery to either lower extremity in the past year. Furthermore, subjects in both groups were asymptomatic with and without activity, and subjects were asymptomatic during the DLST. Prior to all testing all subjects read and signed an informed

consent form approved by a University of North Carolina at Chapel Hill Biomedical Institutional Review Board (IRB).

Measurement and Instrumentation

A manual goniometer was used to measure joint angles in degrees for ROM assessment of the muscles of interest. Flexibility measurements were taken for the hip adductors ($ICC_{(2,1)}$ .89 SEM = 1.743), the hip internal rotators ($ICC_{(2,1)}$ .97 SEM 2.625), gastrocnemius, and soleus. ICCs were not calculated for these final two range of motion measures.

Concentric and eccentric muscle strength was evaluated using a Biodex System 3 Pro isokinetic dynamometer (Biodex Medical Systems, Shirley, NY), measured in Foot-pounds (Ft*lbs) of torque. The data were then analyzed with a customized Matlab 7.0 program (The Mathworks, Inc., Natick, MA) to determine the average peak torque, as well as time to peak torque, for the hip external rotators, internal rotators, hip abductors, and hip extensors. Each average was measured over the middle three of five total trials.

The mean amplitude electromyographic (EMG) activity of the gluteus medius, gluteus maximus, and adductor group was measured using an eight channel DelSys Bagnoli EMG System (Boston, MA). DE-2.1 single differential surface electrodes (DelSys Boston, MA) with a contact dimension of 1.0cm x 0.1cm and a contact spacing of 1.0cm over the muscle bellies and parallel to the fibers of the gluteus medius, gluteus maximus, and adductor muscles. Electrodes were plugged into a belt mounted I/O unit that plugged into the DelSys Bagnoli EMG system. This system amplified (x10,000 Hz) the EMG signal as it passed into the computer and was stored for analysis. The EMG data were processed with passive

demeaning (0.0 ms begin/ 10.0 ms end), a Butterworth notch filter at 60.0 Hz, a band pass Butterworth filter from 10.0 Hz – 350 Hz, and finally RMS smoothing was used at a time constant of 25 msec. All EMG data were normalized to the percentage of maximum voluntary isometric contraction to allow for comparison between subjects. All EMG data collection and processing was done using Datapac2K2 (Run Technologies, Mission Viejo, CA).

An electro-goniometer was placed over the knee joint so that knee joint ankle could be recorded and related to EMG activity during the DLST. Electro-goniometer data were filtered with a low pass Butterworth at 15.0 Hz.

A tripod was used to standardize squat depth; as well as a metronome to standardize squat speed at 66 beats per minute. Subjects used two beats to descend, two beats to ascend and one beat to rest between squats.

Procedures

Students and faculty of the University of North Carolina at Chapel Hill were asked through email and fliers to volunteer for screening for this study. Screening consisted of a questionnaire pertaining to previous history of injury or surgery to the lower extremity. Each subject completed their individual testing in one session. Prior to testing, subjects had the testing procedures explained to them and were asked to read and sign an informed consent form. Each testing session began with the recording of the subject's gender, age (years), height (cm), and weight (kg). Subjects were then video taped performing the DLST both with and without a two-inch heel block to ensure that they met the inclusion criteria for their assigned group. The tester then assessed the subject's dominant leg, defined as the leg they

would use to kick a soccer ball for maximum distance, for the following variables: the subject's passive hip abduction ROM; passive external rotation ROM; passive straight knee ankle dorsiflexion ROM; passive bent knee dorsiflexion ROM; Concentric/eccentric isokinetic strength for hip external and internal rotation, hip abduction, and hip extension; and EMG activity during a DLST in the gluteus medius, gluteus maximus, and adductor complex. The valgus group also had EMG recorded for a DLST while standing on a two-inch heel block. Prior to testing subjects were allowed to warm up for five minutes on a stationary bike at a self-determined pace.

ROM measurements

Subject positioning for ROM measurement of hip abduction was supine. The axis of the goniometer was placed over the ASIS of the extremity being measured. The stationary arm was placed along an imaginary line from one ASIS to the other. The movement arm was placed along the anterior midline of the femur using the midline of the patella for reference. The subject was then passively abducted until the tester felt the contralateral ASIS begin to move (Norkin 1995) Three separate measurements were taken and the mean was recorded.

Subject positioning for ROM measurement for hip internal rotation was supine with the dominant hip and knee flexed to 90 degrees. The hip was in neutral abduction/adduction. The axis of the goniometer was the anterior center aspect of the patella. The stationary arm was positioned parallel to the table. The movement arm was placed along the anterior midline of the tibia pointing towards the anterior midpoint of the ankle between the two melleoli.(Norkin 1995) The subject's hip was passively externally rotated until the tester felt the end range. Three separate measurements were taken and the mean was recorded.

Subject positioning for ROM measurement of straight knee dorsiflexion was supine with the dominant knee in full extenion. The ankle was in neutral inversion/eversion. The axis of the goniometer was distal lateral maleolus. The stationary arm was positioned with the lateral midline of the fibula, using the fibular head for reference. The movement arm was placed parallel to the lateral aspect of the fifth metatarsal (Norkin 1995). The subject's ankle was then passively dorsiflexed until the tester felt the end range. Three separate measurements were taken and the mean was recorded.

Subject positioning for ROM measurement of bent knee dorsiflexion was the same as straight knee; however, a bolster was placed under the subject's dominant knee so that it was flexed to at least 30 degrees(Norkin 1995). The subject's ankle was then passively dorsiflexed until the tester felt the end range. Three separate measurements were taken and the mean was recorded.

Electromyography

The sites for electrode placement were shaven and cleansed with alcohol to improve signal transmission from the muscles. Electrodes were placed over the muscle bellies of the gluteus medius, gluteus maximus, and adductor complex. A reference electrode was placed on the tibial tuberosity. Electrodes were placed in a parallel to muscle fibers.

The electrodes for the gluteus medius were placed halfway between the iliac crest and the greater trochanter of the femur (Kleissen 1990). The electrodes for the gluteus maximus were placed 20% of the distance between the spinous process of S2 and a point 10 cm distal to the greater trochanter. The electrodes for the adductor complex were placed on the muscle belly at the mid point of the femur (Leveau 1992). All electrode placements were confirmed

with an isometric manual muscle test and checked for cross talk. Maximal voluntary isometric contraction (MVIC) was used to normalize muscle activity between subjects (% MVIC).

Strength Measurements

Reliability for all strength tests was demonstrated by Halverson and Hawkey, abstract published in Journal of Athletic Training supplement 2004.

The hip external rotators were tested in a seated position. The subject's hip and knee was flexed to 90 degrees. The dynamometer was aligned with the long axis of the femur. Pressure was applied to the medial aspect of the distal tibia. The thigh was stabilized to the chair using straps. A towel was also placed between the subjects' knees to act as a fulcrum for external rotation and prevent adduction. The external rotators were tested through twenty degrees of motion that began at five degrees of external rotation and ended at fifteen degrees of internal rotation.

The hip internal rotators were tested in a seated position. The subject's hip and knee were flexed to 90 degrees. The dynamometer was aligned with the long axis of the femur. Pressure was applied to the lateral aspect of the distal tibia. The thigh was stabilized to the chair using straps. The internal rotators were tested through twenty degrees of motion that began at five degrees of internal rotation and ended at fifteen degrees of external rotation.

The hip abductors were tested with the subject in a side-lying position to isolate the gluteus medius. The joint axis was located at 0.5 inches medial to the ASIS at the level of the greater trochanter (Lyons, Perry et al. 1983). The hip was abducted and externally rotated, making sure not to let the trunk and pelvis rotate backward. Pressure was applied

against the thigh in the direction of adduction. Pressure was not applied against the external rotation component of the start position (Kendall 1993). The trunk was stabilized by strapping the subject to the chair. The muscle was tested from 0-20 degrees of hip abduction.

The hip extensors were tested in a supported, standing position in an attempt to isolate the gluteus maximus and maximize stabilization. The dynamometer axis of rotation was aligned with the anterior superior tip of the greater trochanter (Lyons, Perry et al. 1983). The subjects stood in front of the Biodex chair, and the seat was raised to the level of the subjects' ASIS. If the chair was unable to reach the subjects' ASIS, the subjects were then asked to flex the contralateral knee until the chair was even with the level of the ASIS. The subjects flexed their trunk to ninety degrees and laid their chest on the chair. The trunk was stabilized to the Biodex chair prior to testing using straps. This stabilization was aimed at preventing accessory trunk motions that might influence strength testing. The knee of the test leg was flexed to ninety degrees. The stance leg (non-test leg) was flexed at the knee such that the subjects' chest was comfortably resting on the chair. The subjects were then asked to actively extend the hip through a range of motion that began at ninety degrees of hip flexion (femur perpendicular to the groud) and ended at fifty degrees of hip flexion. Pressure was applied against the distal portion of the posterior thigh in the direction of hip flexion (Kendall 1993).

All muscles were tested concentrically and eccentrically at 60 deg * $sec^{-1}$. The testing procedure accounted for gravity corrections during hip abduction and hip extension testing since the test limb was sufficiently close to the horizontal plane. The test limb did not come close enough to the horizontal plane to warrant a gravity correction during the testing of the hip external or internal rotators.

Following the isokinetic testing of each muscle group, the subject's strength was tested isometrically. The positioning and alignment of the subjects was exactly the same for the isometric testing as it was used during the isokinetic testing. The test limb was positioned in the middle of the isokinetic ROM or neutral position for isometric testing. The test limb was placed at seventy degrees of hip flexion while testing the hip extensors. The test limb was placed at ten degrees of hip abduction while testing the hip abductors. The test limb was placed in a neutral position (zero degrees of abduction/adduction) while testing the hip adductors. Each subject performed three maximal isometric contractions. The contractions were held for five seconds each, and there was 10-12 seconds rest between each repetition. The mean amplitude of the three trials during the middle three seconds of each trial was recorded.

The EMG data for the MVIC of the gluteus maximus was recorded while testing hip extension. The EMG data for the MVIC of the gluteus medius was recorded while testing hip abduction. The EMG data for the MVIC of the adductor complex was recorded while still in the testing position for hip abduction. The subjects were asked to maximally adduct the hip against the Biodex dynamometer for five seconds. EMG from these MVIC's was recorded so that the EMG data recorded during the DLST could be normalized and used to compare between subjects.

Double-Legged Squat Task

Subjects were asked to stand with hips, feet, and knees facing forward and arms fully extended overhead parallel to their ears. The subjects then were instructed to go down into a squat position as if they were trying to sit in a chair. Squat depth was standardized to 70

degrees of knee flexion to ensure that each subject went through at least 60 degrees of motion. Subjects were instructed to squat while their knee joint angle was measured with a manual goniometer. When the desired amount of 70 degrees of knee flexion was achieved a tripod was set up to assist the subject in knowing the proper squat depth. An electrogoniometer was then placed on the subject's knee so that EMG data could be examined in relation to knee position. The subjects then performed the squat task five times. EMG activity was recorded for the gluteus medius, gluteus maximus, and the adductor complex from 0-60 degrees of knee flexion during each of the squat tasks. Subjects in the control group only performed the DLST without the heel block. Subjects in the valgus group performed the DLSQ with and without the heel block while EMG data were recorded.

## Data Analysis

One way analysis of variance tests were used to analyze differences between groups in the ROM measurements. A 2 x 2 analysis of variance was used to analyze the straight and bent knee ankle dorsiflexion ROMs. 2 x 2 mixed model analysis of variance tests were used to analyze differences between groups in concentric and eccentric peak torque as well as time to peak torque. EMG data differences were analyzed both between groups and between phases within groups with separate 2 x 2 mixed model analyses of variances. Tukey Post Hoc testing was used to identify where significance was found for the ankle dorsiflexion and EMG data. All data were analyzed using SPSS 13.0 (Chicago, IL). All null hypotheses were tested for significance at $p < .05$.

# CHAPTER 4 – RESULTS

## ROM Measurements

Means, standard deviations, and effect size for hip abduction ROM are presented in Table 2. There was no significant difference [$F_{(1,29)} = 0.01$, $p = .920$] for hip abduction range of motion between the control and the valgus groups. Means, standard deviations, and effect size are presented in Table 2. There was no significant difference [$F_{(1,29)} = 0.859$, $p = .362$] for hip external rotation ROM between the control and the valgus groups. There was a significant group by knee position interaction effect for ankle dorsiflexion [$F_{(1,26)} = 17.4$ $p < .001$]. Tukey Post Hoc tests revealed that the difference between groups with straight knee dorsiflexion was significant. This difference is illustrated in Figure 1.

## Hip External Rotation Concentric/Eccentric Peak Torque

Means, standard deviations, and effect sizes are presented in Table 3. There was no significant difference for hip external rotation concentric [$F_{(1,29)} = 1.309$, $p = .262$] or eccentric [$F_{(1,29)} = .514$, $p = .479$] peak torque between the control and valgus groups.

## Hip Internal Rotation Concentric/Eccentric Peak Torque

No significant differences were observed for hip internal rotation concentric [$F_{(1,29)} = 0.00$, $p = .985$] or eccentric [$F_{(1,29)} = 0.06$, $p = .808$] peak torque between the control and valgus groups.

Hip Extension Concentric/Eccentric Peak Torque

There was no significant difference [$F_{(1,29)} = 0.046$, $p = .833$] for hip extension concentric peak torque between the control and valgus groups. There was no significant difference [$F_{(1,29)} = 0.305$, $p = .585$] for hip extension eccentric peak torque between the control and valgus groups.

Hip Abduction Concentric/Eccentric Peak Torque

There was no significant difference [$F_{(1,29)} = 3.682$, $p = .065$] for hip abduction concentric peak torque between the control and valgus groups. However, the p value suggests a trend and the finding might reach significance if the statistical power was greater. This trend is illustrated in Figure 2. There was no significant difference [$F_{(1,29)} = 0.006$, $p = .939$] for hip abduction eccentric peak torque between the normal and valgus groups.

Hip External Rotation Concentric/Eccentric Time to Peak Torque

Means, standard deviations, and effect size are presented in Table 4. There was no significant difference [$F_{(1,29)} = 0.376$, $p = .544$] for hip external rotation concentric time to peak torque between the control and valgus groups. There was no significant difference [$F_{(1,29)} = 0.038$, $p = .847$] for hip external rotation eccentric time to peak torque between the control and valgus groups.

Hip Internal Rotation Concentric/Eccentric Time to Peak Torque

There was a significant difference [$F_{(1,29)} = 4.976$, $p = .034$] for hip internal rotation concentric time to peak torque between the control and valgus groups. The normal group

achieved peak torque almost a full second faster (2 sec vs. 3 sec) than the valgus group (fig 3). There was no significant difference [$F_{(1,29)} = 0.023$, $p = .880$] for hip internal rotation eccentric time to peak torque between the normal and valgus groups.

Hip Extension Concentric/Eccentric Time to Peak Torque

There was no significant difference [$F_{(1,29)} = 0.456$, $p = .501$] for hip extension concentric time to peak torque between the control and valgus groups. There was no significant difference [$F_{(1,29)} = 1.235$, $p = .276$] for hip extension eccentric time to peak torque between the control and valgus groups.

Hip Abduction Concentric/Eccentric Time to Peak Torque

There was no significant difference [$F_{(1,29)} = 3.218$, $p = .083$] for abduction concentric time to peak torque between the control and valgus groups. However, the p value suggests a trend that the valgus group required a half second longer (1.1 sec vs. 1.6 sec) to reach peak torque. This trend is illustrated in Figure 4. There was no significant difference [$F_{(1,29)} = 1.725$, $p = .199$] for hip abduction rotation eccentric time to peak torque between the normal and valgus groups.

Gluteus Maximus EMG Mean Amplitude During a Squatting Task

Means, standard deviations, and effect size are presented in Table 5. There was no main effect for group [$F_{(1,27)} = 0.002$, $p = .962$] for gluteus maximus activity during the ascending and descending phases of the squat. No main effect for phase [$F_{(1,27)} = 0.024$, $p = .877$] was observed for gluteus maximus activity between the ascending and descending

phases of the squat for the control or valgus groups. There was no group by phase interaction effect [$F_{(1,27)} = 0.020$, $p = .888$] for gluteus maximus activity during the squat task.

Gluteus Medius EMG Mean Amplitude During a Squatting Task

There was no main effect for group [$F_{(1,27)} = 1.037$, $p = .318$] during the ascending or descending phases of the squat between the control or valgus groups. There was no main effect for phase [$F_{(1,27)} = 0.101$, $p = .753$] of gluteus medius activity between ascending and descending phases of the squat for either group. No group by phase interaction effect [$F_{(1,27)} = 0.098$, $p = .757$] was observed for gluteus medius activity during the squat task.

Adductor Mean EMG Amplitude During Squatting

There was a group by phase interaction [$F_{(1,27)} = 6.095$, $p = .020$] for adductor activity during the squat task. The control group had higher mean amplitude during the descending portion of the squat and decreased during the ascending phase. In contrast, the valgus group had higher adductor activity during ascending than decending. Tukey post hoc testing revealed that the difference between adductor activity of the control group and the valgus group during the ascent phase was significant. This significance is illustrated in Figure 5. No main effect for group [$F_{(1,27)} = 0.163$, $p = .690$] was observed for adductor activity during the ascending or descending phases of the squat. There was no main effect for phase [$F_{(1,27)} = 0.196$, $p = .661$] for adductor activity between the ascending and descending phases of the squat for either the normal or the valgus group.

Gluteus Maximus EMG Mean Amplitude During Squatting with Heel Block

Means, standard deviations, and effect size for mean gluteus maximus amplitude during the squatting task on the heel block are presented in Table 6. There was no main effect for the heel block [$F_{(1,11)} = 0.134$, $p = .721$] for gluteus maximus activity during the ascending and descending phases of the squat between the valgus group with and without the heel block. There was no main effect for phase [$F_{(1,11)} = 1.525$, $p = .241$] for gluteus maximus activity between the ascending and descending phases of the squat for the valgus group either with or without the heel block. There was no heel block x phase interaction effect [$F_{(1,27)} = 1.430$, $p = .255$] for gluteus maximus activity during the squat task.

Gluteus Medius Mean EMG Amplitude During Squatting with a Heel Block

Means, standard deviations, and effect size for gluteus medius EMG mean amplitude during the squatting task on the heel block are presented in Table 6. No main effect was observed for gluteus medius activity [$F_{(1,11)} = 0.022$, $p = .885$] during ascending and descending phases of a squat between the valgus group with and without the heel block. There was no main effect for phase [$F_{(1,11)} = 2.034$, $p = .179$] of gluteus medius activity between the ascending and descending phases of the squat for the valgus group either with or without the heel block. There was no heel block by phase interaction effect [$F_{(1,11)} = 1.955$, $p = .187$] for gluteus medius activity during the squat task.

Adductor EMG Mean Amplitude During Squatting with and without a Heel Block

Means, standard deviations, and effect size for mean adductor amplitude during the squatting task on the heel block are presented in Table 6. There was no main effect for heel

block [$F_{(1,11)} = 2039$, $p = .148$] for adductor activity during the ascending and descending phases of the squat between the valgus group with and without the heel block. There was a main effect for phase [$F_{(1,11)} = 10.951$, $p = .006$] of adductor activity between the ascending and descending phases of the squat for the valgus group while on the heel block. Adductor activity during the descending phase of the squat was less than the ascending phase. This significance is illustrated in Figure 6. There was no heel block by phase interaction effect [$F_{(1,11)} = 1.7$, $p = .217$] for adductor activity during the squat task.

# CHAPTER 5 – DISCUSSION

The most important findings from this study are that individuals who demonstrated knee valgus during a squat and have the valgus position corrected with a two-inch heel block have different adductor muscle activity during a squat. Our results also show these valgus individuals have less passive ankle dorsiflexion ROM (with a straight knee) when compared to a control group. Moreover, the passive bent knee ankle dorsiflexion ROM of the valgus group was significantly increased over their straight knee ankle dorsiflexion. The control group reached concentric peak torque of the internal rotators quicker than the valgus group. Trends in the data suggest that the control group has larger concentric peak torque in the abductors and achieve peak torque during concentric abduction faster when compared to the valgus group.

## Muscle Activity During Squatting

An analysis of the control group shows that muscle activity during different phases of a squat (descending and ascending) is not different. This means the control group uses hip musculature equally. This is not the case for those who display a valgus motion during a squat and the difference seems to be in the adductor complex. The other two muscles examined (gluteus maximus and gluteus medius) showed similar activity patterns when compared to the control group.

A group by phase interaction was demonstrated by the adductor muscle complex during the squat task. When comparing maximal muscle activity, the control group's adductor muscle had the greatest activity during the decent phase while the valgus group was most active during the ascent phase (Figure 5). Thus, subjects performing proper squat posture utilized all three muscles simultaneously to eccentrically lower themselves, while the valgus group adductor complex was not as active in the eccentric lowering during the descent phase. However, during the ascent phase the control group's adductors were not as active and relied on the gluteus maximus to assist with hip extension. It is important to note that neither the decrease in the adductor activity nor the increase in the gluteus maximus activity from the descent phase to the ascent phase in the normal group were deemed significant. The opposite situation was found to exist with the adductor complex of the valgus group. Adductor activity during the decent phase was significantly less than adductor activity during the ascent phase. Furthermore, their adductor activity during the ascent phase was significantly greater than that of the normal group during the same phase.

Subjects in the valgus group in this study had their valgus corrected when squatting on a two-inch heel block. Current theory (Clark 2001) suggests valgus may result from tight musculature of the ankle rather than weak hip musculature. The heel block allows for increased length of the gastrocnemius and soleus complex, allowing normal motion and correcting valgus. Further research needs to identify individuals that present with valgus that is not corrected by a heel block and validate that hip musculature is the issue and what role it may play in knee valgus.

Increased adductor activity in the valgus group during the ascent phase of a squat could be explained an improved length-tension relationship of the muscle group due to

increased hip flexion. One study examined moment arms of hip extensor muscles (gluteus maximus and adductor magnus) and found that the gluteus maximus moment arm decreased while the adductor magnus moment arm increased while the hip was flexed. The adductor magnus extension moment arm was shown to continue to increase until 75 degrees of hip flexion (Nemeth and Ohlsen 1985). Furthermore, it has been shown that women demonstrate significantly more hip flexion and adduction during single-legged squats (Zeller, McCrory et al. 2003). While our study examines double-legged squats, this is still relevant because valgus was part of our inclusion criteria and a majority of our valgus subjects were women. Females are being put into a position of hip flexion and adduction that may increase their adductor muscle activity during the ascent phase. While in the control group the gluteus maximus increases during the ascent phase, it actually slightly decreases in the ascent phase for the valgus group. This may be explained by the increase in hip adduction decreasing the gluteus maximus' ability to function as an extensor. This position of knee adduction is associated with femoral internal rotation (Ireland 1999). During the ascent phase the gluteus maximus may be functioning more in its role as a hip external rotator to compensate for femoral internal rotation. If this is the case, then it makes sense that the adductor activity increases as they function more in extension. However, the changes in gluteus maximus muscle activity in our study were not found to be significant. Moreover, we did not measure hip flexion angles in our subjects. Therefore this theory needs to be explained further through future research.

A final possible explanation of the difference seen between our groups in adductor muscle activity arises from stance width. Research suggests stance width has a significant effect on adductor longus muscle activity during a squat task (McCaw and Melrose 1999).

Stance width was not measured in this study but we used a self-selected stance width set at shoulder width apart and researcher verified. We think this minimizes any effect stance width may have on our data.

There were no significant differences found in any of the muscles tested in the valgus group between the regular squat and the squat on the heel block, except for the significant difference in adductor activity between phases that had already been discussed in comparison to the control group. This is the first study to examine how hip muscle activity changes when individuals with knee valgus squat on a two-inch heel block. More research needs to be done to fully understand how plantar flexing the ankle by placing and individual on a two-inch heel block affects squatting

The lack of significance in the muscle activity between the valgus group with and without the heel block begins to outline three populations. These populations are a normal or control group, an ankle dysfunction group and a hip dysfunction group. The control group demonstrates a proper squat technique and keeps their knees centered over their toes (Clark 2001). The ankle dysfunction group is the group examined in our study and demonstrates knee valgus during a squat that is corrected by placing a two inch block under their heel. The hip dysfunction group consists of individuals who demonstrate knee valgus during a squat that is not corrected by the heel block. Currently no study has focused on the hip dysfunction group to verify current theory as to what is causing their knee valgus.

Straight and Bent Knee Ankle Dorsiflexion ROM

Another significant finding of this study was the difference of the straight knee ankle dorsiflexion ROM between the valgus group and control group and the difference of the

valgus group between straight knee and bent knee. The valgus group had significantly less straight knee dorsiflexion. The gastrocnemius is a bi-articulate muscle crossing the ankle and knee. When the knee is straight, ROM of the ankle decreases because the gastrocnemius reaches end range, limiting motion. Tightness in the gastrocnemius muscle may have played a role in valgus during the DLST. This point is illustrated further when the knee was bent. The valgus group's dorsiflexion range of motion was significantly increased and approximately equal to the control group. This idea is the foundation of current theory! When the valgus group squatted with the heel block, the gastrocnemius shorts and the resulting tension is removed from the squat, correcting knee valgus. This suggests that the tightness in the gastrocnemius muscle played a role in the knee valgus. It is important to note that when the valgus group was on the heel block, there were no significant changes in hip musculature activity.

Ankle dorsiflexion has been shown to be around 10 degrees during the stance phase of gait (Murray 1967). During more function tasks, such as sit-to-stand, stair climbing, and sport specific activities, the requirement for ankle dorsiflexion ROM can increase to about 25 degrees (Andriacchi, Andersson et al. 1980; Lindsjo, Danckwardt-Lilliestrom et al. 1985; Livingston, Stevenson et al. 1991). The double-legged squat used in our study can be related to the function activities that can require the greater dorsiflexion. Thus, the lack of motion seen in the valgus group can explain their inability to perform the task properly. However, it becomes hard to explain why gastrocnemius tightness in and of itself would contribute to knee valgus. It may be a unilateral issue. If the lateral gastroc is tight or short, it may be responsible for pulling the knee into a valgus position. Currently it is believed that during a squat decreased ankle dorsiflexion would lead to the heels of the individual rising up off of

the floor (Clark 2001). This idea makes more sense when examining the gastrocnemius muscle by itself; however, when considering the entire kinetic chain there appears to be more to the picture. It makes more sense to think that this tightness in the gastrocnemius would pull, from its insertion, the calcaneus into eversion, thus causing the foot to pronate. Our study did not examine foot and ankle pronation but if this is the case, then our results seem to suggest that when the arch flattens and pronation ceases the gastrocnemius begins to influence an increase in knee valgus. Therefore it seems that more research needs to be done to determine whether or not the gastrocnemius muscle itself can cause knee valgus or it if only contributes to increased valgus when it is already present.

Internal Rotation Time to Peak Torque

Our study found that the control group reached their internal rotation concentric peak torque approximately a full second (2 sec vs. 3 sec) before the valgus group. This difference was deemed statistically significant and further strengthens the idea that there is a difference in adductor activity between groups. The current literature suggests that the gluteus maximus and gluteus medius are important hip stabilizers (Gottschalk, Kourosh et al. 1989; Clark 2001; Schmitz, Riemann et al. 2002) Our study showed that the gluteus maximus and gluteus medius activity between the control and the valgus groups were similar even though the valgus group demonstrated poor proximal hip control. This suggests that it may not be the gluteal muscles that are responsible for stabilization but rather other hip internal and external rotators. This can be further explained by the differences discussed above about the adductor activity between the two groups, as the adductors also function as hip internal rotators.

Abduction Concentric Peak Torque and Time to Peak Torque

There was a trend discovered in our study that suggests the control group produced greater concentric peak torque in the abductors than the valgus group and the control group achieved peak torque a half second faster (1.1 sec vs. 1.6 sec). The lack of significance of this may be due to lack of statistical power; an increase in power may draw out the significance of this finding. Regardless, this finding is clinically significant as it suggests that one potential cause of the knee valgus position is that the valgus group lacks abduction strength as well as the ability to achieve maximum strength in time to prevent hip adduction. This could be related to the previous stated findings of ankle dorsiflexion range of motion. It may be that the adduction begins due to a lack of abduction stabilization strength and is increased by the lack of gastrocnemius flexibility and decreased ankle dorsiflexion

Ireland has described a "position of no return" as when an athlete has poor hip control and the hip moves into adduction, leading to femoral internal rotation and a position of knee valgus (Ireland 1999). These trends discovered in our study seem to support this and further explain it by demonstrated ankle dorsiflexion ROM's role in this knee adduction. However, further research is required to further explore these trends and determine if they are significant.

Hip Abduction and Internal Rotation ROM

No difference was observed in hip abduction or internal rotation ROM between the control and valgus groups. Initially, we hypothesized that tight adductors or tight internal

rotators may pull individuals into knee valgus. However, our study failed to identify this as a contributing factor. In fact the means of each ROM between groups was almost identical.

### Hip Extension and External Rotation Concentric and Eccentric Peak Torque

No statistical difference was observed between group concentric or eccentric peak torques. This finding is clinically significant because it suggests that the gluteus maximus muscle does not play a significant role in preventing knee valgus during a squat. It is currently thought that individuals who demonstrate knee valgus have weak gluteus maximus control during squatting (Clark 2001). Again it becomes important to note that it appears that the subjects tested had ankle dysfunction and not necessarily hip dysfunction, and that individuals not corrected by the heel block may have differences in gluteus maximus strength.

### Limitations

The greatest limitation of this study was the lack of statistical power for some of the analyses. Ideally, each group would have around 20 subjects to have enough power to draw out significant differences that may exist. This was unable to be achieved in this study due to the difficulty in identifying subjects who met the valgus group criteria. However, most of the analyses that lacked power also had small effect sizes. Therefore, if power was increased such that significance was found, it still may not be clinically significant.

Another limitation for this study is that the order of testing was not randomized. Every subject followed the same protocol in the same order. However, since the subjects were observed to exhibit the bilateral knee valgus both before and after ROM and strength

testing it is not believed that either altered the way in which the subjects performed the squat task.

The inability to identify many males who fit the inclusion criteria for the valgus group limits the generalizability this study. The control group is more evenly divided between males and females; however, the valgus group consists of primarily females. Although, the demographics between each group suggest that subjects were closely matched by age, height, and weight.

The lack of lower leg EMG activity is also a limitation of this study. While the ROM of ankle dorsiflexion was measured, no information about the muscle activity around the ankle of the ankle dysfunction group was available to help further understand what may be contributing to their valgus knee position.

## Future Research

Current theory places subjects into categories if they are identified has having knee valgus (Clark 2001). There is a control population that demonstrates correct squat technique. There is a hip dysfunction population that demonstrates bilateral knee valgus both with and without a two-inch heel block. Finally, there is an ankle dysfunction population that demonstrates bilateral knee valgus during a squat that is corrected by a two-inch heel block. This study contrasted the control population against the ankle population and how hip musculature and ankle ROM contributes to knee valgus. Future research needs to verify that this classification system is correct and document differences between groups. Areas of focus should be the hip musculature (gluteus maximus, gluteus medius and adductor complex), ankle musculature (medial and lateral gastrocnemius, tibialis anterior, and soleus),

and these variables relation to this position of knee valgus during a squat task. Future research should also focus on the kinematics of the squat to verify that valgus is corrected or not with the heel block. Finally, once the theory has been estabilished, research should attempt to implement training programs to correct valgus.

# APPENDIX A: TABLES

**Table 1: Subject Demographics; Mean and Standard Deviation**

| Group | Gender | | Age(yr) | | Height(cm) | | Weight(kg) | |
|---|---|---|---|---|---|---|---|---|
| | Male | Female | Mean | SD | Mean | SD | Mean | SD |
| Normal | 7 | 10 | 23.82 | 5.76 | 166.12 | 31.13 | 69.59 | 15.37 |
| Valgus | 2 | 12 | 22.36 | 3.08 | 167.21 | 9.3 | 65.93 | 9.9 |

**Table 2: Ranges of Motion; Means and Standard Deviations**

| ROM | Normal | | | Valgus | | | Effect Size |
|---|---|---|---|---|---|---|---|
| | Mean | | SD | Mean | | SD | |
| Hip Abd | 36.88 | ± | 5.34 | 35.29 | ± | 3.97 | 0.35 |
| Hip ER | 73.92 | ± | 17.51 | 74.23 | ± | 7.02 | 0.04 |
| AnkleSKD | 17.88 | ± | 7.93 | 13.43 | ± | 7.85* | 0.59 |
| AnkleBKD | 19.86 | ± | 8.37 | 19.88 | ± | 8.37** | 0.003 |

$p < .001$ for group by ROM interaction

* Denotes Significant Difference from Normal Group AnkleSKD
** Denotes Significant Difference from Valgus Group AnkleSKD

**Abd - Abduction**
**ER - External Rotation**
**SKD - Straight Knee Dorsiflexion**
**BKD - Bent Knee Dorsiflexion**

**Table 3: Isokinetic Peak Torque Normalized to Body Weight (ft * lbs/kg); Means and Standard Deviations**

| ROM | Contraction | Normal | | | Valgus | | | Effect Size |
|---|---|---|---|---|---|---|---|---|
| | | Mean | | SD | Mean | | SD | |
| Hip ER | Concentric | 0.315 | ± | 0.075 | 0.273 | ± | 0.134 | 0.43 |
| | Eccentric | 0.605 | ± | 0.143 | 0.557 | ± | 0.229 | 0.27 |
| Hip IR | Concentric | 0.806 | ± | 0.293 | 0.804 | ± | 0.201 | <.000 |
| | Eccentric | 0.444 | ± | 0.18 | 0.428 | ± | 0.188 | 0.09 |
| Hip Ext | Concentric | 1.281 | ± | 0.521 | 1.244 | ± | 0.424 | 0.08 |
| | Eccentric | 0.806 | ± | 0.415 | 0.73 | ± | 0.335 | 0.21 |
| Hip Abd | Concentric | 0.438 | ± | 0.175 | 0.327 | ± | 0.142* | 0.76 |
| | Eccentric | 0.508 | ± | 0.277 | 0.501 | ± | 0.217 | 0.03 |

* Denotes trend that Valgus group shows less concentric hip abduction peak torque (p = .065)

ER - External Rotation
IR - Internal Rotation
Ext - Extension
Abd - Abduction

**Table 4: Isokinetic Time to Peak Torque (seconds); Means and Standard Deviations**

| ROM | Contraction | Normal | | | Valgus | | | Effect Size |
|---|---|---|---|---|---|---|---|---|
| | | Mean | | SD | Mean | | SD | |
| Hip ER | Concentric | 3.35 | ± | 1.63 | 2.98 | ± | 1.75 | 0.23 |
| | Eccentric | 3.23 | ± | 1.24 | 3.12 | ± | 1.83 | 0.07 |
| Hip IR | Concentric | 2.29 | ± | 1.11 | 3.21 | ± | 1.18* | 0.83 |
| | Eccentric | 2.76 | ± | 1.35 | 2.86 | ± | 2.16 | 0.06 |
| Hip Ext | Concentric | 4.49 | ± | 1.76 | 4.9 | ± | 1.58 | 0.25 |
| | Eccentric | 2.51 | ± | 1.98 | 3.31 | ± | 1.92 | 0.41 |
| Hip Abd | Concentric | 1.18 | ± | 0.58 | 1.62 | ± | 0.79** | 0.7 |
| | Eccentric | 2.73 | ± | 1.42 | 3.36 | ± | 1.22 | 0.49 |

* Denotes that Valgus group took significantly longer to reach IR concentric peak torque (p = .034)
** Denotes trend that Valgus group shows longer time to concentric peak torque (p = .083)

ER - External Rotation
IR - Internal Rotation
Ext - Extension
Abd - Abduction

**Table 5: Mean EMG Amplitude (Normalized to MVIC) During a Squat Task; Means and Standard Deviations**

| | | Normal | | | Valgus | | | Effect Size |
|---|---|---|---|---|---|---|---|---|
| | | Mean | | SD | Mean | | SD | |
| Gluteus Maximus | Descending | 10.98 | ± | 12.53 | 11.37 | ± | 5.65 | 0.02 |
| | Ascending | 11.52 | ± | 8.03 | 11.4 | ± | 5.72 | 0.02 |
| Gluteus Medius | Descending | 14.99 | ± | 10.04 | 19.02 | ± | 9.72 | 0.39 |
| | Ascending | 15.5 | ± | 11.02 | 19.03 | ± | 9.75 | 0.39 |
| Adductors | Descending | 29.68 | ± | 39.02 | 18.85 | ± | 14.26 | 0.16 |
| | Ascending | 18.02 | ± | 7.62 | 35.6 | ± | 33.78*† | 0.16 |

p = .020 for group x phase interaction

* Denotes significant difference from valgus group descending activity

† Denotes significant difference from normal group ascending activity

**Table 6: Mean EMG Amplitude (Normalized to MVIC) During a Squat Task with Heel Block; Means and Standard Deviations**

| | | Valgus (no heel block) | | | Valgus (heel block) | | | Effect Size |
|---|---|---|---|---|---|---|---|---|
| | | Mean | | SD | Mean | | SD | |
| Gluteus Maximus | Descending | 11.37 | ± | 5.65 | 10.58 | ± | 5.06 | 0.5 |
| | Ascending | 11.4 | ± | 5.72 | 13.07 | ± | 8.6 | 0.5 |
| Gluteus Medius | Descending | 19.02 | ± | 9.72 | 18.14 | ± | 9.43 | 0.58 |
| | Ascending | 19.03 | ± | 9.75 | 20.26 | ± | 11.86 | 0.58 |
| Adductors | Descending | 18.85 | ± | 14.26 | 18.09 | ± | 14.08 | 0.73 |
| | Ascending | 35.6 | ± | 33.78 | 28.49 | ± | 20.95 | 0.73 |

# APPENDIX B: FIGURES

Figure1: Ankle Dorsiflexion ROM

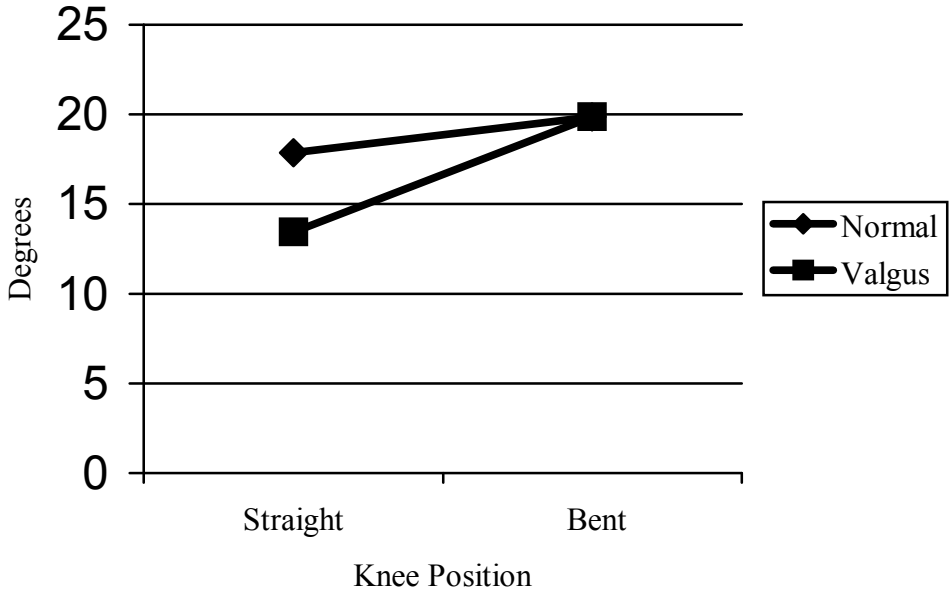


Figure 2: Hip Abduction Isokinetic Strength (Normalized to Body Weight)

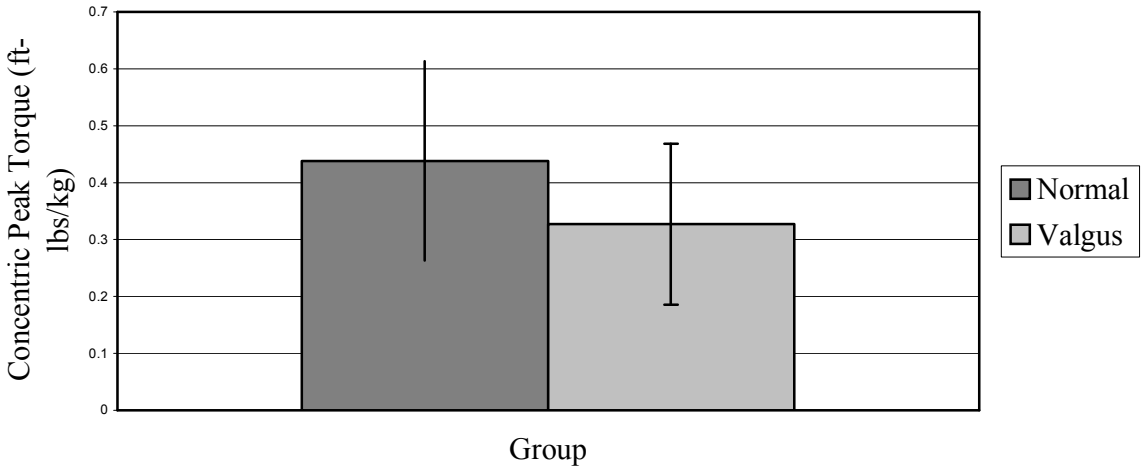


Figure 3: Internal Rotation Time to Peak Torque

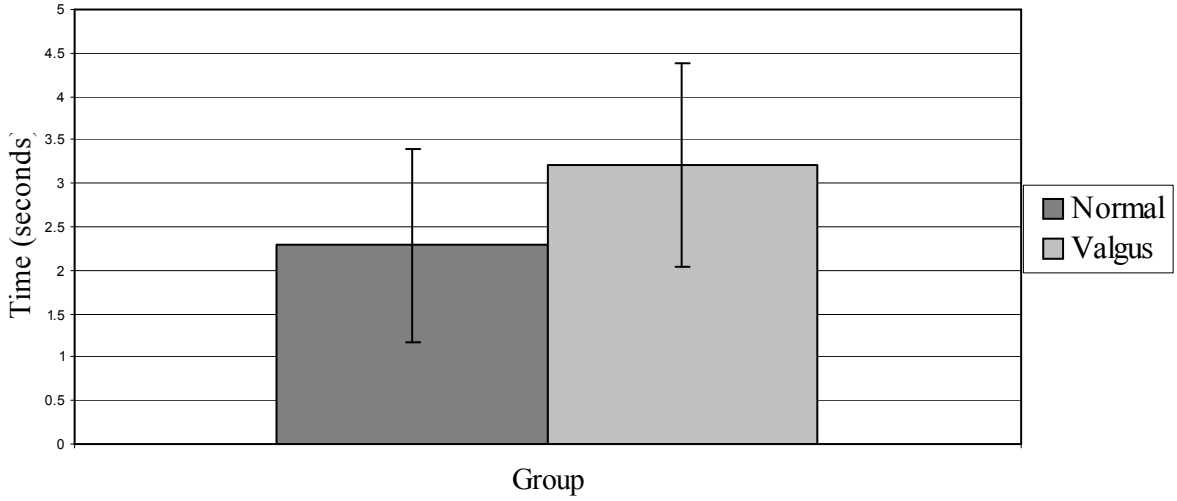


Figure 4: Abduction Concentric Time to Peak Torque

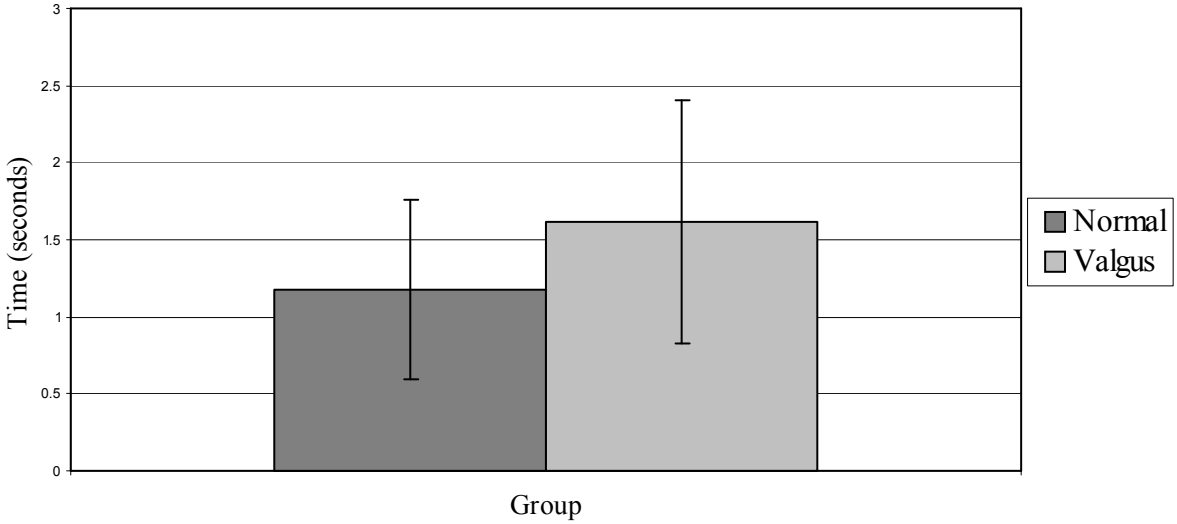


Figure 5: Adductor Mean EMG Amplitudes

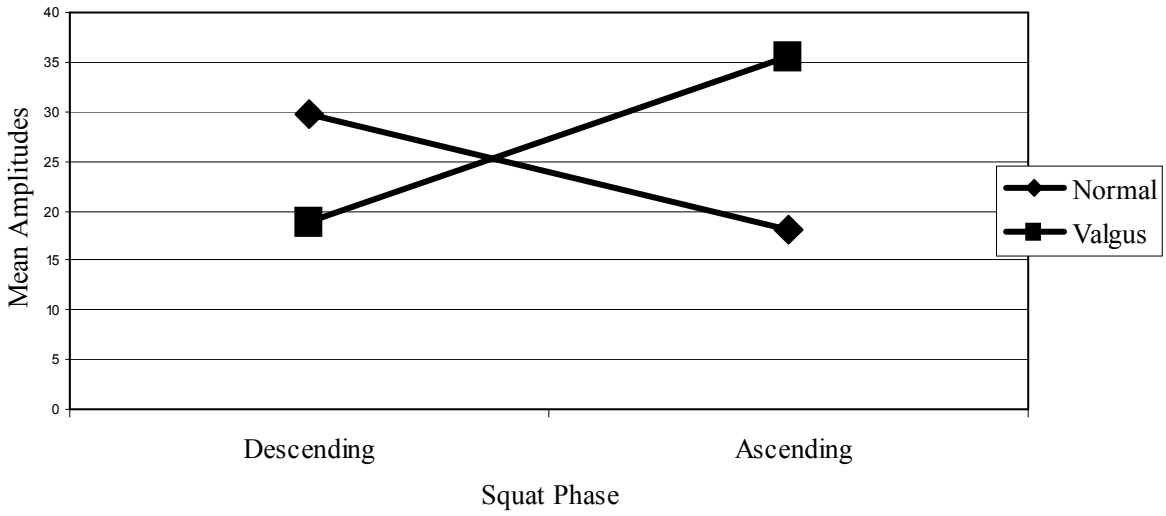


Figure 6: Hip Abduction ROM Measurement Positioning

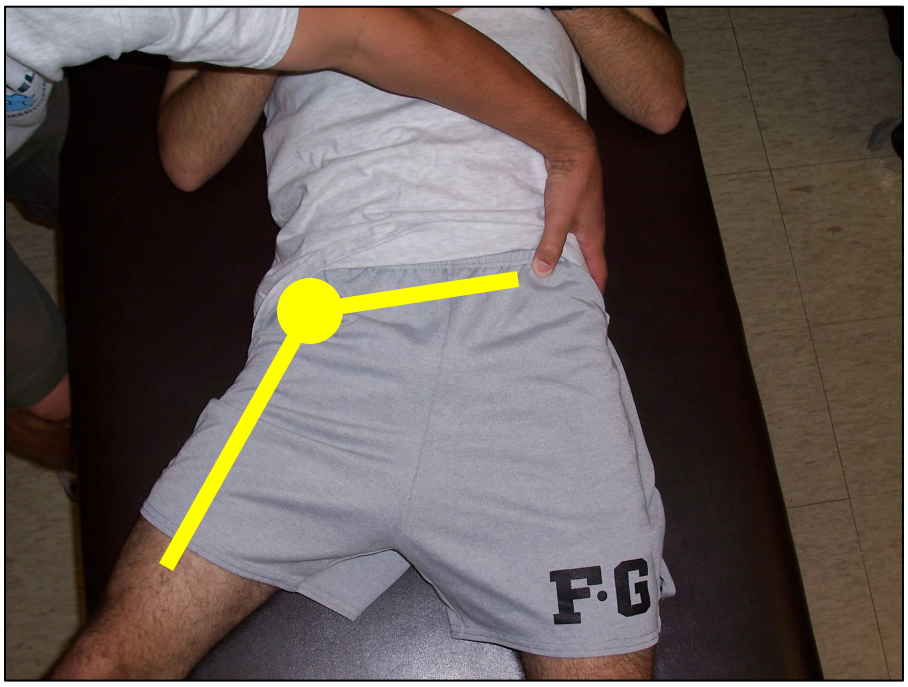


Figure 7: Hip External Rotation Measurement Positioning

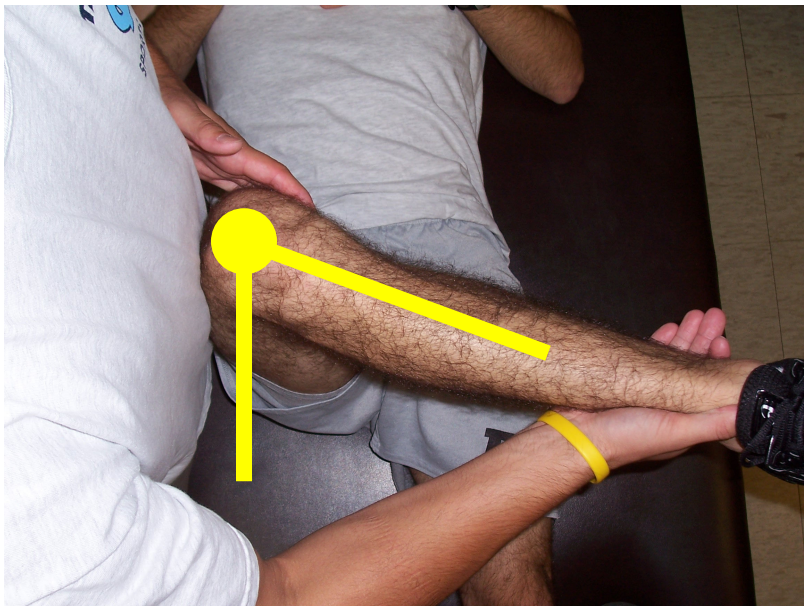


Figure 8: Straight Knee Ankle Dorsiflexion ROM Measurement Positioning

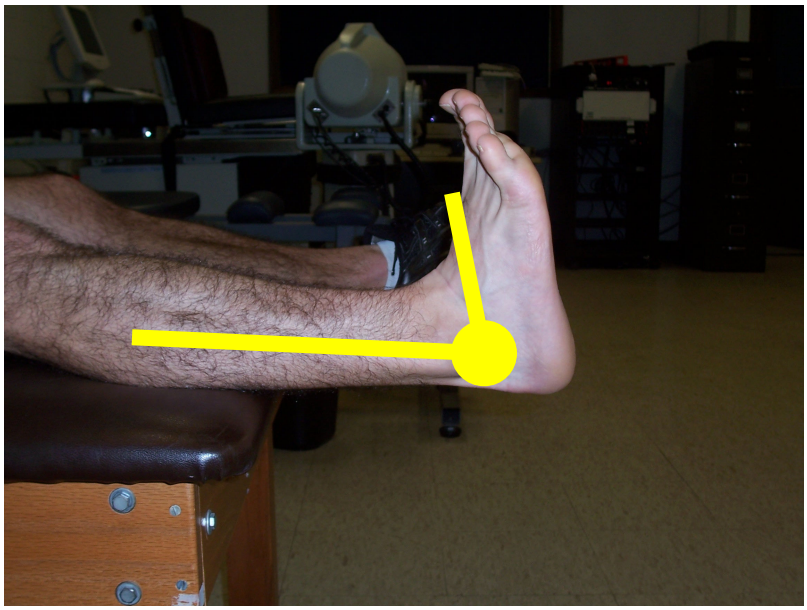


Figure 9: Bent Knee Ankle Dorsiflexion ROM Measurement Positioning

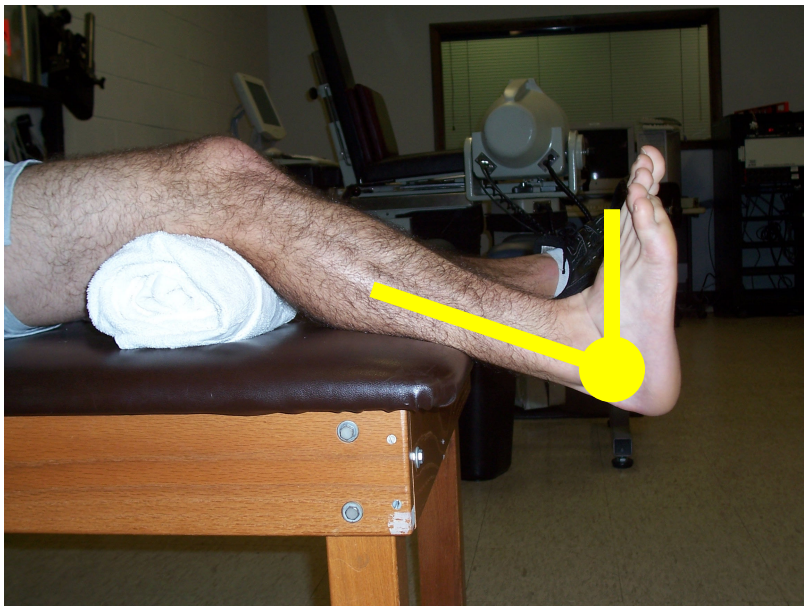


Figure 10: Gluteus Medius Electrode Placement

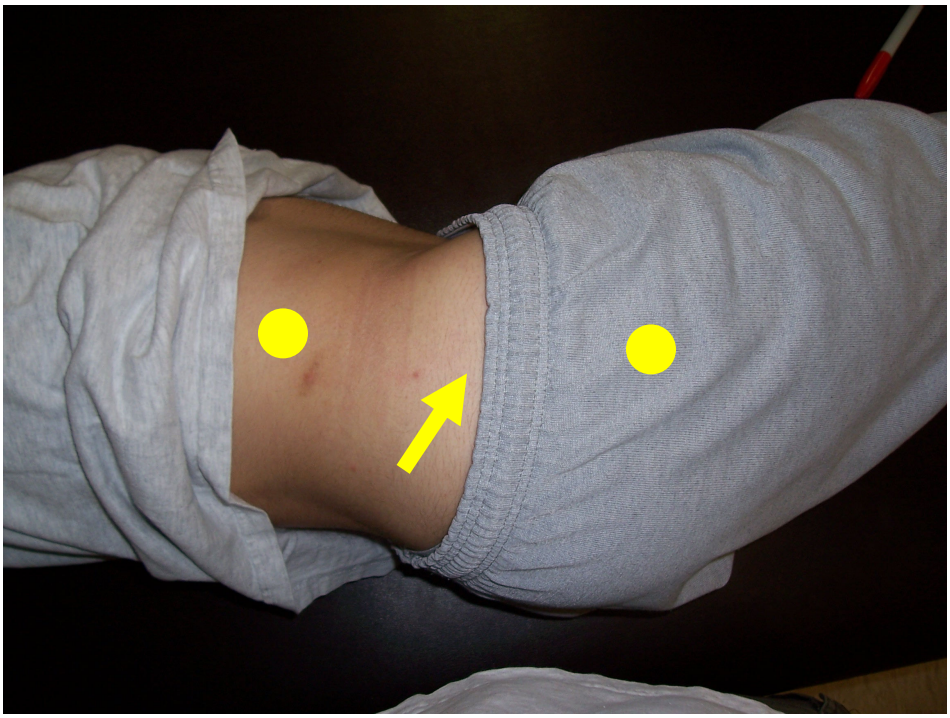


Figure 11: Gluteus Maximus Electrode Placement

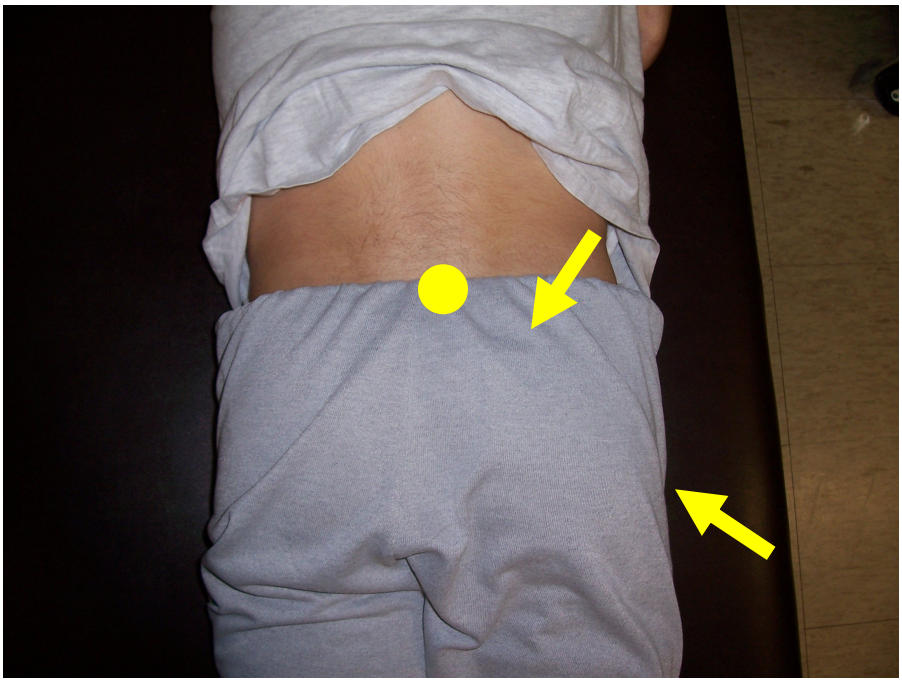


Figure 12: Adductor Electrode Placement

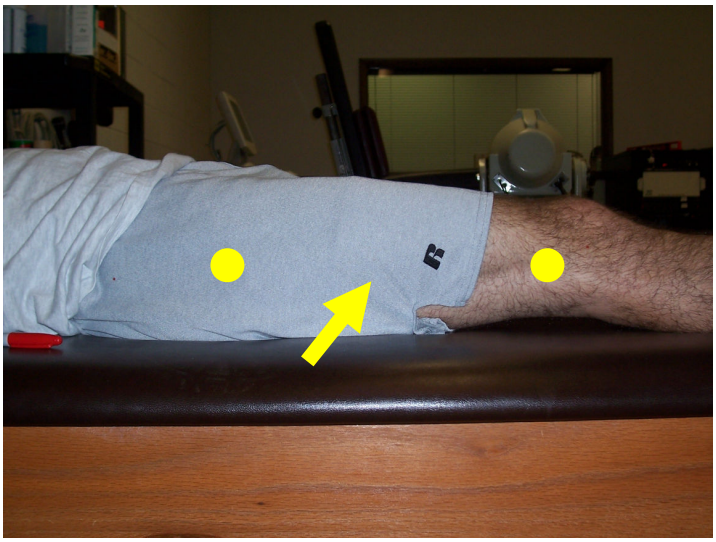


Figure 13: Hip External Rotation Strength Measurement Positioning

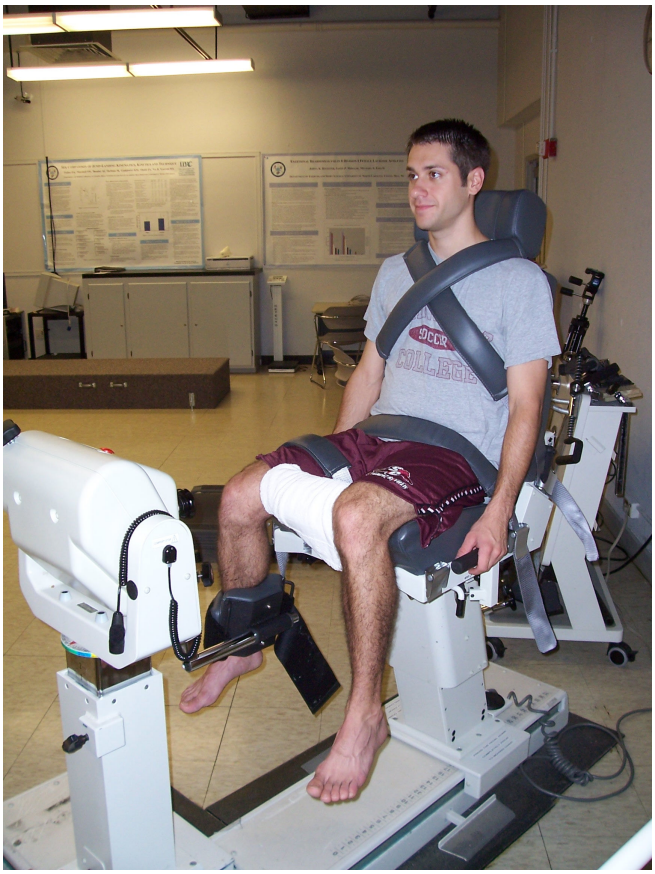


Figure 14: Hip Internal Rotation Strength Measurement Positioning

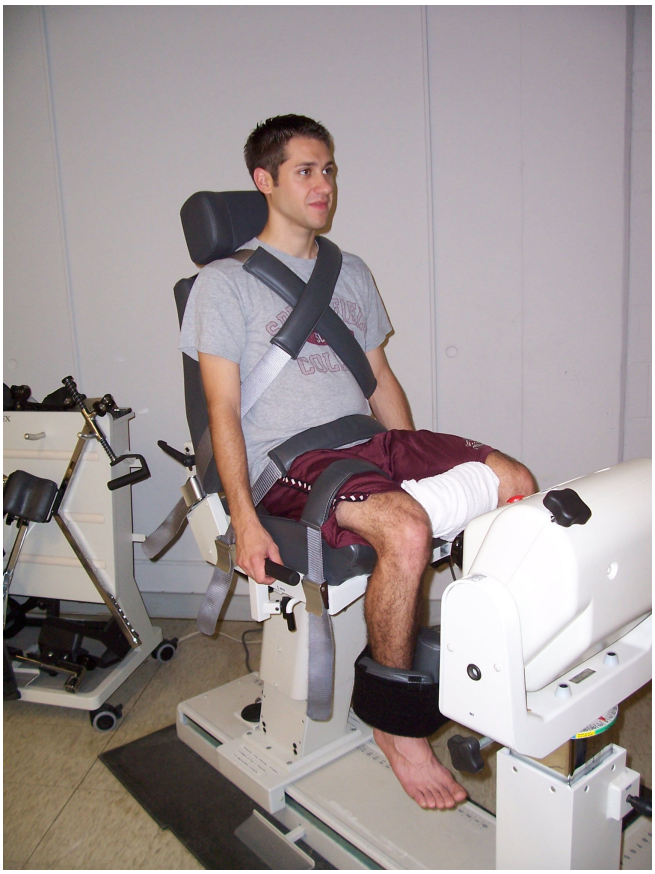


Figure 15: Hip Extension Strength Measurement Positioning

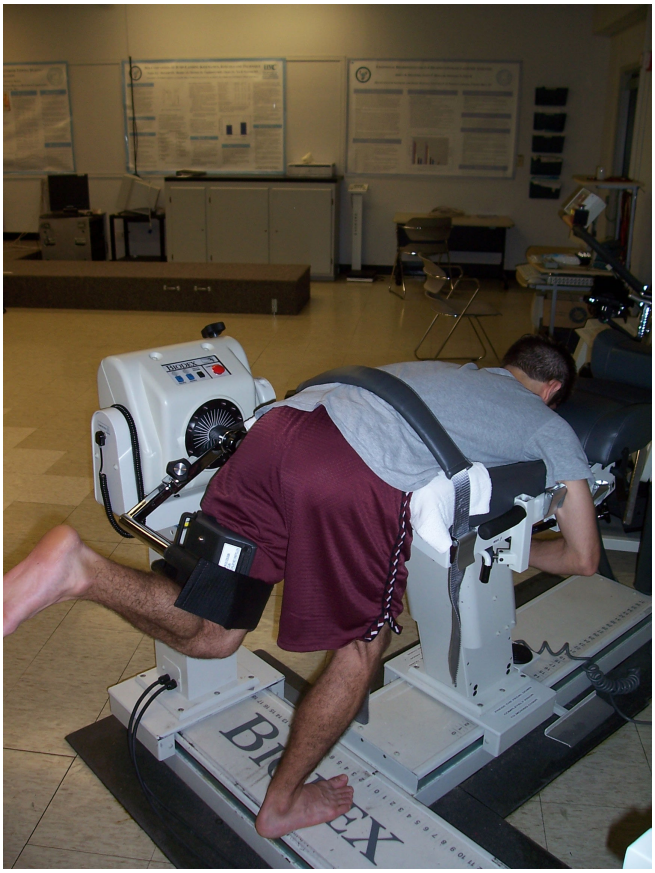


Figure 16: Hip Abduction Strength Measurement Positioning

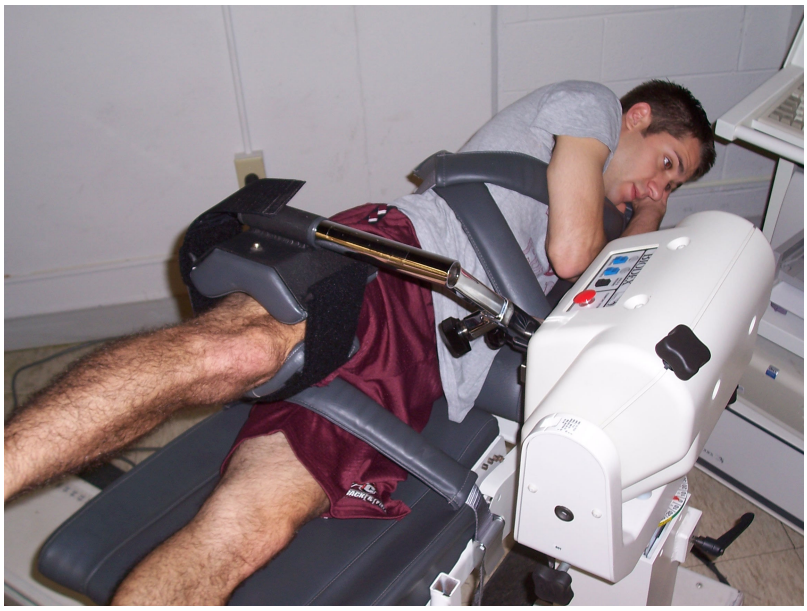


Figure 17: Squat Task Positioning

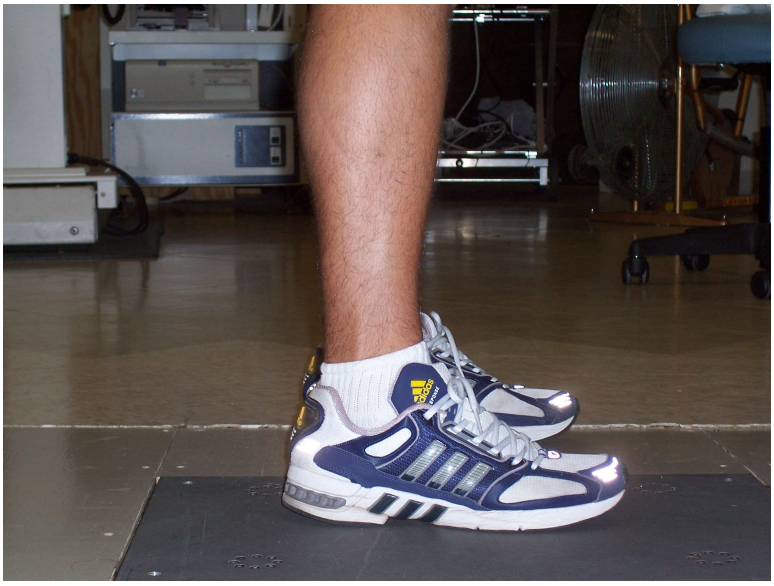
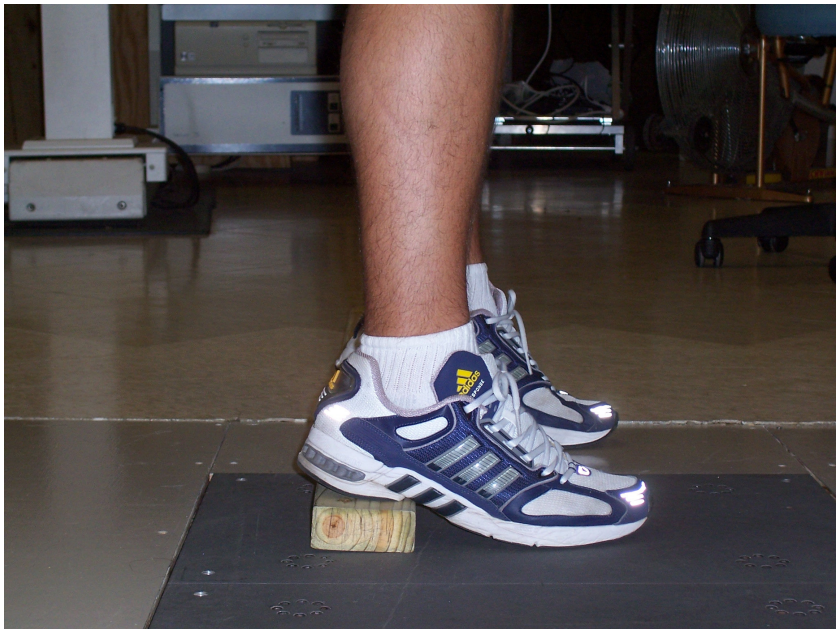


Figure 18: Squat Task Positioning – Heel Block



# APPENDIX C: MANUSCRIPT

**The Effects of Hip Musculature on Knee Valgus During a Squat Task; and How Muscle Activity Changes When Standing on a Two-Inch Heel Block**

**Objective:** To compare hip ROM, strength, muscle activity, and ankle dorsiflexion ROM between groups that demonstrate knee valgus during a squat task and those that do not (control). Also, determine if muscle activity changes after knee valgus is corrected by a two-inch heel block.

**Design:** A single-session experimental research design was used to compare the control group and the valgus group

**Participants:** Seventeen (10 Females, 7 Males) control subjects (age[yr] = 23.82 ± 5.76, height[cm] = 166.12 ± 31.13, weight[kg] = 69.59 ± 15.37) and fourteen (12 Female, 2 Male) valgus subjects (age[yr] = 22.36 ± 3.08, height[cm] = 167.21 ± 9.3, weight[kg] = 65.93 ± 9.9) without lower extremity injury.

**Dependent Variables:** Supine hip abduction and external rotation ROM. Ankle dorsiflexion ROM (straight and bent knee). Hip internal rotation, external rotation, extension, and abduction eccentric and concentric peak torque and time to peak torque. EMG mean amplitude of the gluteus maximus, gluteus medius and adductor complex during a squat with and without a two inch heel block.

**Data Analysis:** Mixed model analysis of variance tested for difference both between and within groups.

**Results:** A significant group by phase interaction effect ($p = 0.02$) existed for mean adductor amplitude between the valgus and the control group. A significant difference ($p < .001$) in straight knee ankle dorsiflexion ROM existed between the control and the valgus group. A

significant difference ($p = 0.034$) existed between the internal rotation concentric time to peak torque between the two groups.

**Conclusion:** The adductor complex plays a significant role in hip extension. Increased activity of the adductor during extension could pull the knees into valgus. Gastrocnemius tightness might contribute to knee valgus during a squat. There appears to be three distinct populations when considering this knee valgus squatting position. 1. Normal individuals who do not have valgus. 2. Ankle dysfunction individuals who's valgus position corrects with a heel block. 3. Hip dysfunction individuals who's valgus position does not correct with a heel block.

**Keywords:** Knee valgus, double leg squat, hip adductor activity, gastrocnemius flexibility

## INTRODUCTION

Baseline screenings are commonly utilized in sports medicine as a method to assess injury status and establish return to play criteria should injury occur (McKeag 1985; Adirim and Cheng 2003). More recently baseline screenings have been used to develop corrective exercise programs to prevent injury from occurring (Nicholas and Tyler 2002). Typically baseline screenings have utilized isolated measures of flexibility, muscle strength, and functional performance; as well as identifying faulty posture (Wang, Chen et al. 2006). Acquiring this information serves two purposes. Initially this information is required to ensure that the athletes are not injured at the beginning of a competitive season. However, most often this information is used to identify possible problematic alignments and movements that might predispose an athlete to injury and address the problem before injury occurs. If risk factors can be identified and corrected in the preseason, some of these injuries may be prevented.

Posture is a very important and often neglected part of overall health. Ideal posture maintains that structural integrity and optimum alignment of each component of the kinetic chain (Clark, 2001). The kinetic chain consists of the myofascial system, articular system, and the neural system (Clark, 2001). When one component of this system is out of alignment, then the entire system is placed at a disadvantage. Postural malalignment is thought to create predictable patterns of tissue overload and dysfunction, initiating the cumulative injury cycle (Clark, 2001). This cumulative injury cycle begins with tissue trauma, inflammation, leading to muscle spasm, adhesions, altered neuromuscular control, and muscle imbalance. This cycle is thought to cause decreased athletic performance and eventual injury (Clark, 2001).

Functional movement analyses are becoming increasingly popular as a tool during dynamic postural assessment. Double leg and single leg squatting tasks are common during

functional movement analyses. These methods can be easily implemented and are time efficient, thus are attractive measures for the clinician. During functional movement analyses, the clinician observes for dysfunctional movement patterns that are believed to represent muscle imbalances caused by lack of flexibility, muscle weakness, and/or muscle activation. For example, individuals who demonstrate excessive knee valgus during a double leg squat are hypothesized to display a tight adductor muscle complex, tight gastrocnemius/soleus complex, and weak gluteus medius and maximus muscles, as well as a lack of neuromuscular control in the aforementioned muscles. (Clark 2001) However, research has not been performed to validate the idea of functional movement analyses as a method to identify muscle imbalances.

The adductor muscle complex functions both as a hip adductor and internal rotator. (Rosse 1997) Tightness in this complex would not allow full motion and cause the femur to pull into adduction and internal rotation. During a squat task, this may result in a valgus motion at the knee. The gluteus medius muscle has various functions. The anterior fibers function to internally rotate the hip. (Earl 2005) However, the most common thought of function of the gluteus medius is its role in hip abduction and stabilizing the hip and limiting adduction. (Schmitz, Riemann et al. 2002; Earl 2005) A weaknesss in this muscle that affected motion would allow the hip to excessively adduct that may cause the knee to exhibit a valgus motion. The gastrocnemius muscle is the prime mover in ankle plantar flexion. (Rosse 1997) A tightness in this muscle could affect both the ankle or the knee joint because it is bi-articular. During functional movements, it may cause either the heel to rise or the knee to flex excessively. Also due to its insertion into the calcaneus it may have an impact on the foot flattening. These muscle imbalances can lead to movement dysfunctions that cause an increase in stress to certain structures and contribute to the cumulative injury cycle.

Knee valgus alignment during dynamic tasks (e.g. squatting) is a common postural dysfunction seen in the lower extremity. Knee valgus alignment during squatting is defined as the mid-patella moving medially and crossing over the ipsilateral great toe as the knee flexes while squatting downward. Knee valgus alignment has been described as a potentially dangerous movement pattern (Ireland 1999). Knee valgus alignment is accompanied by movement of the hip into adduction and internal rotation, which are commonly described mechanisms for anterior cruciate ligament (ACL) injury (Ireland 1999). It has also been shown that patello-femoral compressive forces increase with knee valgus alignment (Escamilla 2001) Thus, knee valgus alignment is also believed to be a contributing factor to patello-femoral pain syndrome. Furthermore, the medial collateral ligament (MCL) is stressed when the knee is exposed to a valgus moment. The MCL can become injured when that valgus stress becomes too great. Individuals who undergo excessive knee valgus motion during functional tasks may place greater stress on the MCL and be at greater risk for injury. These injuries can be detrimental to an individual's physical well-being. Therefore, it is important to understand the factors that influence knee valgus alignment as this may improve our understanding of lower extremity injury risk factor, which may lead to the development of exercise programs to correct knee valgus alignment and reduce injury risk. Currently, knee valgus alignment is thought to occur due to weakness or inhibition in the hip abdcutor muscles (e.g. gluteus medius, gluteus maximus) and hip external rotator muscles. Meanwhile, the hip adductor and internal rotator muscles are believed to be tight or overactive (Clark 2001). However, research has not investigated if these hypothesized muscle imbalances actually exist in individuals demonstrating knee valgus alignment during a functional squatting task.

Squat tests, both single and double legged, have been used in the past as functional tests because they put the knee through common motions found in athletics.(Beutler, L.W. et al. 2002;

Loudon, Wiesner et al. 2002; Zeller, McCrory et al. 2003) Moreover, studies have been done that examine knee valgus during squat tasks. (Zeller, McCrory et al. 2003) However, currently research has yet to focus on how the abovementioned risk factors associated with injury differ between subjects who experience a position of knee valgus versus those who do not when performing a squat.

## METHODS

### Subjects

Approximately 70 subjects were screened by the principal investigator by watching them perform a double leg squat. Those subjects that were observed to exhibit a valgus motion during the squat were then observed with a two-inch heel block underneath their calcaneus. These subjects were recruited through volunteers from emails, fliers, and personal recruiting in classes. Subjects were divided into two groups based upon their results on the double leg squat task (DLST). The valgus group consisted of subjects who demonstrated bilateral knee adduction during the DLST that was corrected by placing a two-inch heel block under their calcaneus. The control group consisted of subjects who did not demonstrate knee adduction on either leg during the DLST. Subjects in the control group were matched to subjects in the hip dysfunction group by age, height, and weight. The control group consisted of 17 subjects while the valgus group consisted of 14 subjects whose ages ranged from 18-26 years. Subject demographics are located in Table 1. Subjects were otherwise healthy individuals that had no current musculoskeletal injuries or had not sustained an injury to either lower extremity in the past six months. Subjects were also excluded if they had surgery to either lower extremity in the past year. Furthermore, subjects in both groups were asymptomatic with and without activity, and subjects were asymptomatic during the DLST. Prior to all testing all subjects read and signed an informed

consent form approved by a University of North Carolina at Chapel Hill Biomedical Institutional Review Board (IRB).

**Measurement and Instrumentation**

A manual goniometer was used to measure joint angles in degrees for ROM assessment of the muscles of interest. Flexibility measurements were taken for the hip adductors ($ICC_{(2,1)}$ .89 SEM = 1.743), the hip internal rotators ($ICC_{(2,1)}$ .97 SEM 2.625), gastrocnemius, and soleus. ICCs were not calculated for these final two range of motion measures.

Concentric and eccentric muscle strength was evaluated using a Biodex System 3 Pro isokinetic dynamometer (Biodex Medical Systems, Shirley, NY), measured in Foot-pounds (Ft*lbs) of torque. The data were then analyzed with a customized Matlab 7.0 program (The Mathworks, Inc., Natick, MA) to determine the average peak torque, as well as time to peak torque, for the hip external rotators, internal rotators, hip abductors, and hip extensors. Each average was measured over the middle three of five total trials.

The mean amplitude electromyographic (EMG) activity of the gluteus medius, gluteus maximus, and adductor group was measured using an eight channel DelSys Bagnoli EMG System (Boston, MA). DE-2.1 single differential surface electrodes (DelSys Boston, MA) with a contact dimension of 1.0cm x 0.1cm and a contact spacing of 1.0cm over the muscle bellies and parallel to the fibers of the gluteus medius, gluteus maximus, and adductor muscles. Electrodes were plugged into a belt mounted I/O unit that plugged into the DelSys Bagnoli EMG system. This system amplified (x10,000 Hz) the EMG signal as it passed into the computer and was stored for analysis. The EMG data were processed with passive demeaning (0.0 ms begin/ 10.0 ms end), a Butterworth notch filter at 60.0 Hz, a band pass Butterworth filter from 10.0 Hz – 350 Hz, and finally RMS smoothing was used at a time constant of 25 msec. All EMG data were normalized to the percentage of maximum voluntary isometric contraction to allow for

comparison between subjects. All EMG data collection and processing was done using Datapac2K2 (Run Technologies, Mission Viejo, CA).

An electro-goniometer was placed over the knee joint so that knee joint ankle could be recorded and related to EMG activity during the DLST. Electro-goniometer data were filtered with a low pass Butterworth at 15.0 Hz.

A tripod was used to standardize squat depth; as well as a metronome to standardize squat speed at 66 beats per minute. Subjects used two beats to descend, two beats to ascend and one beat to rest between squats.

**Procedures**

Students and faculty of the University of North Carolina at Chapel Hill were asked through email and fliers to volunteer for screening for this study. Screening consisted of a questionnaire pertaining to previous history of injury or surgery to the lower extremity. Each subject completed their individual testing in one session. Prior to testing, subjects had the testing procedures explained to them and were asked to read and sign an informed consent form. Each testing session began with the recording of the subject's gender, age (years), height (cm), and weight (kg). Subjects were then video taped performing the DLST both with and without a two-inch heel block to ensure that they met the inclusion criteria for their assigned group. The tester then assessed the subject's dominant leg, defined as the leg they would use to kick a soccer ball for maximum distance, for the following variables: the subject's passive hip abduction ROM; passive external rotation ROM; passive straight knee ankle dorsiflexion ROM; passive bent knee dorsiflexion ROM; Concentric/eccentric isokinetic strength for hip external and internal rotation, hip abduction, and hip extension; and EMG activity during a DLST in the gluteus medius, gluteus maximus, and adductor complex. The valgus group also had EMG recorded for a DLST

while standing on a two-inch heel block. Prior to testing subjects were allowed to warm up for five minutes on a stationary bike at a self-determined pace.

**ROM Measurements**

Subject positioning for ROM measurement of hip abduction was supine. The axis of the goniometer was placed over the ASIS of the extremity being measured. The stationary arm was placed along an imaginary line from one ASIS to the other. The movement arm was placed along the anterior midline of the femur using the midline of the patella for reference. The subject was then passively abducted until the tester felt the contralateral ASIS begin to move (Norkin 1995) Three separate measurements were taken and the mean was recorded.

Subject positioning for ROM measurement for hip internal rotation was supine with the dominant hip and knee flexed to 90 degrees. The hip was in neutral abduction/adduction. The axis of the goniometer was the anterior center aspect of the patella. The stationary arm was positioned parallel to the table. The movement arm was placed along the anterior midline of the tibia pointing towards the anterior midpoint of the ankle between the two melleoli.(Norkin 1995) The subject's hip was passively externally rotated until the tester felt the end range. Three separate measurements were taken and the mean was recorded.

Subject positioning for ROM measurement of straight knee dorsiflexion was supine with the dominant knee in full extenion. The ankle was in neutral inversion/eversion. The axis of the goniometer was distal lateral maleolus. The stationary arm was positioned with the lateral midline of the fibula, using the fibular head for reference. The movement arm was placed parallel to the lateral aspect of the fifth metatarsal (Norkin 1995). The subject's ankle was then passively dorsiflexed until the tester felt the end range. Three separate measurements were taken and the mean was recorded.

Subject positioning for ROM measurement of bent knee dorsiflexion was the same as straight knee; however, a bolster was placed under the subject's dominant knee so that it was flexed to at least 30 degrees(Norkin 1995). The subject's ankle was then passively dorsiflexed until the tester felt the end range. Three separate measurements were taken and the mean was recorded.

**Electromyography**

The sites for electrode placement were shaven and cleansed with alcohol to improve signal transmission from the muscles. Electrodes were placed over the muscle bellies of the gluteus medius, gluteus maximus, and adductor complex. A reference electrode was placed on the tibial tuberosity. Electrodes were placed in a parallel to muscle fibers.

The electrodes for the gluteus medius were placed halfway between the iliac crest and the greater trochanter of the femur (Kleissen 1990). The electrodes for the gluteus maximus were placed 20% of the distance between the spinous process of S2 and a point 10 cm distal to the greater trochanter. The electrodes for the adductor complex were placed on the muscle belly at the mid point of the femur (Leveau 1992). All electrode placements were confirmed with an isometric manual muscle test and checked for cross talk. Maximal voluntary isometric contraction (MVIC) was used to normalize muscle activity between subjects (% MVIC).

**Strength Measurements**

Reliability for all strength tests was demonstrated by Halverson and Hawkey, abstract published in Journal of Athletic Training supplement 2004.

The hip external rotators were tested in a seated position. The subject's hip and knee was flexed to 90 degrees. The dynamometer was aligned with the long axis of the femur. Pressure was applied to the medial aspect of the distal tibia. The thigh was stabilized to the chair using

straps. A towel was also placed between the subjects' knees to act as a fulcrum for external rotation and prevent adduction. The external rotators were tested through twenty degrees of motion that began at five degrees of external rotation and ended at fifteen degrees of internal rotation.

The hip internal rotators were tested in a seated position. The subject's hip and knee were flexed to 90 degrees. The dynamometer was aligned with the long axis of the femur. Pressure was applied to the lateral aspect of the distal tibia. The thigh was stabilized to the chair using straps. The internal rotators were tested through twenty degrees of motion that began at five degrees of internal rotation and ended at fifteen degrees of external rotation.

The hip abductors were tested with the subject in a side-lying position to isolate the gluteus medius. The joint axis was located at 0.5 inches medial to the ASIS at the level of the greater trochanter (Lyons, Perry et al. 1983). The hip was abducted and externally rotated, making sure not to let the trunk and pelvis rotate backward. Pressure was applied against the thigh in the direction of adduction. Pressure was not applied against the external rotation component of the start position (Kendall 1993). The trunk was stabilized by strapping the subject to the chair. The muscle was tested from 0-20 degrees of hip abduction.

The hip extensors were tested in a supported, standing position in an attempt to isolate the gluteus maximus and maximize stabilization. The dynamometer axis of rotation was aligned with the anterior superior tip of the greater trochanter (Lyons, Perry et al. 1983). The subjects stood in front of the Biodex chair, and the seat was raised to the level of the subjects' ASIS. If the chair was unable to reach the subjects' ASIS, the subjects were then asked to flex the contralateral knee until the chair was even with the level of the ASIS. The subjects flexed their trunk to ninety degrees and laid their chest on the chair. The trunk was stabilized to the Biodex chair prior to testing using straps. This stabilization was aimed at preventing accessory trunk

motions that might influence strength testing. The knee of the test leg was flexed to ninety degrees. The stance leg (non-test leg) was flexed at the knee such that the subjects' chest was comfortably resting on the chair. The subjects were then asked to actively extend the hip through a range of motion that began at ninety degrees of hip flexion (femur perpendicular to the groud) and ended at fifty degrees of hip flexion. Pressure was applied against the distal portion of the posterior thigh in the direction of hip flexion (Kendall 1993).

All muscles were tested concentrically and eccentrically at 60 deg * $sec^{-1}$. The testing procedure accounted for gravity corrections during hip abduction and hip extension testing since the test limb was sufficiently close to the horizontal plane. The test limb did not come close enough to the horizontal plane to warrant a gravity correction during the testing of the hip external or internal rotators.

Following the isokinetic testing of each muscle group, the subject's strength was tested isometrically. The positioning and alignment of the subjects was exactly the same for the isometric testing as it was used during the isokinetic testing. The test limb was positioned in the middle of the isokinetic ROM or neutral position for isometric testing. The test limb was placed at seventy degrees of hip flexion while testing the hip extensors. The test limb was placed at ten degrees of hip abduction while testing the hip abductors. The test limb was placed in a neutral position (zero degrees of abduction/adduction) while testing the hip adductors. Each subject performed three maximal isometric contractions. The contractions were held for five seconds each, and there was 10-12 seconds rest between each repetition. The mean amplitude of the three trials during the middle three seconds of each trial was recorded.

The EMG data for the MVIC of the gluteus maximus was recorded while testing hip extension. The EMG data for the MVIC of the gluteus medius was recorded while testing hip abduction. The EMG data for the MVIC of the adductor complex was recorded while still in the

testing position for hip abduction. The subjects were asked to maximally adduct the hip against the Biodex dynamometer for five seconds. EMG from these MVIC's was recorded so that the EMG data recorded during the DLST could be normalized and used to compare between subjects.

**Double-Legged Squat Task**

Subjects were asked to stand with hips, feet, and knees facing forward and arms fully extended overhead parallel to their ears. The subjects then were instructed to go down into a squat position as if they were trying to sit in a chair. Squat depth was standardized to 70 degrees of knee flexion to ensure that each subject went through at least 60 degrees of motion. Subjects were instructed to squat while their knee joint angle was measured with a manual goniometer. When the desired amount of 70 degrees of knee flexion was achieved a tripod was set up to assist the subject in knowing the proper squat depth. An electrogoniometer was then placed on the subject's knee so that EMG data could be examined in relation to knee position. The subjects then performed the squat task five times. EMG activity was recorded for the gluteus medius, gluteus maximus, and the adductor complex from 0-60 degrees of knee flexion during each of the squat tasks. Subjects in the control group only performed the DLST without the heel block. Subjects in the valgus group performed the DLSQ with and without the heel block while EMG data were recorded.

**Data Analysis**

One way analysis of variance tests were used to analyze differences between groups in the ROM measurements. A 2 x 2 analysis of variance was used to analyze the straight and bent knee ankle dorsiflexion ROMs. 2 x 2 mixed model analysis of variance tests were used to analyze differences between groups in concentric and eccentric peak torque as well as time to

peak torque. EMG data differences were analyzed both between groups and between phases within groups with separate 2 x 2 mixed model analyses of variances. Tukey Post Hoc testing was used to identify where significance was found for the ankle dorsiflexion and EMG data. All data were analyzed using SPSS 13.0 (Chicago, IL). All null hypotheses were tested for significance at $p < .05$.

## RESULTS

### ROM Measurements

Means, standard deviations, and effect size for hip abduction ROM are presented in Table 2. There was no significant difference [$F_{(1,29)} = 0.01$, $p = .920$] for hip abduction range of motion between the control and the valgus groups. Means, standard deviations, and effect size are presented in Table 2. There was no significant difference [$F_{(1,29)} = 0.859$, $p = .362$] for hip external rotation ROM between the control and the valgus groups. There was a significant group by knee position interaction effect for ankle dorsiflexion [$F_{(1,26)} = 17.4$ $p < .001$]. Tukey Post Hoc tests revealed that the difference between groups with straight knee dorsiflexion was significant. This difference is illustrated in Figure 1.

### Hip External Rotation Concentric/Eccentric Peak Torque

Means, standard deviations, and effect sizes are presented in Table 3. There was no significant difference for hip external rotation concentric [$F_{(1,29)} = 1.309$, $p = .262$] or eccentric [$F_{(1,29)} = .514$, $p = .479$] peak torque between the control and valgus groups.

### Hip Internal Rotation Concentric/Eccentric Peak Torque

No significant differences were observed for hip internal rotation concentric [$F_{(1,29)} = 0.00$, $p = .985$] or eccentric [$F_{(1,29)} = 0.06$, $p = .808$] peak torque between the control and valgus groups.

### Hip Extension Concentric/Eccentric Peak Torque

There was no significant difference [$F_{(1,29)} = 0.046$, $p = .833$] for hip extension concentric peak torque between the control and valgus groups. There was no significant difference [$F_{(1,29)} = 0.305$, $p = .585$] for hip extension eccentric peak torque between the control and valgus groups.

**Hip Abduction Concentric/Eccentric Peak Torque**

There was no significant difference [$F_{(1,29)} = 3.682$, $p = .065$] for hip abduction concentric peak torque between the control and valgus groups. However, the p value suggests a trend and the finding might reach significance if the statistical power was greater. This trend is illustrated in Figure 2. There was no significant difference [$F_{(1,29)} = 0.006$, $p = .939$] for hip abduction eccentric peak torque between the normal and valgus groups.

**Hip External Rotation Concentric/Eccentric Time to Peak Torque**

Means, standard deviations, and effect size are presented in Table 4. There was no significant difference [$F_{(1,29)} = 0.376$, $p = .544$] for hip external rotation concentric time to peak torque between the control and valgus groups. There was no significant difference [$F_{(1,29)} = 0.038$, $p = .847$] for hip external rotation eccentric time to peak torque between the control and valgus groups.

**Hip Internal Rotation Concentric/Eccentric Time to Peak Torque**

There was a significant difference [$F_{(1,29)} = 4.976$, $p = .034$] for hip internal rotation concentric time to peak torque between the control and valgus groups. The normal group achieved peak torque almost a full second faster (2 sec vs. 3 sec) than the valgus group (fig 3). There was no significant difference [$F_{(1,29)} = 0.023$, $p = .880$] for hip internal rotation eccentric time to peak torque between the normal and valgus groups.

**Hip Extension Concentric/Eccentric Time to Peak Torque**

There was no significant difference [$F_{(1,29)} = 0.456$, $p = .501$] for hip extension concentric time to peak torque between the control and valgus groups. There was no significant difference

[$F_{(1,29)} = 1.235$, $p = .276$] for hip extension eccentric time to peak torque between the control and valgus groups.

**Hip Abduction Concentric/Eccentric Time to Peak Torque**

There was no significant difference [$F_{(1,29)} = 3.218$, $p = .083$] for abduction concentric time to peak torque between the control and valgus groups. However, the p value suggests a trend that the valgus group required a half second longer (1.1 sec vs. 1.6 sec) to reach peak torque. This trend is illustrated in Figure 4. There was no significant difference [$F_{(1,29)} = 1.725$, $p = .199$] for hip abduction rotation eccentric time to peak torque between the normal and valgus groups.

**Gluteus Maximus EMG Mean Amplitude During a Squatting Task**

Means, standard deviations, and effect size are presented in Table 5. There was no main effect for group [$F_{(1,27)} = 0.002$, $p = .962$] for gluteus maximus activity during the ascending and descending phases of the squat. No main effect for phase [$F_{(1,27)} = 0.024$, $p = .877$] was observed for gluteus maximus activity between the ascending and descending phases of the squat for the control or valgus groups. There was no group by phase interaction effect [$F_{(1,27)} = 0.020$, $p = .888$] for gluteus maximus activity during the squat task.

**Gluteus Medius EMG Mean Amplitude During a Squatting Task**

There was no main effect for group [$F_{(1,27)} = 1.037$, $p = .318$] during the ascending or descending phases of the squat between the control or valgus groups. There was no main effect for phase [$F_{(1,27)} = 0.101$, $p = .753$] of gluteus medius activity between ascending and descending phases of the squat for either group. No group by phase interaction effect [$F_{(1,27)} = 0.098$, $p = .757$] was observed for gluteus medius activity during the squat task.

**Adductor Mean EMG Amplitude During Squatting**

There was a group by phase interaction [$F_{(1,27)} = 6.095$, $p = .020$] for adductor activity during the squat task. The control group had higher mean amplitude during the descending portion of the squat and decreased during the ascending phase. In contrast, the valgus group had higher adductor activity during ascending than decending. Tukey post hoc testing revealed that the difference between adductor activity of the control group and the valgus group during the ascent phase was significant. This significance is illustrated in Figure 5. No main effect for group [$F_{(1,27)} = 0.163$, $p = .690$] was observed for adductor activity during the ascending or descending phases of the squat. There was no main effect for phase [$F_{(1,27)} = 0.196$, $p = .661$] for adductor activity between the ascending and descending phases of the squat for either the normal or the valgus group.

**Gluteus Maximus EMG Mean Amplitude During Squatting with Heel Block**

Means, standard deviations, and effect size for mean gluteus maximus amplitude during the squatting task on the heel block are presented in Table 6. There was no main effect for the heel block [$F_{(1,11)} = 0.134$, $p = .721$] for gluteus maximus activity during the ascending and descending phases of the squat between the valgus group with and without the heel block. There was no main effect for phase [$F_{(1,11)} = 1.525$, $p = .241$] for gluteus maximus activity between the ascending and descending phases of the squat for the valgus group either with or without the heel block. There was no heel block x phase interaction effect [$F_{(1,27)} = 1.430$, $p = .255$] for gluteus maximus activity during the squat task.

**Gluteus Medius Mean EMG Amplitude During Squatting with a Heel Block**

Means, standard deviations, and effect size for gluteus medius EMG mean amplitude during the squatting task on the heel block are presented in Table 6. No main effect was observed for gluteus medius activity [$F_{(1,11)} = 0.022$, $p = .885$] during ascending and descending phases of a squat between the valgus group with and without the heel block. There was no main

effect for phase [$F_{(1,11)} = 2.034$, $p = .179$] of gluteus medius activity between the ascending and descending phases of the squat for the valgus group either with or without the heel block. There was no heel block by phase interaction effect [$F_{(1,11)} = 1.955$, $p = .187$] for gluteus medius activity during the squat task.

**Adductor EMG Mean Amplitude During Squatting with and without a Heel Block**

Means, standard deviations, and effect size for mean adductor amplitude during the squatting task on the heel block are presented in Table 6. There was no main effect for heel block [$F_{(1,11)} = 2039$, $p = .148$] for adductor activity during the ascending and descending phases of the squat between the valgus group with and without the heel block. There was a main effect for phase [$F_{(1,11)} = 10.951$, $p = .006$] of adductor activity between the ascending and descending phases of the squat for the valgus group while on the heel block. Adductor activity during the descending phase of the squat was less than the ascending phase. This significance is illustrated in Figure 6. There was no heel block by phase interaction effect [$F_{(1,11)} = 1.7$, $p = .217$] for adductor activity during the squat task.

**DISCUSSION**

The most important findings from this study are that individuals who demonstrated knee valgus during a squat and have the valgus position corrected with a two-inch heel block have different adductor muscle activity during a squat. Our results also show these valgus individuals have less passive ankle dorsiflexion ROM (with a straight knee) when compared to a control group. Moreover, the passive bent knee ankle dorsiflexion ROM of the valgus group was significantly increased over their straight knee ankle dorsiflexion. The control group reached concentric peak torque of the internal rotators quicker than the valgus group. Trends in the data suggest that the control group has larger concentric peak torque in the abductors and achieve peak torque during concentric abduction faster when compared to the valgus group.

**Muscle Activity During Squatting**

An analysis of the control group shows that muscle activity during different phases of a squat (descending and ascending) is not different. This means the control group uses hip musculature equally. This is not the case for those who display a valgus motion during a squat and the difference seems to be in the adductor complex. The other two muscles examined (gluteus maximus and gluteus medius) showed similar activity patterns when compared to the control group.

A group by phase interaction was demonstrated by the adductor muscle complex during the squat task. When comparing maximal muscle activity, the control group's adductor muscle had the greatest activity during the decent phase while the valgus group was most active during the ascent phase (Figure 5). Thus, subjects performing proper squat posture utilized all three muscles simultaneously to eccentrically lower themselves, while the valgus group adductor complex was not as active in the eccentric lowering during the descent phase. However, during the ascent phase the control group's adductors were not as active and relied on the gluteus maximus to assist with hip extension. It is important to note that neither the decrease in the adductor activity nor the increase in the gluteus maximus activity from the descent phase to the ascent phase in the normal group were deemed significant. The opposite situation was found to exist with the adductor complex of the valgus group. Adductor activity during the decent phase was significantly less than adductor activity during the ascent phase. Furthermore, their adductor activity during the ascent phase was significantly greater than that of the normal group during the same phase.

Subjects in the valgus group in this study had their valgus corrected when squatting on a two-inch heel block. Current theory (Clark 2001) suggests valgus may result from tight musculature of the ankle rather than weak hip musculature. The heel block allows for increased

length of the gastrocnemius and soleus complex, allowing normal motion and correcting valgus. Further research needs to identify individuals that present with valgus that is not corrected by a heel block and validate that hip musculature is the issue and what role it may play in knee valgus.

Increased adductor activity in the valgus group during the ascent phase of a squat could be explained an improved length-tension relationship of the muscle group due to increased hip flexion. One study examined moment arms of hip extensor muscles (gluteus maximus and adductor magnus) and found that the gluteus maximus moment arm decreased while the adductor magnus moment arm increased while the hip was flexed. The adductor magnus extension moment arm was shown to continue to increase until 75 degrees of hip flexion (Nemeth and Ohlsen 1985). Furthermore, it has been shown that women demonstrate significantly more hip flexion and adduction during single-legged squats (Zeller, McCrory et al. 2003). While our study examines double-legged squats, this is still relevant because valgus was part of our inclusion criteria and a majority of our valgus subjects were women. Females are being put into a position of hip flexion and adduction that may increase their adductor muscle activity during the ascent phase. While in the control group the gluteus maximus increases during the ascent phase, it actually slightly decreases in the ascent phase for the valgus group. This may be explained by the increase in hip adduction decreasing the gluteus maximus' ability to function as an extensor. This position of knee adduction is associated with femoral internal rotation (Ireland 1999). During the ascent phase the gluteus maximus may be functioning more in its role as a hip external rotator to compensate for femoral internal rotation. If this is the case, then it makes sense that the adductor activity increases as they function more in extension. However, the changes in gluteus maximus muscle activity in our study were not found to be significant.

Moreover, we did not measure hip flexion angles in our subjects. Therefore this theory needs to be explained further through future research.

A final possible explanation of the difference seen between our groups in adductor muscle activity arises from stance width. Research suggests stance width has a significant effect on adductor longus muscle activity during a squat task (McCaw and Melrose 1999). Stance width was not measured in this study but we used a self-selected stance width set at shoulder width apart and researcher verified. We think this minimizes any effect stance width may have on our data.

There were no significant differences found in any of the muscles tested in the valgus group between the regular squat and the squat on the heel block, except for the significant difference in adductor activity between phases that had already been discussed in comparison to the control group. This is the first study to examine how hip muscle activity changes when individuals with knee valgus squat on a two-inch heel block. More research needs to be done to fully understand how plantar flexing the ankle by placing and individual on a two-inch heel block affects squatting

The lack of significance in the muscle activity between the valgus group with and without the heel block begins to outline three populations. These populations are a normal or control group, an ankle dysfunction group and a hip dysfunction group. The control group demonstrates a proper squat technique and keeps their knees centered over their toes (Clark 2001). The ankle dysfunction group is the group examined in our study and demonstrates knee valgus during a squat that is corrected by placing a two inch block under their heel. The hip dysfunction group consists of individuals who demonstrate knee valgus during a squat that is not corrected by the heel block. Currently no study has focused on the hip dysfunction group to verify current theory as to what is causing their knee valgus.

**Straight and Bent Knee Ankle Dorsiflexion ROM**

Another significant finding of this study was the difference of the straight knee ankle dorsiflexion ROM between the valgus group and control group and the difference of the valgus group between straight knee and bent knee. The valgus group had significantly less straight knee dorsiflexion. The gastrocnemius is a bi-articulate muscle crossing the ankle and knee. When the knee is straight, ROM of the ankle decreases because the gastrocnemius reaches end range, limiting motion. Tightness in the gastrocnemius muscle may have played a role in valgus during the DLST. This point is illustrated further when the knee was bent. The valgus group's dorsiflexion range of motion was significantly increased and approximately equal to the control group. This idea is the foundation of current theory! When the valgus group squatted with the heel block, the gastrocnemius shorts and the resulting tension is removed from the squat, correcting knee valgus. This suggests that the tightness in the gastrocnemius muscle played a role in the knee valgus. It is important to note that when the valgus group was on the heel block, there were no significant changes in hip musculature activity.

Ankle dorsiflexion has been shown to be around 10 degrees during the stance phase of gait (Murray 1967). During more function tasks, such as sit-to-stand, stair climbing, and sport specific activities, the requirement for ankle dorsiflexion ROM can increase to about 25 degrees (Andriacchi, Andersson et al. 1980; Lindsjo, Danckwardt-Lilliestrom et al. 1985; Livingston, Stevenson et al. 1991). The double-legged squat used in our study can be related to the function activities that can require the greater dorsiflexion. Thus, the lack of motion seen in the valgus group can explain their inability to perform the task properly. However, it becomes hard to explain why gastrocnemius tightness in and of itself would contribute to knee valgus. It may be a unilateral issue. If the lateral gastroc is tight or short, it may be responsible for pulling the knee into a valgus position. Currently it is believed that during a squat decreased ankle dorsiflexion

would lead to the heels of the individual rising up off of the floor (Clark 2001). This idea makes more sense when examining the gastrocnemius muscle by itself; however, when considering the entire kinetic chain there appears to be more to the picture. It makes more sense to think that this tightness in the gastrocnemius would pull, from its insertion, the calcaneus into eversion, thus causing the foot to pronate. Our study did not examine foot and ankle pronation but if this is the case, then our results seem to suggest that when the arch flattens and pronation ceases the gastrocnemius begins to influence an increase in knee valgus. Therefore it seems that more research needs to be done to determine whether or not the gastrocnemius muscle itself can cause knee valgus or it if only contributes to increased valgus when it is already present.

**Internal Rotation Time to Peak Torque**

Our study found that the control group reached their internal rotation concentric peak torque approximately a full second (2 sec vs. 3 sec) before the valgus group. This difference was deemed statistically significant and further strengthens the idea that there is a difference in adductor activity between groups. The current literature suggests that the gluteus maximus and gluteus medius are important hip stabilizers (Gottschalk, Kourosh et al. 1989; Clark 2001; Schmitz, Riemann et al. 2002) Our study showed that the gluteus maximus and gluteus medius activity between the control and the valgus groups were similar even though the valgus group demonstrated poor proximal hip control. This suggests that it may not be the gluteal muscles that are responsible for stabilization but rather other hip internal and external rotators. This can be further explained by the differences discussed above about the adductor activity between the two groups, as the adductors also function as hip internal rotators.

**Abduction Concentric Peak Torque and Time to Peak Torque**

There was a trend discovered in our study that suggests the control group produced greater concentric peak torque in the abductors than the valgus group and the control group

achieved peak torque a half second faster (1.1 sec vs. 1.6 sec). The lack of significance of this may be due to lack of statistical power; an increase in power may draw out the significance of this finding. Regardless, this finding is clinically significant as it suggests that one potential cause of the knee valgus position is that the valgus group lacks abduction strength as well as the ability to achieve maximum strength in time to prevent hip adduction. This could be related to the previous stated findings of ankle dorsiflexion range of motion. It may be that the adduction begins due to a lack of abduction stabilization strength and is increased by the lack of gastrocnemius flexibility and decreased ankle dorsiflexion

Ireland has described a "position of no return" as when an athlete has poor hip control and the hip moves into adduction, leading to femoral internal rotation and a position of knee valgus (Ireland 1999). These trends discovered in our study seem to support this and further explain it by demonstrated ankle dorsiflexion ROM's role in this knee adduction. However, further research is required to further explore these trends and determine if they are significant.

**Hip Abduction and Internal Rotation ROM**

No difference was observed in hip abduction or internal rotation ROM between the control and valgus groups. Initially, we hypothesized that tight adductors or tight internal rotators may pull individuals into knee valgus. However, our study failed to identify this as a contributing factor. In fact the means of each ROM between groups was almost identical.

**Hip Extension and External Rotation Concentric and Eccentric Peak Torque**

No statistical difference was observed between group concentric or eccentric peak torques. This finding is clinically significant because it suggests that the gluteus maximus muscle does not play a significant role in preventing knee valgus during a squat. It is currently thought that individuals who demonstrate knee valgus have weak gluteus maximus control during squatting (Clark 2001). Again it becomes important to note that it appears that the

subjects tested had ankle dysfunction and not necessarily hip dysfunction, and that individuals not corrected by the heel block may have differences in gluteus maximus strength.

**Limitations**

The greatest limitation of this study was the lack of statistical power for some of the analyses. Ideally, each group would have around 20 subjects to have enough power to draw out significant differences that may exist. This was unable to be achieved in this study due to the difficulty in identifying subjects who met the valgus group criteria. However, most of the analyses that lacked power also had small effect sizes. Therefore, if power was increased such that significance was found, it still may not be clinically significant.

Another limitation for this study is that the order of testing was not randomized. Every subject followed the same protocol in the same order. However, since the subjects were observed to exhibit the bilateral knee valgus both before and after ROM and strength testing it is not believed that either altered the way in which the subjects performed the squat task.

The inability to identify many males who fit the inclusion criteria for the valgus group limits the generalizability this study. The control group is more evenly divided between males and females; however, the valgus group consists of primarily females. Although, the demographics between each group suggest that subjects were closely matched by age, height, and weight.

The lack of lower leg EMG activity is also a limitation of this study. While the ROM of ankle dorsiflexion was measured, no information about the muscle activity around the ankle of the ankle dysfunction group was available to help further understand what may be contributing to their valgus knee position.

**Future Research**

Current theory places subjects into categories if they are identified has having knee valgus (Clark 2001). There is a control population that demonstrates correct squat technique. There is a hip dysfunction population that demonstrates bilateral knee valgus both with and without a two-inch heel block. Finally, there is an ankle dysfunction population that demonstrates bilateral knee valgus during a squat that is corrected by a two-inch heel block. This study contrasted the control population against the ankle population and how hip musculature and ankle ROM contributes to knee valgus. Future research needs to verify that this classification system is correct and document differences between groups. Areas of focus should be the hip musculature (gluteus maximus, gluteus medius and adductor complex), ankle musculature (medial and lateral gastrocnemius, tibialis anterior, and soleus), and these variables relation to this position of knee valgus during a squat task. Future research should also focus on the kinematics of the squat to verify that valgus is corrected or not with the heel block. Finally, once the theory has been estabilished, research should attempt to implement training programs to correct valgus.

# APPENDIX D: IRB MATERIALS

OFFICE OF HUMAN RESEARCH ETHICS -- Institutional Review Board
INSTRUCTIONS FOR APPLICATION FOR IRB APPROVAL
OF HUMAN SUBJECTS RESEARCH
*Version 28-Sep-2005*

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## What is the purpose of this form?

This application is to seek *initial* IRB approval for a research study.

## What parts of this application should you submit?

- For ***all studies***, submit Part A, which consists of these sections:
  Part A.1. Contact Information, Agreements, and Signatures
  Part A.2. Summary Checklist
  Part A.3. Conflict of Interest Questions and Certification
  Part A.4. Questions Common to All Studies
  Part A.5. The Consent Process and Consent Documentation (including Waivers)

- For ***studies that involve direct interaction*** with human subjects (any contact with subjects including questionnaires, interviews, focus groups, observation, treatment interventions, etc), submit:
  Part B. Questions for Studies that Involve Direct Interaction with Human Subjects

- For ***studies*** that use data, records or human biological specimens ***without direct subject contact***, submit:
  Part C. Questions for Studies using Data, Records or Human Biological Specimens without Direct Contact with Subjects

**Note**: You should submit Parts B or C only as applicable. If the study involves *both* direct interaction *and* data collection without contact, use both Parts B and C in addition to Part A.

## Who can serve as principal investigator (PI)?

The PI is the person who will personally conduct or supervise this research study. Under most circumstances, this will be a faculty member. For IRB communication purposes, a trainee/student may be listed as PI. However, a faculty advisor must be identified, who holds ultimate responsibility for ensuring that this project complies with all University, regulatory, and fiscal requirements.

→ *See next page for additional instructions*

**---- Instructions – Do not submit this page with your application ----**

*page 2 of instructions*

Unless otherwise instructed, submit to the IRB that typically serves the home department of the principal investigator (PI). How many copies to submit depends on the IRB and type of review required for a given study (table). Complete submission instructions can be found at http://ohre.unc.edu/submission_instructions.php. All *application and consent materials* should be copied or printed on one side only.

Special submission instructions apply for studies that require additional review. Examples include the General Clinical Research Center (GCRC; http://gcrc.med.unc.edu/investigators/admin/gcrcapp.htm) or the Oncology Protocol Review Committee (PRC; http://cancer.med.unc.edu/research/prc/default.asp). See their web sites for details.

| Number of Copies to be Submitted by Type of Review and IRB (number below must include one original) | | | |
|---|---|---|---|
| IRB | Exempt or Expedited | Full Board | Address for mailing complete application |
| Behavioral | 1 | 16 | CB# 3378, Bank of America Center<br>Chapel Hill, NC 27599-3378 |
| Biomedical (includes Dental) | 3 | 3 | CB# 7097, Medical Building 52<br>Chapel Hill, NC 27599-7097 |
| Nursing | 1 | 14 | CB# 7460, Carrington Hall<br>Chapel Hill, NC 27599-7460 |
| Public Health | 2 | 14 | CB# 7400, Rosenau Hall<br>Chapel Hill, NC 27599-7400 |

**Types of Review**

There are three levels of IRB Review (full board, expedited, and exempt), determined by the nature of the project, level of potential risk to human subjects, and the subject population. *The final determination of type of review applicable to a particular study is made by the IRB.* Regardless of the kind of review, all applications use the same submission form.

Exempt and expedited review can be given to studies that constitute no more than minimal risk to the human subjects, i.e., the risk one experiences in daily living. These reviews are done in the IRB office on a continual basis.

Full board review is required for studies that involve greater than minimal risk or vulnerable populations that require special protection by the IRB. These require review by the convened IRB at the next scheduled meeting. See http://ohre.unc.edu/guide_to_irb.php for additional guidance.

**---- Instructions – Do not submit this page with your application ----**

OFFICE OF HUMAN RESEARCH ETHICS
Institutional Review Board

APPLICATION FOR IRB APPROVAL OF HUMAN SUBJECTS RESEARCH
*Version 28-Sep-2005*

| *For IRB Use* | | | | |
|---|---|---|---|---|
| Behav | Bio | Dent | Nurs | PH |
| IRB Study #_____ | | | | |
| Rec'd_____ | | | | |
| Full | Expedited | | Exempt | |

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## Part A.1. Contact Information, Agreements, and Signatures

**Title of Study:** The Effects of Hip Strength, Range of Motion, and Muscle Activity on a Knee Valgus Posistion During Functional Movement Tasks **Date:** 2-1-05

**Name and degrees of Principal Investigator**: Brian Vesci BS, LAT, ATC, PES
Department: Exercise and Sports Science Mailing address/CB #: Sports Medicine Research Lab
Fetzer Gymnasium CB 8700
UNC-CH
Chapel Hill NC, 27514

UNC-CH PID: 711073070 Pager: N/A
Phone #: 412-855-3080 Fax #: 919-962-0489 Email Address: vesci@email.unc.edu

**For trainee-led projects:** __ undergraduate _X_ graduate __ postdoc __ resident __ other
**Name of faculty advisor**: Dr. Darin Padua
Department: Exercise and Sports Science Mailing address/CB #: Sports Medicine Research Lab
Fetzer Gymnasium CB 8700
UNC-CH
Chapel Hill NC, 27514

Phone #: 919-843-5117 Fax #: 919-962-0489 Email Address: dpadua@email.unc.edu

**Name, phone number, email address of project manager or coordinator, if any**:

List **all other project personnel** including co-investigators, and anyone else who has contact with subjects or identifiable data from subjects: Lindsay Strickland, David Bell

**Name of funding source or sponsor**:
_X_ not funded __ Federal __ State __ industry __ foundation __ UNC-CH
__ other (specify): **Sponsor or award number**:

Include following items with your submission, where applicable. Check the items below and **include in order listed**.

- x This application. One copy must have original PI signatures.
- x Consent and assent forms, fact or information sheets; include phone and verbal consent scripts
- □ HIPAA authorization addendum to consent form
- x All recruitment materials including scripts, flyers and advertising, letters, emails
- □ Questionnaires, scripts used to guide phone or in-person interviews, etc.
- □ Focus group guides
- □ Data use agreements (may be required for use of existing data from third parties)
- □ Addendum for Multi-Site Studies where UNC-CH is the Lead Coordinating Center

- □ Documentation of reviews from any other committees (e.g., GCRC, Oncology)
- □ Documentation of training in human research ethics for all study personnel
- □ Investigator Brochure if a drug study
- □ Protocol, grant application or proposal supporting this submission; (e.g., extramural grant application to NIH or foundation, industry protocol, student proposal)

**Principal Investigator**: I will personally conduct or supervise this research study. I will ensure that this study is performed in compliance with all applicable laws, regulations and University policies regarding human subjects research. I will obtain IRB approval before making any changes or additions to the project. I will notify the IRB of any other changes in the information provided in this application. I will provide progress reports to the IRB at least annually, or as requested. I will report promptly to the IRB all unanticipated problems or serious adverse events involving risk to human subjects. I will follow the IRB approved consent process for all subjects. I will ensure that all collaborators, students and employees assisting in this research study are informed about these obligations. All information given in this form is accurate and complete.

_____ _____

Signature of Principal Investigator Date

**Faculty Advisor if PI is a Student or Trainee Investigator**: I accept ultimate responsibility for ensuring that this study complies with all the obligations listed above for the PI.

_____ _____

Signature of Faculty Advisor Date

**Department or Division Chair, Center Director (or counterpart) of PI:** (or Vice-Chair or Chair's designee if Chair is investigator or otherwise unable to review): I certify that this research is appropriate for this Principal Investigator, that the investigators are qualified to conduct the research, and that there are adequate resources (including financial, support and facilities) available. I support this application, and hereby submit it for further review.

_____ _____

Signature of Department Chair or designee Date

_____ _____

Print Name of Department Chair or designee Department

## Part A.2. Summary Checklist

| *Are the following involved?* | Yes | No |
|---|---|---|
| A.2.1. Existing data, research records, patient records, and/or human biological specimens? | __ | X |
| A.2.2. Surveys, questionnaires, interviews, or focus groups with subjects? | X | __ |
| A.2.3. Videotaping, audiotaping, filming of subjects? | X | __ |
| A.2.4. Do you plan to enroll subjects from these vulnerable or select populations: | | |
| a. UNC-CH students or UNC-CH staff? | X | __ |
| b. Non-English-speaking? | __ | X |
| c. Decisionally impaired? | __ | X |
| d. Patients? | __ | X |
| e. Prisoners, parolees and other convicted offenders? | __ | X |
| f. Pregnant women? | __ | X |
| g. Minors (less than 18 years)? **If yes**, give age range: to years | __ | X |
| A.2.5. a. Is this a multi-site study (i.e., involves organization(s) outside UNC-CH)? | __ | X |
| b. Will any of these sites be outside the United States? | __ | X |
| ***If yes***, provide contact information for the foreign IRB. | | |
| c. Is UNC-CH the sponsor or lead coordinating center? | __ | X |
| ***If yes***, include the ***Addendum for Multi-site Studies where UNC-CH is the Lead Coordinating Center***. | | |
| A.2.6. Will there be a data and safety monitoring committee (DSMB or DSMC)? | __ | X |
| A.2.7. a. Are you collecting sensitive information such as sexual behavior, HIV status, recreational drug use, illegal behaviors, child/physical abuse, immigration status, etc? | __ | X |
| b. Do you plan to obtain a federal Certificate of Confidentiality for this study? | __ | X |
| A.2.8. a. Investigational drugs? (provide **IND #** ) | __ | X |
| b. Approved drugs for "non-FDA-approved" conditions? | __ | X |
| *All studies testing substances in humans must provide a letter of acknowledgement from the UNC Health Care Investigational Drug Service (IDS).* | | |
| A.2.9. Placebo(s)? | __ | X |
| A.2.10. Investigational devices, instruments, machines, software? (provide **IDE #** ) | __ | X |
| A.2.11. Fetal tissue? | __ | X |
| A.2.12. Genetic studies on subjects' specimens? | __ | X |
| A.2.13. Storage of subjects' specimens for future research? | __ | X |
| ***If yes**, see instructions within the form **Consent for Stored Samples**.* | | |
| A.2.14. Diagnostic or therapeutic ionizing radiation, or radioactive isotopes, which subjects would not receive otherwise? | __ | X |
| ***If yes**, approval by the **UNC-CH Radiation Safety** **Committee** is required.* | | |
| A.2.15. Recombinant DNA or gene transfer to human subjects? | __ | X |
| ***If yes**, approval by the **UNC-CH Institutional Biosafety** **Committee** is required.* | | |
| A.2.16. Does this study involve UNC-CH cancer patients? | __ | X |
| ***If yes**, submit this application directly to the **Oncology Protocol Review Committee**.* | | |
| A.2.17. Will subjects be studied in the General Clinical Research Center (GCRC)? | __ | X |
| ***If yes**, obtain the **GCRC Addendum** from the GCRC and submit complete application (IRB application and Addendum) to the GCRC.* | | |

## Part A.3. Conflict of Interest Questions and Certification

The following questions apply to **all investigators and study staff** engaged in the design, conduct, or reporting results of this project **and/or their immediate family members.** For these purposes, "family" includes the individual's spouse and dependent children. "Spouse" includes a person with whom one lives together in the same residence and with whom one shares responsibility for each other's welfare and shares financial obligations.

| | | |
|---|---|---|
| A.3.1. Currently or during the term of this research study, does any member of the research team or his/her family member have or expect to have: | | |
| (a) A personal financial interest in or personal financial relationship (including gifts of cash or in-kind) with the sponsor of this study? | __ yes | _X_ no |
| (b) A personal financial interest in or personal financial relationship (including gifts of cash or in-kind) with an entity that owns or has the right to commercialize a product, process or technology studied in this project? | __ yes | _X_ no |
| (c) A board membership of any kind or an executive position (paid or unpaid) with the sponsor of this study or with an entity that owns or has the right to commercialize a product, process or technology studied in this project? | __ yes | _X_ no |
| A.3.2. Has the University or has a University-related foundation received a cash or in-kind gift from the Sponsor of this study for the use or benefit of any member of the research team? | __ yes | _X_ no |
| A.3.3. Has the University or has a University-related foundation received a cash or in-kind gift for the use or benefit of any member of the research team from an entity that owns or has the right to commercialize a product, process or technology studied in this project? | __ yes | _X_ no |

**If the answer to ANY of the questions above is *yes***, the affected research team member(s) must complete and submit to the Office of the University Counsel the form accessible at http://coi.unc.edu. List name(s) of all research team members for whom any answer to the questions above is *yes*:

_____

**Certification by Principal Investigator: By submitting this IRB application, I (the PI) certify that the information provided above is true and accurate regarding my own circumstances, that I have inquired of every UNC-Chapel Hill employee or trainee who will be engaged in the design, conduct or reporting of results of this project as to the questions set out above, and that I have instructed any such person who has answered "yes" to any of these questions to complete and submit for approval a Conflict of Interest Evaluation Form. I understand that as Principal Investigator I am obligated to ensure that any potential conflicts of interest that exist in relation to my study are reported as required by University policy.**

_____ _____

Signature of Principal Investigator Date

**Faculty Advisor if PI is a Student or Trainee Investigator: I accept ultimate responsibility for ensuring that the PI complies with the University's conflict of interest policies and procedures.**

| | |
|---|---|
| Signature of Faculty Advisor | Date |

## Part A.4. Questions Common to All Studies

*For all questions, if the study involves only secondary data analysis, focus on your proposed design, methods and procedures, and not those of the original study that produced the data you plan to use.*

A.4.1. **Brief Summary**. Provide a *brief* non-technical description of the study, which will be used for internal and external communications regarding this research. Include purpose, methods, and participants. Typical summaries are 50-100 words.

Lower extremity postural alignment, such as knee valgus (e.g. knock knees), is commonly described as a potential risk factor for various lower extremity injuries (e.g. anterior cruciate ligament sprain, patello-femoral pain). Thus, an understanding of factors that influence knee valgus is believed to be an important aspect of understanding potential causes of lower extremity injuries. Muscle strength, activation, and flexibility are all believed to be contributing factors to knee valgus alignment. However, research has not investigated the influence of muscle strength, activation, and flexibility on knee valgus alignment. Therefore, the purpose of this study is to determine if there are significant differences in hip muscle strength, activation, and flexibility in individuals with knee valgus alignment compared to those with normal knee alignment. A secondary purpose of this study is to investigate the effects of a 6-week exercise program on knee valgus alignment, muscle strength, muscle activation, and flexibility. Sixty participants will be recruited from the general population at the University of North Carolina at Chapel Hill as part of this study.

A.4.2. **Purpose and Rationale**. Provide a summary of the background information, state the research question(s), and tell why the study is needed. If a complete rationale and literature review are in an accompanying grant application or other type of proposal, only provide a brief summary here. If there is no proposal, provide a more extensive rationale and literature review.

Posture is a very important and often neglected part of overall health. Ideal posture maintains that structural integrity and optimum alignment of each component of the kinetic chain (Clark, 2001). The kinetic chain consists of the myofascial system, articular system, and the neural system (Clark, 2001). When one component of this system is out of alignment, then the entire system is placed at a disadvantage. Postural malalignment is thought to create predictable patterns of tissue overload and dysfunction, initiating the cumulative injury cycle (Clark, 2001). This cumulative injury cycle begins with tissue trauma, inflammation, leading to muscle spasm, adhesions, altered neuromuscular control, and muscle imbalance. This cycle is thought to cause decreased athletic performance and eventual injury (Clark, 2001).

Knee valgus alignment during dynamic tasks (e.g. squatting) is a common postural dysfunction seen in the lower extremity. Knee valgus alignment during squatting is defined as the mid-patella moving medially and crossing over the ipsilateral great toe as the knee flexes while squatting downward. Knee valgus alignment has been described as a potentially dangerous movement pattern (Ireland, 1999). Knee valgus alignment is accompanied by movement of the hip into adduction and internal rotation, which are commonly described mechanisms for anterior cruciate ligament (ACL) injury (Ireland, 1999). It has also been shown that patello-femoral compressive forces increase with knee valgus alignment (Escamilla, 2001). Thus, knee valgus alignment is also believed to be a contributing factor to patello-femoral pain syndrome. Furthermore, the medial collateral ligament (MCL) is stressed when the knee is exposed to a valgus moment. The MCL can become injured when that valgus stress becomes too great. Individuals who undergo excessive knee valgus motion during functional tasks may place greater stress on the MCL and be at greater risk for injury. These injuries can be detrimental to an individual's physical well-being. Therefore, it is important to

understand the factors that influence knee valgus alignment as this may improve our understanding of lower extremity injury risk factor, which may lead to the development of exercise programs to correct knee valgus alignment and reduce injury risk. Currently, knee valgus alignment is thought to occur due to weakness or inhibition in the hip abdcutor muscles (e.g. gluteus medius, gluteus maximus) and hip external rotator muscles. Meanwhile, the hip adductor and internal rotator muscles are believed to be tight or overactive (Clark, 2001). However, research has not investigated if these hypothesized muscle imbalances actually exist in individuals demonstrating knee valgus alignment during a functional squatting task.

The purpose of this study is to ascertain what factors lead to knee valgus during squatting tasks. Once these factors are determined, a one-time intervention protocol will be administered to test whether or not these factors can be altered with an immediate intervention. This intervention will focus on lengthening tight hip musculature, strengthening weakened hip musculature, and performing functional lower extremity exercises intending to improve muscular activation. Furthermore, a six-week long intervention protocol will also be implemented to study how these factors can be changed over time.

Specific Aim 1: To compare hip muscle strength, hip muscle flexibility, and hip muscle activation between individuals with knee valgus alignment and those without knee valgus alignment (normal alignment)

Specific Aim 2: To compare knee valgus alignment, hip muscle strength, hip muscle flexibility, and hip muscle activation before and after a one-time supervised exercise program.

Specific Aim 3: To compare knee valgus alignment, hip muscle strength, hip muscle flexibility, and hip muscle activation before and after a six-week long exercise program.

A.4.3. **Full description of the study design, methods and procedures.** Describe the research study. Discuss the study design; study procedures; sequential description of what subjects will be asked to do; assignment of subjects to various arms of the study if applicable; doses; frequency and route of administration of medication and other medical treatment if applicable; how data are to be collected (questionnaire, interview, focus group or specific procedure such as physical examination, venipuncture, etc.). Include information on who will collect data, who will conduct procedures or measurements. Indicate the number and duration of contacts with each subject; outcome measurements; and follow-up procedures. If the study involves medical treatment, distinguish standard care procedures from those that are research. If the study is a clinical trial involving patients as subjects and use of placebo control is involved, provide justification for the use of placebo controls.

This study's design incorporates a single testing session for the normal knee alignment (NKA) control group and a repeated measures design for the dysfunction groups, the knee valgus intervention and knee valgus control (KVI and KVC). Volunteers from the university community will attend a general screening session in the Sports Medicine Research Laboratory. During this screening session, volunteers will be asked to perform a double-leg squat test and assessed by the researchers for the knee valgus alignment in real time. Forty volunteers who demonstrate a noticeable knee valgus position, as defined by demonstrating medial mid-patella movement crossing over the ipsilateral great toe bilaterally, during the final descent phase of the squat, with and without a 2-inch heel block under their heel, will be asked to volunteer for the study. From this group of subjects, twenty subjects will be randomly assigned to one of the dysfunction groups, either the knee valgus intervention (KVI)

group or knee valgus control (KVC) group. Twenty volunteers who do not demonstrate the knee valgus position will also be asked to volunteer for the study and be placed in the NKA control group.

Following the general screening session, all subjects will report to the Sports Medicine Research Laboratory for a single testing session. Upon arrival, all subjects will complete an informed consent form approved by the Institutional Review Board at the University of North Carolina at Chapel Hill along with a general health and activity level questionnaire. All subjects will be dressed in a t-shirt, athletic shorts and shoes. Subjects will be video taped performing the double leg squat task used in the initial screening. Subjects will then perform a five-minute warm-up on a stationary bicycle at a pace deemed comfortable to them. All testing will be performed on the subject's dominant leg, which will be defined as the leg used to kick a ball for maximal distance.

*Range of Motion Assessment*

After the warm-up, range of motion of the hip internal rotators and adductor complex will be recorded using a manual goniometer. For both range of motion measurements, the subjects will be in a supine position. In order to measure the hip internal rotator's range of motion, the subject's leg will be placed into ninety degrees of hip flexion and knee flexion. The axis of the goniometer will be placed over the inferior pole of the patella while the stationary arm will be aligned with the subject's trunk and the movement arm will be placed along the anterior midline of the tibia. The tester will passively move the hip into external rotation until resistance is felt by the tester. At this position, the hip internal rotators' range of motion will be recorded from the goniometer. In order to measure the hip adductor complex's range of motion, the leg will be in full knee extension and zero degrees of hip flexion/extension with the toe perpendicular to the floor. The axis of the goniometer will be placed over the dominant leg's ASIS with the stationary arm aligned with the opposite ASIS while the movement arm is placed along the anterior midline of the femur using the anterior midline of the patella for reference. The tester will passively abduct the leg until resistance is felt by the tester. At this position, hip adductor range of motion will be recorded from the goniometer.

*Muscle Activation Assessment*

Following muscle range of motion measurements, surface electromyography (EMG) will be used to measure the electrical activity of several hip muscles. Two surface electrodes will be placed over the muscle bellies of the gluteus maximus, gluteus medius, and the adductor complex. A single reference electrode will be placed over the tibial tuberosity to serve as an electrical ground reference. To reduce impedance to the EMG signal and allow for proper electrode fixation, electrode sites will be prepared by shaving any hair from the immediate vicinity of the muscle belly, lightly abrading the skin with an abrasive pad, and cleansing the skin with isopropyl alcohol. To prevent movement of the electrodes and subsequent alteration of the EMG signal, electrodes will be secured to the leg using prewrap and athletic tape. Manual muscle test will be performed to serve as a normalization of muscle activation. Three five-second maximal voluntary contraction trials will be performed during manual muscle testing on the isokinetic dynamometer. Signals from the electrodes will be passed to a battery operated FM transmitter worn by the subject, thus allowing for uninhibited movement. A receiver and analog-to-digital converted will convert the analog signal into digital data whereby it may be further analyzed by a computer utilizing custom software. These procedures for electromyography are similar to a study conducted by Michael DiStefano (IRB # 03-EXSS-648).

EMG data will be collected while subjects perform the identical squat task as was performed during the initial screening procedures. Following the double leg squat, instructions will then be given to each subject regarding the two jump landings and the researcher will demonstrate the maneuvers. Before any trials are recorded, each participant will have three to five trials to practice the jump landings. The practice trials will conclude when the subjects can demonstrate consistent movements with the jump landing. During the first jump landing, subjects will be required to jump forward off of a 30-centimeter box onto a force plate located on the ground. The distance between

the front of the box and the center of the force plate will be standardized for each subject, half their body height. Subjects will be instructed to land with their dominant foot in the center of the force plate and then jump as high as they can. This jump landing maneuver has been previously described in a study conducted by Lindsay Strickland (IRB # 04-EXSS-450). The second jump landing task is a transverse jump, instead of a forward jump involving similar procedures as the first jump landing task described. Instead of jumping forward onto the force plate, subjects will rotate ninety degrees in the air before landing. After landing, the subjects will then jump again in the air as high as they can as in the first jump described. The ninety-degree turn will occur in the air during the first part of the jump landing. A total of 5 trials will be performed with a 30 second rest period in between each trial. Trials will be repeated if there is a problem with the recording, if the subject does not land properly on the force plate, or if the subject does not perform the jump landing correctly. During all jump landing trials, EMG and force plate data will be recorded.

*Strength Assessment*

Strength measurements for the hip internal rotators, external rotators, abductors, and extensors will be recorded by an isokinetic dynamometer at 60 degrees per second (Strength testing procedures are adopted from previous study IRB# 03-EXSS-538). For each strength test, subjects will perform one trial with five repetitions.

For hip internal rotation and external rotation strength, subjects will be seated with the hip and knee flexed to ninety degrees and the thigh stabilized with the chair straps. For hip internal rotation strength, the dynamometer will be aligned along the long axis of the femur, pressure will be applied to the distal lateral fibula, and will be tested through twenty degrees of motion beginning at five degrees of internal rotation through fifteen degrees of external rotation. The hip external rotation strength will be tested in the same position however the pressure will be applied to the distal medial tibia. Motion will start at five degrees of external rotation and end at fifteen degrees of internal rotation. Also a towel will be placed between the subjects knees to reduce the risk of hip adduction.

Hip extension strength will be tested in a supported standing position with the chair at the subject's ASIS level. The subject's trunk will be stabilized to the chair by straps, and the dynamometer axis of rotation will be aligned with the anterior superior tip of the greater trochanter. Pressure will be applied to the distal posterior thigh and motion will start at ninety degrees of hip flexion and end at fifty degrees of hip flexion.

Hip abduction strength will be tested in a side lying position with the subject strapped in for stability. The dynamometer axis of rotation will be aligned .5 inches medial to the ASIS at the level of the greater trochanter. Pressure will be applied at the distal femur in the direction of adduction. Motion will be tested from zero to twenty degrees of hip abduction. MVIC's for the muscles having EMG activity recorded will be taken while the subject is in position after each individual isokinetic test. MVIC data will be collected for three seconds.

*Intervention*

The KVI group will perform 2 interventions. The first intervention will occur during the first testing session (acute intervention) and the second intervention will take place over a six-week period (long term intervention) both consisting of the same exercises. The intervention consists of and subjects will be asked to perform a series of two myofascial techniques and three static stretching exercises, which will take approximately 10 minutes to complete. Following completion of the myofascial release and stretching exercises the subjects will perform two strengthening exercises and two integration exercises, which will take approximately 10 minutes to complete We will ask the participants to perform all exercises four times a week over the six-week long term intervention period. These specific exercises include: 1) myofascial technique to inhibit the hip adductors (1minute), 2) myofascial technique to inhibit the tensor fascia latae (1minute), 3) stretching exercise

for the hip adductors (2 repetitions for 30 seconds), 4) stretching exercise for the tensor fascia latae (2 repetitions for 30 seconds), 5) stretching exercise for the biceps femoris (2 repetitions for 30 seconds) 6) strengthening exercise for the gluteus medius (3 sets of 10 repetitions) 7) strengthening exercise for the gluteus maximus (3 sets of 10 repetitions) 8) lateral tube walking (3 sets of 10 repetitions) and 9) single leg reach for balance (3 sets of 3 repetitions). (Please see the included sheet entitled "Exercise Program Quick Reference Guide" for pictures of these exercises). The KVC group will be asked to sit and relax for 20 minutes before repeating the testing again (double leg squat, jump landing, transverse jump landing. Each dysfunction group, (KVI, KVC), will be asked to return 6 weeks after the initial testing session in order to be video taped during a squat task, -re-assess measures of strength, flexibility, and muscle activation during the three tasks. The NKA group will be finished after their initial testing session.

A.4.4. **Benefits to subjects and/or society.** Describe any potential for direct benefit to individual subjects, as well as the benefit to society based on scientific knowledge to be gained; these should be clearly distinguished. Consider the nature, magnitude, and likelihood of any direct benefit to subjects. If there is no direct benefit to the individual subject, say so here and in the consent form (if there is a consent form). Do not list monetary payment or other compensation as a benefit.

All participants will receive an intervention protocol aimed at correcting the movement dysfunction through lengthening, strengthening, and improving muscle activity in the hip musculature; however, this protocol is one of the aspects of the study being researched, therefore the potential exists that it will not benefit the subject whatsoever. In addition, all participants will also receive rehabilitation equipment necessary for the intervention program. The subjects in the KVI and the KNA group will receive these materials at the time of their first testing session. The KVC will receive the package when they have completed all of their testing. The sports medicine community will gain insight into what role flexibility, strength, and muscle activity play in contributing to knee valgus during a closed-chain knee flexion position. Also, if these causative factors can be corrected in a one-time intervention or through a six week intervention protocol, then correction of these factors could potentially lead to a reduction in knee injuries from athletics.

A.4.5. **Full description of risks and measures to minimize risks.** Include risk of psychosocial harm (e.g., emotional distress, embarrassment, breach of confidentiality), economic harm (e.g., loss of employment or insurability, loss of professional standing or reputation, loss of standing within the community) and legal jeopardy (e.g., disclosure of illegal activity or negligence), as well as known side effects of study medication, if applicable, and risk of pain and physical injury. Describe what will be done to minimize these risks. Describe procedures for follow-up, when necessary, such as when subjects are found to be in need of medical or psychological referral. If there is no direct interaction with subjects, and risk is limited to breach of confidentiality (e.g., for existing data), state this.

As with any physical activity, participation in this study carries a risk of bodily injury. The motions that subjects will be asked to perform are ones that repeatedly occur during physical activity. Therefore, subjects will be familiar and able to perform the tasks with minimal injury risk. To further minimize injury risk, participants will be allowed a warm up on a stationary bike to prepare themselves for testing. In case of injury, medical personnel (certified athletic trainers) will be located in the same building as testing, and ice will be available if needed. The subjects will be free to cease participation at any time.

There exists a risk of embarrassment or discomfort to the subject due to the location of the EMG electrode placement. This will be minimized by the fact that at no time will any subject be asked to

remove any article of clothing. All electrode placements can be easily reached without removing clothing and with exposing only a small amount of skin. To further minimize this risk, a researcher of the same sex as the subject will do the electrode placement. Also, a towel will be used to drape and further minimize the amount skin that is exposed.

There exists a small risk of muscle imbalances developing in subjects who are in the intervention group. Through stretching and strengthening certain muscle groups and not others there always exists a small chance of injury due to these imbalances. However, the exercises that will be given to subjects are aimed at correcting imbalances that may already exist, which should minimize any risk of injury associated with the intervention. Also, the potential for muscle strain injuries exist when stretching or strengthening, or bruising can occur from myofascial techniques. To minimize these risks, all subjects will receive the same instruction from certified athletic trainers who are trained in how to properly execute these exercises so that there is little risk for injury. Subjects will be given a handout describing how to properly perform exercises and at any time have the right to contact the researchers to answer any questions they may have about how to properly perform the exercises.

There exists a risk of minor pain being experienced by the subject from the shaving and abrading of the areas prior to electrode placement. Subjects will be informed of this risk in the consent form they read and sign; however, due to the necessity of these steps to ensure a clear EMG signal there are no steps to take to avoid this possibility of pain.

A.4.6. **Data analysis.** Tell how the qualitative and/or quantitative data will be analyzed. Explain how the sample size is sufficient to achieve the study aims. This might include a formal power calculation or explanation of why a small sample is sufficient (e.g., qualitative research, pilot studies).

The data of each dependent variable will be analyzed using two-way repeated measures analyses of variance comparing groups and testing sessions. Prior studies using similar techniques indicate for an estimated power of .80, 20 subjects will be needed for each group.

A.4.7. **Will you collect or receive any of the following identifiers as part of the study data?** Does not apply to consent forms.

__ No _x Yes *If yes, check all that apply*:

a. _x Names
b. _x Telephone numbers
c. __ Any elements of dates (other than year) for dates directly related to an individual, including birth date, admission date, discharge date, date of death. For ages over 89: all elements of dates (including year) indicative of such age, except that such ages and elements may be aggregated into a single category of age 90 and older
d. __ Any geographic subdivisions smaller than a State, including street address, city, county, precinct, zip code and their equivalent geocodes, except for the initial three digits of a zip code
e. __ Fax numbers
f. _x Electronic mail addresses
g. __ Social security numbers
h. __ Medical record numbers

i. __ Health plan beneficiary numbers
j. __ Account numbers
k. __ Certificate/license numbers
l. __ Vehicle identifiers and serial numbers (VIN), including license plate numbers
m. __ Device identifiers and serial numbers (e.g., implanted medical device)
n. __ Web universal resource locators (URLs)
o. __ Internet protocol (IP) address numbers
p. __ Biometric identifiers, including finger and voice prints
q. __Full face photographic images and any comparable images
r. __ Any other unique identifying number, characteristic or code, other than dummy identifiers that are not derived from actual identifiers and for which the re-identification key is maintained by the health care provider and not disclosed to the researcher

A.4.8. **Data sharing.** With whom will *identifiable* (contains any of the 18 identifiers listed in question 7 above) data be shared outside the immediate research team? For each, explain confidentiality measures. Include data use agreements, if any.

**_x_** No one
__ Coordinating Center**:**
__ Statisticians**:**
__ Consultants**:**
__ Other researchers**:**
__ Registries**:**
__ Sponsors:
__ External labs for additional testing:
__ Journals:
__ Publicly available dataset:
__ Other:

A.4.9. **Confidentiality of the data**. Describe procedures for maintaining confidentiality of the data you will collect or will receive. Describe how you will protect the data from access by those not authorized. How will data be transmitted among research personnel? Where relevant, discuss the potential for deductive disclosure (i.e., directly identifying subjects from a combination of indirect IDs). Describe your plan to destroy identifiers. When will identifiers be destroyed?

No subjects will be identified in any report or publication about this study. All subjects will be assigned an identification number (ID) for data collection. This ID number will be matched to the identifiers listed above in an excel document. This will be the only place in which a subjects identifiers and ID number will co-exist. This document will be stored on a separate cd apart from all other data that will be collected. These identifiers will be collected during the screening session for the sole purpose of contacting subjects to schedule subsequent testing sessions. Once a subject has completed all of his/her testing sessions, then their identifiers will be deleted from the excel document until all subjects have been tested and the document is destroyed. All information on the data collection form used for testing will be referenced with the subject ID number. At no time will the identifiers above be listed on the same document as data collected during testing. All data will be stored on cds which will be kept in the Sports Medicine Research Lab. All videotapes will be stored in a secure area of the Sports Medicine Research Lab. All data analysis will be performed on computers in the Sports Medicine Research Lab where a password is necessary for access to the computers. Only members performing research have access to these computers, therefore identification of any subjects or data is very unlikely. If disclosure is ever required, UNC-CH will take all steps allowable by law to protect the privacy of personal information.

Personal privacy during testing sessions will be maintained through limiting the people within the research lab to current employees of the lab and the testers themselves. The only door to enter the lab is locked with key card access to ensure privacy. Patients will be properly draped with a towel during electrode placement to ensure privacy.

A.4.10. **Data security for storage and transmission**. Please check all that apply.

*For electronic data:*

__ Secure network __ Password access __ Encryption
__ Other (describe):
__ Portable storage (e.g., laptop computer, flash drive)
*Describe how data will be protected for any portable device:*

*For hardcopy data (including human biological specimens, CDs, tapes, etc.):*

__ Data de-identified by research team (stripped of the 18 identifiers listed in question 7 above)
_x_ Locked suite or office
_x_ Locked cabinet
_x_ Data coded by research team with a master list secured and kept separately
__ Other (describe):

## Part A.5. The Consent Process and Consent Documentation (including Waivers)

The standard consent process is for all subjects to sign a document containing all the elements of informed consent, as specified in the federal regulations. Some or all of the elements of consent, including signatures, may be altered or waived under certain circumstances.

- If you will obtain consent in any manner, complete **section A.5.1**.
- If you are obtaining consent, but requesting a waiver of the requirement for a signed consent document, complete **section A.5.2**.
- If you are requesting a waiver of any or all of the elements of consent, complete **section A.5.3**.

You may need to complete more than one section. For example, if you are conducting a phone survey with verbal consent, complete sections A.5.1, A.5.2, and possibly A.5.3.

A.5.1. **Describe the process of obtaining informed consent from subjects**. If children will be enrolled as subjects, describe the provisions for obtaining parental permission and assent of the child. If decisionally impaired adults are to be enrolled, describe the provision for obtaining surrogate consent from a legally authorized representative (LAR). If non-English speaking people will be enrolled, explain how consent in the native language will be obtained. Address both written translation of the consent and the availability of oral interpretation. *After you have completed this part A.5.1, if you are not requesting a waiver of any type, you are done with Part A.5.; proceed to Part B.*

Informed consent will be obtained from all subjects prior to any testing. Subjects will report to the University of North Carolina-Chapel Hill, Sports Medicine Research Lab in Fetzer Gym. Before beginning the testing session the subject will be asked to read an informed consent agreement outlining the procedures, protocols and potential risks of the study. This informed consent agreement form will be in accordance with the standards set forth by the Medical IRB at the University of North Carolina at Chapel Hill. After the subjects sign the consent form, a copy will be given to them, and testing will commence.

A.5.2. **Justification for a waiver of *written* (i.e., signed) consent**. *The default is for subjects to sign a written document that contains all the elements of informed consent.* Under limited circumstances, the requirement for a signed consent form may be waived by the IRB if either of the following is true:

a. The only record linking the subject and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality (e.g., study involves sensitive data that could be damaging if disclosed). __ yes __ no
**Explain.**

b. The research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context (e.g., phone survey). __ yes __ no
**Explain.**

*If you checked "yes" to either, will consent be oral? Will you give out a fact sheet? Use an online consent form, or include information as part of the survey itself, etc?*

A.5.3. **Justification for a full or partial waiver of consent.** *The default is for subjects to sign a written document that contains all the elements of informed consent.* A waiver might be requested for research involving only existing data or human biological specimens (see also Part C). More rarely, it might be requested when the research design requires withholding some study details at the outset (e.g., behavioral research involving deception). In limited circumstances, parental permission may be waived. This section should also be completed for a waiver of HIPAA authorization if research involves Protected Health Information (PHI) subject to HIPAA regulation, such as patient records.

__ Requesting **waiver of some elements** (specify; see SOP 28 on the IRB web site):
__ Requesting **waiver of consent entirely**
If you check either of the boxes above, answer items a-f.. To justify a full waiver of the requirement for informed consent, you must be able to answer "yes" (or "not applicable" for question c) to items a-f. **Insert brief explanations that support your answers.**

a. Will the research involve no greater than minimal risk to subjects or to their privacy? __ yes __ no
**Explain.**

b. Is it true that the waiver will *not* adversely affect the rights and welfare of subjects? *(Consider the right of privacy and possible risk of breach of confidentiality in light of the information you wish to gather.)* __ yes __ no
**Explain.**

c. When applicable to your study, do you have plans to provide subjects with pertinent information after their participation is over? *(e.g., Will you provide* __ yes __ not applicable

*details withheld during consent, or tell subjects if you found information with direct clinical relevance? This may be an uncommon scenario.)*
**Explain**.

d. Would the research be impracticable without the waiver? *(If you checked "yes," explain how the requirement to obtain consent would make the research impracticable, e.g., are most of the subjects lost to follow-up or deceased?).* __ yes __ no
**Explain.**

e. Is the risk to privacy reasonable in relation to benefits to be gained or the importance of the knowledge to be gained? __ yes __ no
**Explain.**

**If you are accessing patient records for this research, you must also be able to answer "yes" to item f to justify a waiver of HIPAA authorization from the subjects.**

f. Would the research be impracticable if you could not record (or use) Protected Health Information (PHI)? *(If you checked "yes," explain how* not *recording or using PHI would make the research impracticable).* __ yes __ no
**Explain.**

## Part B. Questions for Studies that Involve Direct Interaction with Human Subjects

→ *If this does not apply to your study, do not submit this section.*

B.1. **Subjects.** Specify number, gender, ethnicity, race, and age. Specify whether subjects are healthy volunteers or patients. If patients, specify any relevant disease or condition and indicate how potential subjects will be identified.

Subjects will be divided into two groups based upon their results on the double leg squat task (DLST). The dysfunction group will consist of subjects who demonstrate bilateral knee adduction during the DLST both with and without a two-inch heel block place under the calcaneus. The heel block will be used to ensure that tightness in the posterior lower leg is not influencing a knee valgus alignment. The dysfunction group will be further divided, randomly, into an intervention group (KVI) and a control group (KVC). The normal alignment control group (NKA) will consist of subjects who do not demonstrate knee adduction on either leg during the DLST with and without a two-inch heel block. Subjects in the control group will be matched to subjects in the hip dysfunction groups by age, height, weight, gender and physical activity level. Each group will consist of 20 subjects whose ages range from 18-35 years. Subjects will be otherwise healthy volunteers that have no current musculoskeletal injuries or have not sustained an injury to either lower extremity in the past six months. No potential subject will be excluded due to gender, ethnicity, or race.

B.2. **Inclusion/exclusion criteria.** List required characteristics of potential subjects, and those that preclude enrollment. Justify exclusion of any group, especially by criteria based on gender, ethnicity, race, or age. If pregnant women are excluded, or if women who become pregnant are withdrawn, specific justification must be provided.

Inclusion Criteria for Dysfunction Groups: Aysmptomatic with & without activity and during the double leg squat; Demonstrates bilateral knee adduction during double leg squat (no heel block); Demonstrates bilateral knee adduction during double leg squat with 2-inch heel block placed underneath calcaneus.

Inclusion Criteria for Normal Alignment Group: Aysmptomatic with & without activity and during the double leg squat; Does not demonstrate bilateral knee adduction during double leg squat with and without a two-inch heel block.

No potential subject will be excluded due to gender, ethnicity, or race. Pregnant women will be excluded and women who become pregnant will be withdrawn due to the complexity and activity necessary for the functional tasks.

B.3. **Methods of recruiting.** Describe how and where subjects will be identified and recruited. Indicate who will do the recruiting, and tell how subjects will be contacted. Describe efforts to ensure equal access to participation among women and minorities. Describe how you will protect the privacy of potential subjects during recruitment. *For prospective subjects whose status (e.g., as patient or client), condition, or contact information is not publicly available (e.g., from a phone book or public web site), the initial contact should be made with legitimate knowledge of the subjects' circumstances. Ideally, the individual with such knowledge should seek prospective subjects' permission to release names to the PI for recruitment. Alternatively, the knowledgeable individual could provide information about the study, including contact information for the investigator, so that interested prospective subjects can contact the investigator.* Provide the IRB with a copy of any document or script that will be used to obtain the patients' permission for release of names or to introduce the study. Check with your IRB for further guidance.

All potential subjects will be recruited through informational emails and flyers written by the principal investigator. The contact number in the email and the flyer will be that of the investigator, Brian Vesci. The potential subjects will have the freedom to either respond or ignore the emails; therefore, they will not feel obligated to participate in the study.

Emails will be sent to the current student and faculty population of the University of North Carolina at Chapel Hill via listservs. Efforts to ensure equal access to participation among women and minorities will be limited only by the current population of women and minorities in the student body and faculty population.

B.4. **Protected Health Information (PHI).** If you need to access Protected Health Information (PHI) to identify potential subjects who will then be contacted, you will need a *limited waiver of HIPAA authorization*. If this applies to your study, please provide the following information.

a. Will the information collected be limited only to that necessary to contact the subjects to ask if they are interested in participating in the study?

b. How will confidentiality/privacy be protected prior to ascertaining desire to participate?

c. When and how will you destroy the contact information if an individual declines participation?

B.5. **Duration of entire study and duration of an individual subject's participation, including follow-up evaluation if applicable.** Include the number of required contacts and approximate duration of each contact.

All subjects will have an initial contact during the screening process. This will last approximately five minutes per subject.

Subjects in the normal alignment group (NKA) will only require one more contact for the testing session. This will last approximately one hour.

Subjects in the dysfunction groups (KVI, KVC) will require two further contacts beyond the initial screening. Both of these testing sessions will last approximately one and a half hours. The first of these testing sessions will occur following the general screening session and the final testing session will occur six weeks later.

B.6. **Where will the subjects be studied?** Describe locations where subjects will be studied, both on and off the UNC-CH campus.

All subjects will be studied in the Sports Medicine Research Lab in the Fetzer Gymnasium building on the campus of the University of North Carolina at Chapel Hill

B.7. **Privacy.** Describe procedures that will ensure privacy of the subjects in this study. Examples include the setting for interviews, phone conversations, or physical examinations; communication methods or mailed materials (e.g., mailings should not indicate disease status or focus of study on the envelope).

No subjects will be identified in any report or publication about this study. All subjects will be assigned an identification number (ID) for data collection. All data will be stored on cds which will be kept in the Sports Medicine Research Lab. All videotapes will be stored in a secure area of the Sports Medicine Research Lab. All data analysis will be performed on computers in the Sports Medicine Research Lab where a password is necessary for access to the computers. Only members performing research have access to these computers, therefore identification of any subjects or data is very unlikely. If disclosure is ever required, UNC-CH will take all steps allowable by law to protect the privacy of personal information.

Personal privacy during testing sessions will be maintained through limiting the people within the research lab to current employees of the lab and the testers themselves. The only door to enter the lab is locked with key card access to ensure privacy. Patients will be properly draped with a towel during electrode placement to ensure privacy.

B.8. **Inducements for participation.** Describe all inducements to participate, monetary or non-monetary. If monetary, specify the amount and schedule for payments and how this will be prorated if the subject withdraws (or is withdrawn) from the study prior to completing it. For compensation in foreign currency, provide a US$ equivalent. Provide evidence that the amount is not coercive (e.g., describe purchasing power for foreign countries). Include food or refreshments that may be provided.

All participants in this study will receive an exercise package valued at approximately thirty to forty dollars per participant following completion of the study. This package will include exercise tubing, foam rollers, and the exercise protocol.

B.9. **Costs to be borne by subjects.** Include child care, travel, parking, clinic fees, diagnostic and laboratory studies, drugs, devices, all professional fees, etc. If there are no costs to subjects other than their time to participate, indicate this.

There will be no cost borne by subjects other than their time.

## Part C. Questions for Studies using Data, Records or Human Biological Specimens without Direct Contact with Subjects

→ *If this does not apply to your study, do not submit this section.*

C.1. What records, data or human biological specimens will you be using? *(check all that apply)*:

__ Data already collected for another research study
__ Data already collected for administrative purposes (e.g., Medicare data, hospital discharge data)
__ Medical records (custodian may also require form, e.g., HD-974 if UNC-Health Care System)
__ Electronic information from clinical database (custodian may also require form)
__ Patient specimens (tissues, blood, serum, surgical discards, etc.)
__ Other (specify):

C.2. For each of the boxes checked in 1, how were the original data, records, or human biological specimens collected? Describe the process of data collection including consent, if applicable.

C.3. For each of the boxes checked in 1, where do these data, records or human biological specimens currently reside?

C.4. For each of the boxes checked in 1, from whom do you have permission to use the data, records or human biological specimens? Include data use agreements, if required by the custodian of data that are not publicly available.

C.5. If the research involves human biological specimens, has the purpose for which they were collected been met before removal of any excess? For example, has the pathologist in charge or the

clinical laboratory director certified that the original clinical purpose has been satisfied? Explain if necessary.

__ yes __ no __ not applicable (explain)

C.6. Do all of these data records or specimens exist at the time of this application? If not, explain how prospective data collection will occur.

__ yes __ no If no, explain

**University of North Carolina-Chapel Hill**
**Consent to Participate in a Research Study**
**Adult Subjects**
**Biomedical Form**

**IRB Study #** 05-EXSS-839
**Consent Form Version Date:** 3/2/06
**Title of Study:** The Effects of Hip Strength, Range of Motion, and Muscle Activity on a Knee Valgus Position During Functional Movement Tasks.

**Principal Investigator:** Brian Vesci, BS, ATC, LAT, PES
**UNC-Chapel Hill Department:** Department of Exercise and Sport Science
**UNC-Chapel Hill Phone number: (**919) 962-7187
**Email Address:** vesci@email.unc.edu
**Co-Investigators:** David R. Bell, MEd, ATC, LAT; Lindsay Strickland, MS, ATC, LAT
**Faculty Advisor:** Darin Padua, PhD, ATC, LAT
**Funding Source:**

**Study Contact telephone number:** 919-962-7187
**Study Contact email:**vesci@email.unc.edu

**What are some general things you should know about research studies?**
You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

**What is the purpose of this study?**

The position of knee valgus (a.k.a. knock knee), which occurs as the knees move inward towards the great toe while moving into a squatted position, has been theorized as a position that may predispose an individual for various knee and lower extremity injuries. Limited research has been performed to investigate potential causes of knee valgus. Also, there is no research investigating exercises to correct knee valgus alignment. Therefore, the primary purpose of this study is to investigate the differences in muscle strength, muscle flexibility, and muscle activation between subjects with and without knee valgus alignment during squatting. A secondary purpose of this study is to examine the effectiveness of an exercise intervention on changing knee valgus alignment, muscle strength, muscle flexibility, and muscle activation.

**Are there any reasons you should not be in this study?**

You should not participate in this study if any of the following apply to you:

- You are not interested in doing strength or flexibility exercises
- You have any current symptoms of injury (redness, swelling, pain)
- You have used an external ankle brace/support on a regular basis within the past three months
- You have had leg surgery in the past year
- You have had a lower extremity injury in the past three months that required you to miss three or more consecutive days of physical activity

**How many people will take part in this study?**

If you decide to be in this study, you will be one of approximately 60 participants in this research study.

**How long will your part in this study last?**

Your participation in this study will depend upon your group assignment. If you are in the group identified with normal knee alignment (NKA), you will only take part in one testing session that will last approximately one hour. If you are in the groups identified with a knee valgus alignment your involvement will consist of two testing sessions. The first testing session will last approximately one and a half hours. The second testing session will take place six weeks after the first session and will last approximately one and a half hours.

**What will happen if you take part in the study?**

Subjects in the knee valgus intervention group (KVI) and the normal knee alignment group (NKA) will receive a foam roller, exercise band, and exercise program aimed at improving their knee valgus alignment at the time of their first testing session. The other group, knee valgus control (KVC), will receive the same exercise package at the completion of their testing. It is important to understand that as a subject you will receive the exercise package however you may receive no benefit from the proposed exercises as they are part of what is being analyzed in the study and their ability to improve knee valgus alignment has not yet been demonstrated.

Subjects will be asked to attend the testing sessions wearing a t-shirt, shorts and athletic shoes. Subjects will be divided into three groups. One group will consist of those who have been identified with normal knee alignment (NKA). The two additional groups will be randomly assigned and are those participants that have been identified as having knee valgus during a squat. One of these groups will be another control group, the knee valgus control (KVC), and the other will receive the exercise program, the knee valgus intervention (KVI).

**Testing Session 1 (NKA, KVC, KVI):**

The session will begin with you being video taped during a squat task to confirm and document whether or not you demonstrate knee valgus. You will then ride a stationary bicycle for five minutes to warm-up. After you are sufficiently warmed up, we will measure the range of motion of your hip. Adhesive electrodes designed to measure electrical activity of your muscles will be placed on the outside and back (high buttocks/low back) of your hip as well as approximately half way between your hip and your knee on the inside of your thigh. A small area will be shaven and cleansed with alcohol to ensure that electrodes will be secured in place. An examiner of the same sex as yourself will perform all electrode placements. At no time will you be asked to remove any articles of clothing. The electrodes can be placed properly with minimal skin exposure and a towel will be used for draping in an attempt to remove any feelings of discomfort. Examiners will then measure your hip muscle strength on an isokinetic-strength testing machine, meaning that your maximal strength will be tested at a predetermined and constant speed.

You will then perform three different activities during which the investigators will measure your muscle activity. They consist of 5 squats, 5 straight ahead jump landings, and 5 jump landings in which the subject will rotate 90 degrees in the air, from an approximately 12-inch high box to a distance half of your body height away.

At this time the NKA group will be finished with testing and will receive the exercises package. The KVI group will be asked to perform a series of exercises that will take approximately 20 minutes to complete. The exercises include five stretching exercises, two strengthening exercises, and two functional exercises. These specific exercises include:

1) Foam roller stretch to the inside of the thigh (1 minute)
2) Foam roller stretch to the outside of the thigh (1 minute)
3) Stretching exercise for the inside of the thigh (2 repetitions for 30 seconds)
4) Stretching exercise for the outside of the thigh (2 repetitions for 30 seconds)
5) Stretching exercise for the back of the thigh (2 repetitions for 30 seconds)

6) Strengthening exercise for the outside of the thigh (3 sets of 10 repetitions)
7) Strengthening exercise for the back of the thigh (3 sets of 10 repetitions)
8) Side stepping with resistance band around ankles (3 sets of 10 repetitions)
9) Single leg squat reach for balance (3 sets for 3 repetitions)

The KVC group will rest for 20 minutes instead of performing exercises. After the rest or exercise period each subject will perform the squats, jump landing, and transverse jump landing for a second time. Subjects will not have to repeat the strength testing after the rest or exercises. Finally, the exercise group (KVI) will be asked to perform the exercise program at home, four times a week over a six-week period. Each subject in the exercise group will be given a handout with pictures depicting each exercise, as well as a daily exercise log to chart when and which exercises were performed.

**Testing Session 2 (KVC, KVI):**
Both groups identified with a knee valgus alignment will return to the Sports Medicine Research Laboratory after 6-weeks. The second testing session will be very similar to the first. All groups will: 1) warm-up on the stationary bike, 2) have the electrodes placed again, and 3) have their strength test again exactly as the first session. Finally, each group will perform 5 squats, 5 jump landings (half the distance of their height), and 5 transverse landings (half the distance of their height). No exercise intervention will take place in the second session. At this point after the second testing session the KVC group will be given the exercise package and will have the experimental exercise protocol explained to them.

**What are the possible benefits from being in this study?**
Research is designed to benefit society by gaining new knowledge about knee valgus. The benefits to you from being in this study may include a prescriptive exercise program designed to attempt to correct hip muscle weakness and tightness that may exist. The researcher will discuss your performance on the jumping and squatting maneuvers with you if you wish. This information may help educate you on improving your jumping and squatting technique. The results of this study may benefit society by providing data on what factors may influence a knee valgus position during functional movements that may predispose someone to various knee injuries as well as if any intervention exercise programs can be implemented to correct these factors.

**What are the possible risks or discomforts involved with being in this study?**
This study involves a jumping and squatting maneuver that may involve the following risks and/or discomforts to you:

- Possibility of a ligament injury to the joints of your lower extremities
- Possibility of muscle strains/pulls/soreness in your lower extremities
- Possibility of pain due to shaving and abrading sites of electrode placement
- Possible embarrassment due to electrode placement
- There may be uncommon or previously unrecognized risks that might occur

While the possibility of the above mentioned risks exist, all appropriate precautions will be taken to minimize these risks.

No penalty will be incurred if you decide to not participate or if you withdraw yourself from testing during the study. Please do not feel pressured to participate, or continue with the study if at any point you feel uncomfortable.

**What if we learn about new findings or information during the study?**
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

**How will your privacy be protected?**
No subjects will be identified in any report or publication about this study. All subjects will be identified as a number throughout data collection. All data storage and analysis will be on computers the sports medicine research lab where a password is necessary for access to the computers. Only members performing research have access to the lab and use of its computers. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, The University of North Carolina at Chapel Hill will take all steps allowable by law to protect the privacy of personal information.

**What will happen if you are injured by this research?**
All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

**What if you want to stop before your part in the study is complete?**
You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

**Will you receive anything for being in this study?**
You will be receiving an exercise package valued at approximately thirty to forty dollars consisting of exercise and rehabilitation equipment (foam rollers, exercise tubing), as well as the exercise protocol, following completion of the study. If you are in exercise group (KVI) or the normal knee alignment group (NKA) you will receive the exercise equipment and the exercise protocol at the time of your first testing session. If you are not in this group, you will receive the exercise package, as well as the exercise intervention, when you have completed all testing associated with the study.

**Will it cost you anything to be in this study?**
The only cost to you will be in your time and transportation to the University of North Carolina at Chapel Hill Sports Medicine Research Laboratory for your testing session.

**What if you are a UNC student?**
You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

**What if you are a UNC employee?**
Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

**Who is sponsoring this study?**
The National Academy of Sports Medicine is donating the equipment provided to the subjects for this study. However they are not sponsoring the study. Researchers for this study are not receiving any type of compensation for their work.

**What if you have questions about this study?**
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

**What if you have questions about your rights as a research subject?**
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

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**IRB Study # 05-EXSS-839**

**Subject's Agreement:**

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_____ _____

Signature of Research Subject Date

_____

Printed Name of Research Subject

_____ _____

Signature of Person Obtaining Consent Date

_____

Printed Name of Person Obtaining Consent

University of North Carolina – Chapel Hill
Research Study Questionnaire
Adult Subjects

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Medical IRB Study # 05-EXSS-839

**Title of Study:** The Effects of Hip Strength, Range of Motion, and Muscle Activity on a Knee Valgus Position During Functional Movement Tasks.
**Principal Investigator:** Brian Vesci, BS, ATC, LAT, PES
**UNC-CH Department:** EXSS
**Phone Number:** 919-962-7187

**Co-Investigators:** David Bell, Med, ATC, LAT; Lindsay Strickland, MS, ATC, LAT

**Sponsor:** None

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**1. Are you currently in good general health?**

**YES / NO**

**2. Have you had a lower extremity injury in the past three months that required three consecutive days missed from physical activity?**

**YES / NO**

**3. Do you have any current symptoms of injury?**

**YES / NO**

**4. How often do you exercise per week? _____ Days**

**5. Approximately how many minutes do you exercise per day?_____Minutes**

**6. What type of exercise activity do you most often participate in (walking, running, aerobics, basketball, etc.)?**

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Email to potential subjects

Subject:
Are you interested in contributing to research aimed at preventing lower extremity knee injuries?

Script:
You may be eligible to participate in a research study investigating lower body posture during squatting and jumping. This study is sponsored by the UNC Department of Exercise and Sport Science.

If chosen to participate in this study you will be asked to attend either one (control subjects) or two (non-control subjects) testing sessions. The control subjects session will last approximately one hour. Sessions for the non control subjects will last approximately one and a half hours. During testing sessions you will be video taped while performing a squatting task, have strength measurements taken of various hip muscles, EMG muscle activity recorded for various hip muscles (including electrode placement on the buttocks and halfway down the inside of your thigh), and may asked to participate in an exercise program for six weeks at which point you will be tested again. If you qualify for the control group you will not have to participate in any exercise program.

Criteria for inclusion in the control group consists of having no pain while performing a squat and having what is judged by the tester as normal knee alignment while squatting. Inclusion criteria for the intervention group consists of having no pain while squatting and having what the tester judges to be knee valgus (knock knees) alignment while squatting.

Volunteers will be asked to attend a general screening session to determine if they are eligible. To volunteer you must be healthy, free from lower extremity injury, and between the ages of 18-35.

If selected to participate as a subject in this study you will receive an exercise package including equipment and exercises aimed at improving your lower body posture

All interested individuals should contact the principal investigator, Brian Vesci, at vesci@email.unc.edu

# ARE YOU INTERESTED IN CONTRIBUTING TO RESEARCH AIMED AT PREVENTING KNEE INJURIES?

You may be eligible to participate in a research study investigating lower body posture during squatting and jumping. This study is being conducted by the UNC Department of Exercise and Sport Science

If chosen to participate in this study you will be video taped while performing a squatting task, have strength measurements taken of various hip muscles, EMG muscle activity recorded for various hip muscles (including electrode placement on the buttocks and halfway down the inside of your thigh), Control subjects, being judged to have normal knee alignment, will have one testing session lasting approximately one hour. Intervention subjects will be asked to participate in a six week exercise program and will be tested twice, both sessions will last approximately one and a half hours.

Volunteers will be asked to attend a general screening session to determine if they are eligible. To volunteer you must be healthy, free from lower extremity injury, have no pain when performing a squat, and between the ages of 18-35.

If selected to participate as a subject in this study you will receive an exercise package including equipment and exercises aimed at improving your lower body posture

To receive more information, contact:

Brian Vesci LAT, ATC, PES
vesci@email.unc.edu
412-855-3080

UNC Sports Medicine Research Lab
919-962-7187

# APPENDIX E: DATA COLLECTION MATERIALS

**Data Collection Form**

**Subject ID**_____

**Group**_____ **Leg L R** **Sex M F**
**Height**_____cm **Weight**_____kg **Age**_____

**Range of Motion**
**Passive Hip Abduction** 1)____2)____3)____ Avg(SPSS)_____
**Passive Hip ER** 1)____2)____3)____ Avg(SPSS)_____

**Electrode Placement**
**Iliac crest to greater trochanter** _____ / 2 = _____
**S2 – 10 cm distal to greater trochanter** _____ x .2 = _____
**Greater trochanter to lateral epicondyle** _____ / 2 = _____

**Isokinetic Strength (Average Torque)**

**Hip ER Arm Level** _____
**Hip IR Arm level** _____
**Hip Extension Arm level** _____
**Hip Abduction Arm level** _____

**MVIC Testing Order:** Gmax____ Gmed____ Add____

**Activity Testing Order:** DLSQ:____ JL: _____ TJP: _____

**File information:** Sub#: Session: 1 or 2 Pre or Post

**Please write in all final concatenate files saved for this subject:**

1) MVIC File:

2) DLSQ File:

3) Jump Landing File (JL):

4) Transverse Landing File (TJP):

# APPENDIX F: RAW DATA

| Subject | Group | Height | Weight | Age | Leg | Sex | HipAB1 | HipAB2 | HipAB3 | HipABAVG |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 175 | 98 | 28 | 2 | 1 | 45 | 37 | 35 | 39 |
| 2 | 1 | 173 | 99 | 25 | 1 | 1 | 40 | 35 | 41 | 38.666667 |
| 3 | 1 | 173 | 66 | 23 | 2 | 1 | 39 | 32 | 36 | 35.666667 |
| 4 | 1 | 193 | 79 | 23 | 1 | 1 | 32 | 34 | 35 | 33.666667 |
| 5 | 1 | 175 | 59 | 24 | 1 | 2 | 45 | 42 | 42 | 43 |
| 6 | 1 | 163 | 54 | 22 | 1 | 2 | 42 | 37 | 38 | 39 |
| 7 | 1 | 168 | 61 | 18 | 2 | 2 | 27 | 24 | 22 | 24.333333 |
| 8 | 1 | 170 | 64 | 18 | 1 | 2 | 38 | 37 | 35 | 36.666667 |
| 9 | 1 | 173 | 54 | 23 | 1 | 2 | 42 | 36 | 41 | 39.666667 |
| 10 | 1 | 170 | 77 | 23 | 2 | 2 | 28 | 32 | 35 | 31.666667 |
| 11 | 1 | 175 | 79 | 24 | 1 | 1 | 34 | 37 | 36 | 35.666667 |
| 12 | 1 | 170 | 64 | 22 | 1 | 2 | 41 | 45 | 38 | 41.333333 |
| 13 | 1 | 48 | 43 | 44 | 1 | 2 | 48 | 43 | 44 | 45 |
| 14 | 1 | 183 | 86 | 25 | 1 | 1 | 36 | 34 | 30 | 33.333333 |
| 15 | 1 | 170 | 59 | 21 | 1 | 2 | 45 | 47 | 43 | 45 |
| 16 | 1 | 170 | 66 | 22 | 1 | 2 | 31 | 33 | 36 | 33.333333 |
| 17 | 1 | 175 | 75 | 20 | 1 | 1 | 32 | 29 | 35 | 32 |
| 18 | 2 | 163 | 61 | 21 | 2 | 2 | 33 | 31 | 32 | 32 |
| 19 | 2 | 168 | 61 | 20 | 1 | 2 | 26 | 40 | 35 | 33.666667 |
| 20 | 2 | 163 | 61 | 20 | 1 | 2 | 34 | 43 | 41 | 39.333333 |
| 21 | 2 | 165 | 54 | 25 | 1 | 2 | 45 | 45 | 44 | 44.666667 |
| 22 | 2 | 165 | 64 | 26 | 1 | 2 | 41 | 39 | 38 | 39.333333 |
| 23 | 2 | 157 | 61 | 22 | 1 | 2 | 35 | 30 | 32 | 32.333333 |
| 24 | 2 | 157 | 61 | 25 | 1 | 2 | 32 | 30 | 34 | 32 |
| 25 | 2 | 183 | 73 | 20 | 1 | 1 | 33 | 34 | 27 | 31.333333 |
| 26 | 2 | 157 | 57 | 21 | 1 | 2 | 35 | 33 | 32 | 33.333333 |
| 27 | 2 | 170 | 84 | 23 | 1 | 2 | 38 | 42 | 40 | 40 |
| 28 | 2 | 163 | 59 | 20 | 1 | 2 | 35 | 36 | 35 | 35.333333 |
| 29 | 2 | 175 | 79 | 20 | 1 | 2 | 37 | 31 | 34 | 34 |
| 30 | 2 | 188 | 84 | 20 | 1 | 1 | 28 | 31 | 40 | 33 |
| 31 | 2 | 167 | 64 | 30 | 1 | 2 | 35 | 29 | 37 | 33.666667 |

| HipER1 | HipER2 | HipER3 | HipERAVG | Gast1 | Gast2 | Gast3 | GastAVG | Sol1 | Sol2 |
|---|---|---|---|---|---|---|---|---|---|
| 40 | 45 | 43 | 42.666667 | 1 | 1 | 3 | 1.666667 | 5 | 6 |
| 64 | 66 | 65 | 65 | 14 | 17 | 16 | 15.66667 | 16 | 12 |
| 76 | 74 | 76 | 75.333333 | 24 | 24 | 23 | 23.66667 | 24 | 23 |
| 49 | 47 | 48 | 48 | 8 | 10 | 11 | 9.666667 | 13 | 14 |
| 105 | 102 | 103 | 103.33333 | 18 | 18 | 22 | 19.33333 | 19 | 26 |
| 83 | 84 | 85 | 84 | 17 | 16 | 15 | 16 | 15 | 16 |
| 62 | 64 | 65 | 63.666667 | 16 | 18 | 16 | 16.66667 | 20 | 22 |
| 72 | 75 | 72 | 73 | 22 | 24 | 26 | 24 | 24 | 25 |
| 105 | 108 | 108 | 107 | | | | 0 | | |
| 72 | 77 | 73 | 74 | 18 | 17 | 15 | 16.66667 | 21 | 18 |
| 60 | 59 | 58 | 59 | | | | 0 | | |
| 93 | 93 | 96 | 94 | 18 | 21 | 20 | 19.66667 | 22 | 24 |
| 78 | 83 | 77 | 79.333333 | 23 | 18 | 19 | 20 | 13 | 17 |
| 68 | 71 | 66 | 68.333333 | | | | 0 | | |
| 86 | 89 | 89 | 88 | 33 | 36 | 35 | 34.66667 | 40 | 42 |
| 68 | 65 | 67 | 66.666667 | 25 | 22 | 24 | 23.66667 | 24 | 24 |
| 64 | 64 | 68 | 65.333333 | 11 | 8 | 8 | 9 | 12 | 11 |
| 78 | 79 | 79 | 78.666667 | 3 | 3 | 4 | 3.333333 | 6 | 8 |
| 63 | 68 | 71 | 67.333333 | 8 | 8 | 9 | 8.333333 | 14 | 16 |
| 78 | 79 | 79 | 78.666667 | 6 | 8 | 7 | 7 | 9 | 12 |
| 63 | 62 | 65 | 63.333333 | 10 | 13 | 13 | 12 | 21 | 20 |
| 68 | 67 | 68 | 67.666667 | 26 | 25 | 24 | 25 | 28 | 27 |
| 78 | 79 | 78 | 78.333333 | 18 | 15 | 17 | 16.66667 | 26 | 27 |
| 86 | 85 | 87 | 86 | 16 | 14 | 17 | 15.66667 | 24 | 27 |
| 65 | 66 | 63 | 64.666667 | 23 | 25 | 25 | 24.33333 | 29 | 35 |
| 68 | 72 | 74 | 71.333333 | 14 | 17 | 13 | 14.66667 | 21 | 23 |
| 75 | 72 | 74 | 73.666667 | 3 | 3 | 3 | 3 | 10 | 12 |
| 65 | 75 | 80 | 73.333333 | 28 | 26 | 30 | 28 | 34 | 29 |
| 84 | 85 | 84 | 84.333333 | 14 | 8 | 12 | 11.33333 | 16 | 15 |
| 78 | 68 | 78 | 74.666667 | 9 | 8 | 11 | 9.333333 | 22 | 20 |
| 76 | 81 | 83 | 80 | 9 | 9 | 10 | 9.333333 | 12 | 13 |

| GlutMax1 | T1 | T2 | GlutMax2 | T1 | T2 | GlutMax3 | T1 | GlutMaxAVG |
|---|---|---|---|---|---|---|---|---|
| 0.637 | 1.99 | 4.99 | 0.752 | 11.41 | 14.41 | 0.796 | 19.91 | 0.728333333 |
| 0.539 | 1.99 | 4.99 | 0.475 | 10.99 | 13.99 | 0.48 | 18.5 | 0.498 |
| 0.93 | 2.5 | 5.5 | 1.498 | 10 | 13 | 1.268 | 16 | 1.232 |
| 1.002 | 3 | 6 | 1.272 | 9.5 | 12.5 | 1.459 | 17.5 | 1.244333333 |
| 0.198 | 1.99 | 4.99 | 0.188 | 8.5 | 11.5 | 0.237 | 15 | 0.207666667 |
| 0.687 | 1.85 | 4.85 | 0.593 | 10.15 | 13.15 | 0.601 | 17.65 | 0.627 |
| 1.24 | 1.75 | 4.75 | 0.75 | 10.25 | 13.25 | 0.63 | 17.75 | 0.873333333 |
| 0.788 | 3.93 | 6.93 | 0.804 | 12.25 | 15.25 | 0.837 | 19.75 | 0.809666667 |
| 0.925 | 1.99 | 4.99 | 0.933 | 10.5 | 13.5 | 1.069 | 18.99 | 0.975666667 |
| 0.24 | 1.99 | 4.99 | 0.259 | 10.3 | 13.3 | 0.25 | 19.8 | 0.249666667 |
| 0.689 | 2.79 | 5.79 | 0.913 | 11.3 | 14.3 | 1 | 19.3 | 0.867333333 |
| 0.546 | 2.58 | 5.58 | 0.719 | 10.46 | 13.46 | 0.652 | 20.16 | 0.639 |
| 0.558 | 2.18 | 5.18 | 0.455 | 10.18 | 13.18 | 0.348 | 18.68 | 0.453666667 |
| 0.513 | 3.381 | 6.381 | 0.622 | 13.58 | 16.58 | 0.803 | 21.58 | 0.646 |
| 1.031 | 2.38 | 5.38 | 0.996 | 10.38 | 13.38 | 0.936 | 18.88 | 0.987666667 |
| 0.71 | 2.58 | 5.58 | 0.558 | 9.88 | 12.88 | 0.486 | 18.38 | 0.584666667 |
| 0.38 | 2.18 | 5.18 | 0.329 | 11.18 | 14.18 | 0.371 | 19.18 | 0.36 |
| 0.591 | 1.267 | 4.267 | 0.517 | 7.766 | 10.766 | 0.488 | 14.27 | 0.532 |
| 1.296 | 1.77 | 4.77 | 1.423 | 8.27 | 11.27 | 1.321 | 15.77 | 1.346666667 |
| 0.495 | 1.99 | 4.99 | 0.686 | 9.77 | 12.77 | 0.464 | 16.77 | 0.548333333 |
| 0.562 | 1.59 | 4.59 | 0.612 | 9.59 | 12.59 | 0.475 | 17.09 | 0.549666667 |
| 0.576 | 1.79 | 4.79 | 0.584 | 8.99 | 11.99 | 0.69 | 16.99 | 0.616666667 |
| 0.76 | 1.69 | 4.69 | 0.984 | 9.19 | 12.19 | 0.801 | 16.09 | 0.848333333 |
| 0.424 | 7.24 | 10.24 | 0.384 | 16.74 | 19.74 | 0.278 | 26.24 | 0.362 |
| 1.612 | 1.99 | 4.99 | 1.467 | 9.5 | 12.5 | 1.472 | 16.99 | 1.517 |
| 0.31 | 2.354 | 5.354 | 0.22 | 9.15 | 12.15 | 0.22 | 15.65 | 0.25 |
| 0.23 | 1.45 | 4.45 | 0.21 | 9.95 | 12.95 | 0.21 | 16.95 | 0.216666667 |
| 0.39 | 1.78 | 4.78 | 0.4 | 8.95 | 11.95 | 0.36 | 16.95 | 0.383333333 |
| 0.59 | 1.38 | 4.38 | 0.53 | 9.38 | 12.38 | 0.59 | 16.38 | 0.57 |
| 0.2 | 2.89 | 5.89 | 0.28 | 9.28 | 12.28 | 0.32 | 17.78 | 0.266666667 |
| 0.44 | 1.89 | 4.89 | 0.3 | 8.89 | 11.89 | 0.53 | 15.89 | 0.423333333 |

| GlutMed1 | T1 | T2 | GlutMed2 | T1 | T2 | GlutMed3 | T1 | GlutMedAVG |
|---|---|---|---|---|---|---|---|---|
| 0.409 | 26.91 | 29.91 | 0.638 | 34.91 | 37.91 | 0.571 | 42.91 | 0.539333333 |
| 0.548 | 25.99 | 28.99 | 0.567 | 36.5 | 39.5 | 0.532 | 44.5 | 0.549 |
| 0.872 | 22.5 | 25.5 | 0.811 | 30 | 33 | 0.683 | 36.5 | 0.788666667 |
| 0.94 | 23.5 | 26.5 | 0.762 | 31 | 34 | 0.602 | 37.5 | 0.768 |
| 0.311 | 20.1 | 23.1 | 0.263 | 28.6 | 31.6 | 0.268 | 34.09 | 0.280666667 |
| 0.439 | 26.15 | 29.15 | 0.336 | 35.65 | 38.65 | 0.319 | 44.15 | 0.364666667 |
| 0.555 | 25.25 | 28.25 | 0.557 | 34.25 | 37.25 | 0.523 | 41.25 | 0.545 |
| 0.676 | 26.25 | 29.25 | 0.831 | 34.75 | 37.75 | 0.923 | 43.25 | 0.81 |
| 0.341 | 26.5 | 29.5 | 0.317 | 33.99 | 36.99 | 0.38 | 41.5 | 0.346 |
| 0.206 | 26.8 | 29.8 | 0.236 | 39.3 | 42.3 | 0.32 | 48.8 | 0.254 |
| 0.944 | 28.79 | 31.79 | 1.121 | 36.73 | 39.73 | 0.934 | 45.09 | 0.999666667 |
| 0.642 | 29.16 | 32.16 | 0.6 | 37.16 | 40.16 | 0.437 | 45.36 | 0.559666667 |
| 0.552 | 26.18 | 29.18 | 0.471 | 34.18 | 37.18 | 0.46 | 43.18 | 0.494333333 |
| 0.138 | 29.48 | 32.48 | 0.205 | 36.88 | 39.88 | 0.239 | 43.18 | 0.194 |
| 0.494 | 26.38 | 29.38 | 0.51 | 34.38 | 37.38 | 0.501 | 42.88 | 0.501666667 |
| 0.737 | 26.38 | 29.38 | 0.684 | 34.38 | 37.38 | 0.671 | 41.38 | 0.697333333 |
| 0.687 | 26.18 | 29.18 | 0.588 | 34.18 | 37.18 | 0.614 | 42.68 | 0.629666667 |
| 0.39 | 22.77 | 25.77 | 0.441 | 29.77 | 32.77 | 0.409 | 36.77 | 0.413333333 |
| 0.649 | 21.77 | 24.77 | 0.732 | 28.27 | 31.27 | 0.563 | 35.27 | 0.648 |
| 0.196 | 21.77 | 24.77 | 0.253 | 30.27 | 33.27 | 0.373 | 37.77 | 0.274 |
| 0.456 | 22.09 | 25.09 | 0.372 | 29.59 | 32.59 | 0.33 | 36.59 | 0.386 |
| 0.681 | 22.99 | 25.99 | 0.642 | 28.99 | 31.99 | 0.571 | 36.99 | 0.631333333 |
| 0.293 | 116.42 | 119.42 | 0.201 | 123.92 | 126.92 | 0.093 | 131.42 | 0.195666667 |
| 0.152 | 34.74 | 37.74 | 0.164 | 43.24 | 46.24 | 0.214 | 50.72 | 0.176666667 |
| 1.879 | 22.99 | 25.99 | 2.088 | 30.49 | 33.49 | 1.928 | 37.5 | 1.965 |
| 0.17 | 22.15 | 25.15 | 0.16 | 31.15 | 34.15 | 0.18 | 38.15 | 0.17 |
| 0.37 | 23.45 | 26.45 | 0.29 | 30.45 | 33.45 | 0.37 | 37.45 | 0.343333333 |
| 0.32 | 22.95 | 25.95 | 0.33 | 30.45 | 33.45 | 0.22 | 37.95 | 0.29 |
| 0.29 | 23.38 | 26.38 | 0.33 | 31.38 | 34.38 | 0.33 | 38.38 | 0.316666667 |
| 0.43 | 25.28 | 28.28 | 0.34 | 32.28 | 35.28 | 0.28 | 38.78 | 0.35 |
| 0.38 | 22.89 | 25.89 | 0.35 | 30.39 | 33.39 | 0.29 | 37.89 | 0.34 |

| Add1 | T1 | T2 | Add2 | T1 | T2 | Add3 | T1 | AddAVG | GMaxDecAmp1 |
|---|---|---|---|---|---|---|---|---|---|
| 0.332 | 50.4 | 53.4 | 0.373 | 56.9 | 59.9 | 0.533 | 65.4 | 0.41267 | 0.1 |
| 0.427 | 52.5 | 55.5 | 0.515 | 60.5 | 63.5 | 0.606 | 68.5 | 0.516 | 0.04 |
| 0.263 | 42.5 | 45.5 | 0.256 | 49 | 52 | 0.25 | 55.5 | 0.25633 | 0.03 |
| 0.501 | 43 | 46 | 0.453 | 49.5 | 52.5 | 0.448 | 56.5 | 0.46733 | 0.07 |
| 0.314 | 40.59 | 43.59 | 0.33 | 48.59 | 51.59 | | | 0.322 | 0.04 |
| 0.283 | 53.15 | 56.15 | 0.232 | 61.65 | 64.65 | 0.272 | 69.65 | 0.26233 | 0.06 |
| 0.356 | 48.25 | 51.25 | 0.426 | 57.25 | 60.25 | 0.314 | 64.75 | 0.36533 | 0.14 |
| 0.311 | 50.75 | 53.75 | 0.349 | 58.75 | 61.75 | 0.348 | 66.75 | 0.336 | 0.03 |
| 0.378 | 49.5 | 52.5 | 0.703 | 56.5 | 59.5 | 0.547 | 64.5 | 0.54267 | 0.05 |
| 0.175 | 58.83 | 61.83 | 0.152 | 68.33 | 71.33 | 0.168 | 75.83 | 0.165 | 0.04 |
| 0.324 | 51.59 | 54.59 | 0.477 | 58.59 | 61.59 | 0.484 | 66.09 | 0.42833 | 0.03 |
| 0.163 | 53.36 | 56.36 | 0.354 | 62.86 | 65.86 | 0.563 | 72.86 | 0.36 | 0.04 |
| 0.309 | 50.68 | 53.68 | 0.208 | 58.68 | 61.68 | 0.231 | 66.48 | 0.24933 | 0.04 |
| 0.362 | 51.68 | 54.68 | 0.42 | 59.18 | 62.18 | 0.381 | 66.48 | 0.38767 | 0.04 |
| 0.612 | 50.38 | 53.38 | 0.634 | 58.38 | 61.38 | 0.549 | 65.88 | 0.59833 | 0.06 |
| 0.478 | 49.38 | 52.38 | 0.588 | 56.88 | 59.88 | 0.587 | 63.88 | 0.551 | 0.06 |
| 0.331 | 49.68 | 52.68 | 0.255 | 57.18 | 60.18 | 0.371 | 64.18 | 0.319 | |
| 0.644 | 47.77 | 50.77 | 0.592 | 55.27 | 58.27 | 0.601 | 62.76 | 0.61233 | |
| 0.471 | 41.27 | 44.27 | 0.443 | 48.27 | 51.27 | 0.276 | 54.77 | 0.39667 | 0.03 |
| 0.429 | 43.77 | 46.77 | 0.5 | 50.27 | 53.27 | 0.593 | 56.77 | 0.50733 | 0.05 |
| 0.829 | 43.09 | 46.09 | 0.953 | 50.09 | 53.09 | 0.996 | 57.59 | 0.926 | 0.05 |
| 1.044 | 43.99 | 46.99 | 0.987 | 50.99 | 53.99 | 1.004 | 57.99 | 1.01167 | 0.08 |
| 0.693 | 137.9 | 140.9 | 0.567 | 144.9 | 147.9 | 0.583 | 152.5 | 0.61433 | 0.03 |
| 0.156 | 58.25 | 61.25 | 0.137 | 65.24 | 68.24 | 0.133 | 73.74 | 0.142 | 0.04 |
| 0.248 | 45.99 | 48.99 | 0.3 | 52.99 | 55.99 | 0.282 | 60.5 | 0.27667 | 0.06 |
| 0.21 | 45.15 | 48.15 | 0.2 | 52.65 | 55.65 | 0.18 | 60.15 | 0.19667 | 0.04378 |
| 0.25 | 44.45 | 47.45 | 0.21 | 51.45 | 54.45 | 0.31 | 58.95 | 0.25667 | 0.04598 |
| 0.54 | 44.95 | 47.95 | 0.66 | 52.45 | 55.45 | 0.64 | 59.95 | 0.61333 | 0.05065 |
| 0.29 | 45.38 | 48.38 | 0.48 | 52.88 | 55.88 | 0.47 | 59.88 | 0.41333 | 0.06411 |
| 0.35 | 47.28 | 50.28 | 0.43 | 54.28 | 57.28 | 0.5 | 61.78 | 0.42667 | 0.02558 |
| 0.23 | 45.93 | 48.93 | 0.21 | 53.48 | 56.48 | 0.15 | 62.41 | 0.19667 | 0.05139 |

| GmDecAmp1 | AddDecAmp1 | GMAscAmp1 | GmAscAmp1 | AddAscAmp1 | GMDecAmp2 |
|---|---|---|---|---|---|
| 0.06 | 0.06 | 0.07 | 0.07 | 0.05 | 0.06 |
| 0.04 | 0.04 | 0.04 | 0.03 | 0.04 | 0.06 |
| 0.47 | 0.47 | 0.03 | 0.13 | 0.04 | 0.04 |
| 0.09 | 0.09 | 0.18 | 0.09 | 0.05 | 0.06 |
| 0.03 | 0.03 | 0.09 | 0.04 | 0.05 | 0.04 |
| 0.05 | 0.05 | 0.07 | 0.09 | 0.06 | 0.04 |
| 0.12 | 0.12 | 0.08 | 0.07 | 0.05 | 0.12 |
| 0.04 | 0.04 | 0.05 | 0.07 | 0.1 | 0.04 |
| 0.04 | 0.04 | 0.08 | 0.09 | 0.06 | 0.07 |
| 0.07 | 0.07 | 0.02 | 0.03 | 0.05 | 0.05 |
| 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.03 |
| 0.04 | 0.04 | 0.07 | 0.05 | 0.07 | 0.04 |
| 0.03 | 0.03 | 0.05 | 0.04 | 0.07 | 0.05 |
| 0.03 | 0.03 | 0.08 | 0.03 | 0.11 | 0.04 |
| 0.03 | 0.03 | 0.06 | 0.03 | 0.06 | 0.06 |
| 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 |
| | | | | | |
| | | | | | |
| 0.05 | 0.05 | 0.03 | 0.05 | 0.07 | 0.03 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.5 | 0.07 |
| 0.03 | 0.03 | 0.05 | 0.03 | 0.06 | 0.05 |
| 0.05 | 0.05 | 0.08 | 0.05 | 0.015 | 0.07 |
| 0.06 | 0.06 | 0.03 | 0.06 | 0.17 | 0.04 |
| 0.05 | 0.05 | 0.04 | 0.05 | 0.12 | 0.04 |
| 0.04 | 0.04 | 0.06 | 0.04 | 0.06 | 0.06 |
| 0.03126 | 0.03126 | 0.04298 | 0.03171 | 0.09713 | 0.04857 |
| 0.04852 | 0.04852 | 0.04588 | 0.04856 | 0.08147 | 0.04327 |
| 0.05612 | 0.05612 | 0.05058 | 0.05623 | 0.08286 | 0.04936 |
| 0.08532 | 0.08532 | 0.06391 | 0.08647 | 0.10334 | 0.06213 |
| 0.05875 | 0.05875 | 0.02462 | 0.05577 | 0.06336 | 0.02808 |
| 0.11185 | 0.11185 | 0.05249 | 0.11192 | 0.009565 | 0.04807 |

| GmDecAmp2 | AddDecAmp2 | GMAscAmp2 | GmAscAmp2 | AddAscAmp2 | GMDecAmp3 |
|---|---|---|---|---|---|
| 0.07 | 0.05 | 0.05 | 0.08 | 0.06 | 0.05 |
| 0.04 | 0.04 | 0.06 | 0.04 | 0.07 | 0.05 |
| 0.69 | 0.69 | 0.04 | 1.11 | 0.07 | 0.04 |
| 0.07 | 0.07 | 0.15 | 0.07 | 0.05 | 0.07 |
| 0.03 | 0.03 | 0.08 | 0.03 | 0.06 | 0.03 |
| 0.08 | 0.08 | 0.08 | 0.1 | 0.07 | 0.04 |
| 0.11 | 0.11 | 0.09 | 0.09 | 0.05 | 0.12 |
| 0.05 | 0.05 | 0.05 | 0.08 | 0.09 | 0.04 |
| 0.04 | 0.04 | 0.08 | 0.09 | 0.06 | 0.06 |
| 0.06 | 0.06 | 0.03 | 0.05 | 0.05 | 0.04 |
| 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.03 |
| 0.05 | 0.05 | 0.08 | 0.06 | 0.07 | 0.04 |
| 0.04 | 0.04 | 0.06 | 0.04 | 0.07 | 0.05 |
| 0.03 | 0.03 | 0.09 | 0.03 | 0.09 | 0.04 |
| 0.4 | 0.04 | 0.06 | 0.04 | 0.06 | 0.06 |
| 0.05 | 0.05 | 0.05 | 0.06 | 0.05 | 0.03 |
| | | | | | |
| | | | | | |
| 0.05 | 0.05 | 0.03 | 0.05 | 0.06 | 0.04 |
| 0.06 | 0.06 | 0.07 | 0.06 | 0.05 | 0.06 |
| 0.04 | 0.04 | 0.05 | 0.04 | 0.05 | 0.05 |
| 0.06 | 0.06 | 0.07 | 0.06 | 0.018 | 0.08 |
| 0.06 | 0.06 | 0.04 | 0.06 | 0.19 | 0.04 |
| 0.04 | 0.04 | 0.04 | 0.04 | 0.11 | 0.05 |
| 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 |
| 0.04258 | 0.04258 | 0.04829 | 0.04214 | 0.11685 | 0.04992 |
| 0.04948 | 0.04948 | 0.04342 | 0.04923 | 0.08965 | 0.04115 |
| 0.05217 | 0.05217 | 0.04961 | 0.05216 | 0.08979 | 0.05329 |
| 0.09892 | 0.09892 | 0.06211 | 0.09839 | 0.11926 | 0.06444 |
| 0.05995 | 0.05995 | 0.02785 | 0.05898 | 0.06287 | 0.02653 |
| 0.11058 | 0.11058 | 0.04679 | 0.11034 | 0.08518 | 0.05407 |

| GmDecAmp3 | AddDecAmp3 | GMAscAmp3 | GmAscAmp3 | AddAscAmp3 | GMDecAmp4 |
|---|---|---|---|---|---|
| 0.07 | 0.07 | 0.04 | 0.07 | 0.05 | 0.07 |
| 0.05 | 0.05 | 0.05 | 0.06 | 0.07 | 0.05 |
| 0.14 | 0.14 | 0.05 | 0.17 | 0.05 | 0.03 |
| 0.08 | 0.08 | 0.2 | 0.09 | 0.06 | 0.06 |
| 0.06 | 0.06 | 0.09 | 0.07 | 0.08 | 0.04 |
| 0.08 | 0.08 | 0.09 | 0.1 | 0.07 | 0.06 |
| 0.1 | 0.1 | 0.08 | 0.07 | 0.05 | 0.15 |
| 0.06 | 0.06 | 0.04 | 0.08 | 0.1 | 0.04 |
| 0.04 | 0.04 | 0.09 | 0.08 | 0.06 | 0.06 |
| 0.07 | 0.7 | 0.03 | 0.04 | 0.05 | 0.06 |
| 0.04 | 0.04 | 0.05 | 0.05 | 0.04 | 0.04 |
| 0.06 | 0.06 | 0.08 | 0.06 | 0.07 | 0.04 |
| 0.04 | 0.04 | 0.05 | 0.04 | 0.06 | 0.04 |
| 0.03 | 0.03 | 0.1 | 0.03 | 0.09 | 0.04 |
| 0.04 | 0.04 | 0.06 | 0.03 | 0.07 | 0.05 |
| 0.05 | 0.05 | 0.06 | 0.08 | 0.05 | 0.03 |
| | | | | | |
| | | | | | |
| 0.05 | 0.05 | 0.04 | 0.05 | 0.07 | 0.04 |
| 0.05 | 0.05 | 0.06 | 0.05 | 0.06 | 0.07 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.05 |
| 0.05 | 0.05 | 0.08 | 0.05 | 0.16 | 0.07 |
| 0.05 | 0.05 | 0.04 | 0.05 | 0.17 | 0.04 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.17 | 0.05 |
| 0.07 | 0.07 | 0.07 | 0.07 | 0.06 | 0.1 |
| 0.03516 | 0.03516 | 0.05011 | 0.0353 | 0.08845 | 0.07649 |
| 0.0478 | 0.0478 | 0.04102 | 0.04759 | 0.07969 | 0.04368 |
| 0.06444 | 0.06444 | 0.06265 | 0.06459 | 0.08658 | 0.05538 |
| 0.09866 | 0.09866 | 0.06403 | 0.09936 | 0.12706 | 0.06453 |
| 0.05682 | 0.05682 | 0.0263 | 0.05709 | 0.06567 | 0.02872 |
| 0.11078 | 0.11078 | 0.05418 | 0.11088 | 0.09993 | 0.05769 |

| GmDecAmp4 | AddDecAmp4 | GMAscAmp4 | GmAscAmp4 | AddAscAmp4 | GMDecAmp5 |
|---|---|---|---|---|---|
| 0.07 | 0.07 | 0.05 | 0.06 | 0.06 | 0.09 |
| 0.05 | 0.05 | 0.06 | 0.05 | 0.08 | 0.07 |
| 0.3 | 0.3 | 0.04 | 0.43 | 0.06 | 0.04 |
| 0.09 | 0.09 | 0.17 | 0.08 | 0.05 | 0.06 |
| 0.04 | 0.04 | 0.08 | 0.05 | 0.06 | 0.05 |
| 0.08 | 0.08 | 0.08 | 0.12 | 0.06 | 0.05 |
| 0.12 | 0.12 | 0.08 | 0.07 | 0.04 | 0.1 |
| 0.05 | 0.05 | 0.05 | 0.08 | 0.11 | 0.04 |
| 0.05 | 0.05 | 0.07 | 0.08 | 0.06 | 0.06 |
| 0.08 | 0.08 | 0.03 | 0.04 | 0.05 | 0.5 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 |
| 0.05 | 0.05 | 0.09 | 0.07 | 0.09 | 0.05 |
| 0.04 | 0.04 | 0.06 | 0.04 | 0.06 | 0.04 |
| 0.02 | 0.02 | 0.1 | 0.03 | 0.11 | 0.04 |
| 0.03 | 0.03 | 0.05 | 0.08 | 0.07 | 0.05 |
| 0.04 | 0.04 | 0.06 | 0.07 | 0.05 | 0.03 |
| | | | | | |
| | | | | | |
| 0.05 | 0.05 | 0.03 | 0.04 | 0.07 | 0.04 |
| 0.05 | 0.05 | 0.07 | 0.05 | 0.06 | 0.08 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.07 | 0.05 |
| 0.06 | 0.06 | 0.07 | 0.05 | 0.17 | 0.06 |
| 0.05 | 0.05 | 0.04 | 0.05 | 0.18 | 0.04 |
| 0.06 | 0.06 | 0.05 | 0.06 | 0.15 | 0.05 |
| 0.09 | 0.09 | 0.1 | 0.09 | 0.07 | 0.07 |
| 0.05763 | 0.05736 | 0.08034 | 0.05718 | 0.09661 | 0.0598 |
| 0.04582 | 0.04582 | 0.04309 | 0.04507 | 0.08115 | 0.04533 |
| 0.06387 | 0.06387 | 0.05597 | 0.06564 | 0.083 | 0.06581 |
| 0.10838 | 0.10832 | 0.06465 | 0.10746 | 0.011638 | 0.06866 |
| 0.05742 | 0.05742 | 0.02901 | 0.05846 | 0.07349 | 0.02581 |
| 0.11272 | 0.11272 | 0.05533 | 0.11293 | 0.09435 | 0.04425 |

| GmDAmp5 | AddDAmp5 | GMAAmp5 | GmAAmp5 | AddAAmp5 | GMDAmpAVG |
|---|---|---|---|---|---|
| 0.06 | 0.06 | 0.08 | 0.06 | 0.05 | 0.074 |
| 0.04 | 0.04 | 0.07 | 0.05 | 0.07 | 0.054 |
| 0.14 | 0.14 | 0.04 | 0.16 | 0.05 | 0.036 |
| 0.09 | 0.09 | 0.19 | 0.09 | 0.05 | 0.064 |
| 0.04 | 0.4 | 0.06 | 0.04 | 0.05 | 0.04 |
| 0.09 | 0.09 | 0.09 | 0.09 | 0.06 | 0.05 |
| 0.12 | 0.12 | 0.08 | 0.06 | 0.04 | 0.126 |
| 0.07 | 0.07 | 0.04 | 0.11 | 0.12 | 0.038 |
| 0.04 | 0.04 | 0.07 | 0.06 | 0.06 | 0.06 |
| 0.06 | 0.06 | 0.04 | 0.05 | 0.05 | 0.138 |
| 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.034 |
| 0.07 | 0.07 | 0.1 | 0.07 | 0.08 | 0.042 |
| 0.04 | 0.04 | 0.08 | 0.04 | 0.06 | 0.044 |
| 0.02 | 0.02 | 0.1 | 0.03 | 0.1 | 0.04 |
| 0.03 | 0.03 | 0.05 | 0.08 | 0.07 | 0.056 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.04 |
| | | | | | 0 |
| | | | | | 0 |
| 0.05 | 0.05 | 0.04 | 0.05 | 0.06 | 0.036 |
| 0.05 | 0.05 | 0.08 | 0.05 | 0.05 | 0.066 |
| 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.05 |
| 0.05 | 0.05 | 0.06 | 0.05 | 0.16 | 0.072 |
| 0.06 | 0.06 | 0.04 | 0.06 | 0.2 | 0.038 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.13 | 0.046 |
| 0.06 | 0.06 | 0.07 | 0.06 | 0.07 | 0.072 |
| 0.0408 | 0.0408 | 0.05934 | 0.04108 | 0.08328 | 0.055712 |
| 0.05675 | 0.05675 | 0.04539 | 0.05607 | 0.08619 | 0.043882 |
| 0.05994 | 0.05994 | 0.0667 | 0.0619 | 0.08267 | 0.054898 |
| 0.11466 | 0.11466 | 0.06867 | 0.11413 | 0.1045 | 0.064774 |
| 0.05647 | 0.05647 | 0.02589 | 0.05688 | 0.07069 | 0.026944 |
| 0.10953 | 0.10953 | 0.04372 | 0.10998 | 0.8704 | 0.051094 |

| GMDesAmpNorm | GmDesAmpAVG | GmDesAmpNorm | ADesAmpAVG | ADesAmpNorm |
|---|---|---|---|---|
| 10.16018307 | 0.066 | 12.23733004 | 0.062 | 15.02423263 |
| 10.84337349 | 0.044 | 8.014571949 | 0.044 | 8.527131783 |
| 2.922077922 | 0.348 | 44.12510566 | 0.348 | 135.7607282 |
| 5.143316368 | 0.084 | 10.9375 | 0.084 | 17.9743224 |
| 19.26163724 | 0.04 | 14.25178147 | 0.112 | 34.7826087 |
| 7.974481659 | 0.076 | 20.84095064 | 0.076 | 28.9707751 |
| 14.42748092 | 0.114 | 20.91743119 | 0.114 | 31.20437956 |
| 4.69328942 | 0.054 | 6.666666667 | 0.054 | 16.07142857 |
| 6.149641271 | 0.042 | 12.13872832 | 0.042 | 7.73955774 |
| 55.27369826 | 0.068 | 26.77165354 | 0.194 | 117.5757576 |
| 3.920061491 | 0.044 | 4.401467156 | 0.044 | 10.27237354 |
| 6.572769953 | 0.054 | 9.648600357 | 0.054 | 15 |
| 9.698750918 | 0.038 | 7.687120701 | 0.038 | 15.24064171 |
| 6.191950464 | 0.026 | 13.40206186 | 0.026 | 6.706792777 |
| 5.669929126 | 0.106 | 21.12956811 | 0.034 | 5.682451253 |
| 6.841505131 | 0.046 | 6.596558317 | 0.046 | 8.34845735 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 2.673267327 | 0.05 | 7.716049383 | 0.05 | 12.60504202 |
| 12.03647416 | 0.052 | 18.97810219 | 0.052 | 10.24967148 |
| 9.096422074 | 0.044 | 11.39896373 | 0.044 | 4.75161987 |
| 11.67567568 | 0.054 | 8.553326294 | 0.054 | 5.337726524 |
| 4.479371316 | 0.056 | 28.62010221 | 0.056 | 9.115572436 |
| 12.70718232 | 0.05 | 28.30188679 | 0.05 | 35.21126761 |
| 4.746209624 | 0.064 | 3.256997455 | 0.064 | 23.13253012 |
| 22.2848 | 0.041486 | 24.40352941 | 0.041432 | 21.06711864 |
| 20.25323077 | 0.049674 | 14.46815534 | 0.049674 | 19.35350649 |
| 14.32121739 | 0.059308 | 20.45103448 | 0.059308 | 9.669782609 |
| 11.36385965 | 0.101188 | 31.95410526 | 0.101176 | 24.47806452 |
| 10.104 | 0.057882 | 16.53771429 | 0.057882 | 13.56609375 |
| 12.06944882 | 0.111092 | 32.67411765 | 0.111092 | 56.48745763 |

| GMAscAmpAVG | GMAscAmpNorm | GmAscAmpAVG | GmAscAmpNorm | AddAAmpAVG |
|---|---|---|---|---|
| 0.058 | 7.963386728 | 0.068 | 12.60815822 | 0.054 |
| 0.056 | 11.24497992 | 0.046 | 8.378870674 | 0.066 |
| 0.04 | 3.246753247 | 0.4 | 50.71851226 | 0.054 |
| 0.178 | 14.30484865 | 0.084 | 10.9375 | 0.052 |
| 0.08 | 38.52327448 | 0.046 | 16.38954869 | 0.06 |
| 0.082 | 13.07814992 | 0.1 | 27.42230347 | 0.064 |
| 0.082 | 9.389312977 | 0.072 | 13.21100917 | 0.046 |
| 0.046 | 5.68135035 | 0.084 | 10.37037037 | 0.104 |
| 0.078 | 7.994533652 | 0.08 | 23.12138728 | 0.06 |
| 0.03 | 12.01602136 | 0.042 | 16.53543307 | 0.05 |
| 0.044 | 5.073020753 | 0.044 | 4.401467156 | 0.04 |
| 0.084 | 13.14553991 | 0.062 | 11.07802263 | 0.076 |
| 0.06 | 13.22556943 | 0.04 | 8.091706001 | 0.064 |
| 0.094 | 14.55108359 | 0.03 | 15.46391753 | 0.1 |
| 0.056 | 5.669929126 | 0.052 | 10.3654485 | 0.066 |
| 0.054 | 9.236031927 | 0.062 | 8.891013384 | 0.052 |
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 |
| 0.034 | 2.524752475 | 0.048 | 7.407407407 | 0.066 |
| 0.066 | 12.03647416 | 0.052 | 18.97810219 | 0.144 |
| 0.05 | 9.096422074 | 0.046 | 11.91709845 | 0.06 |
| 0.072 | 11.67567568 | 0.052 | 8.236536431 | 0.1046 |
| 0.038 | 4.479371316 | 0.056 | 28.62010221 | 0.182 |
| 0.046 | 12.70718232 | 0.05 | 28.30188679 | 0.136 |
| 0.072 | 4.746209624 | 0.066 | 3.358778626 | 0.066 |
| 0.056212 | 22.4848 | 0.041482 | 24.40117647 | 0.096464 |
| 0.04376 | 20.19692308 | 0.049304 | 14.36038835 | 0.08363 |
| 0.057102 | 14.89617391 | 0.060104 | 20.72551724 | 0.08498 |
| 0.064674 | 11.34631579 | 0.101162 | 31.94589474 | 0.0931596 |
| 0.026734 | 10.02525 | 0.057436 | 16.41028571 | 0.067216 |
| 0.050502 | 11.9296063 | 0.11121 | 32.70882353 | 0.231885 |

| AddAscAmpNorm | GMaxDecAmp1board | GMedDecAmp1board | AddDecAmp1board |
|---|---|---|---|
| 13.08562197 | | | |
| 12.79069767 | | | |
| 21.0663199 | | | |
| 11.12696148 | | | |
| 18.63354037 | | | |
| 24.39644219 | | | |
| 12.59124088 | | | |
| 30.95238095 | | | |
| 11.05651106 | | | |
| 30.3030303 | | | |
| 9.338521401 | | | |
| 21.11111111 | | | |
| 25.6684492 | | | |
| 25.79535684 | | | |
| 11.03064067 | | | |
| 9.43738657 | | | |
| 0 | | | |
| 0 | 0.06 | 0.07 | 0.07 |
| 16.63865546 | 0.03 | 0.05 | 0.05 |
| 28.38370565 | 0.06 | 0.05 | 0.05 |
| 6.479481641 | 0.05 | 0.03 | 0.03 |
| 10.33937397 | 0.06 | 0.06 | 0.06 |
| 29.62561042 | 0.04 | 0.04 | 0.04 |
| 95.77464789 | 0.04 | 0.04 | 0.04 |
| 23.85542169 | 0.09 | 0.09 | 0.09 |
| 49.04949153 | 0.04033 | 0.03527 | 0.03527 |
| 32.58311688 | 0.04026 | 0.05816 | 0.05816 |
| 13.85543478 | 0.05102 | 0.05213 | 0.05213 |
| 22.5386129 | 0.08254 | 0.07655 | 0.07655 |
| 15.75375 | 0.02713 | 0.05337 | 0.05337 |
| 117.9076271 | 0.03356 | 0.1032 | 0.1032 |

| GMaxAscAmp1board | GmedAscAmp1board | AddAscAmp1board | GMaxDecAmp2board |
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| 0.06 | 0.06 | 0.09 | 0.07 |
| 0.03 | 0.05 | 0.06 | 0.03 |
| 0.06 | 0.05 | 0.05 | 0.09 |
| 0.05 | 0.03 | 0.05 | 0.04 |
| 0.05 | 0.06 | 0.17 | 0.05 |
| 0.04 | 0.04 | 0.11 | 0.04 |
| 0.05 | 0.07 | 0.11 | 0.05 |
| 0.09 | 0.09 | 0.07 | 0.05 |
| 0.04059 | 0.03548 | 0.08776 | 0.04304 |
| 0.03981 | 0.05612 | 0.06958 | 0.0385 |
| 0.05158 | 0.05162 | 0.08114 | 0.05037 |
| 0.08306 | 0.07663 | 0.09325 | 0.08231 |
| 0.10029 | 0.11744 | 0.11024 | 0.02447 |
| 0.05893 | 0.10929 | 0.11087 | 0.03253 |

| GMedDecAmp2board | AddDecAmp2board | GMaxAscAmp2board | GmedAscAmp2board |
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| 0.06 | 0.06 | 0.07 | 0.06 |
| 0.04 | 0.04 | 0.03 | 0.04 |
| 0.05 | 0.05 | 0.09 | 0.05 |
| 0.03 | 0.03 | 0.04 | 0.03 |
| 0.04 | 0.04 | 0.05 | 0.06 |
| 0.05 | 0.05 | 0.04 | 0.05 |
| 0.04 | 0.04 | 0.05 | 0.07 |
| 0.04 | 0.04 | 0.06 | 0.04 |
| 0.0412 | 0.0412 | 0.04315 | 0.04224 |
| 0.04213 | 0.04213 | 0.0377 | 0.04273 |
| 0.05418 | 0.05418 | 0.05254 | 0.05248 |
| 0.07551 | 0.07551 | 0.08221 | 0.07471 |
| 0.0456 | 0.0456 | 0.09466 | 0.14922 |
| 0.10295 | 0.10295 | 0.07195 | 0.11029 |

| AddAscAmp2board | GMaxDecAmp3board | GMedDecAmp3board | AddDecAmp3board |
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| 0.11 | 0.08 | 0.08 | 0.08 |
| 0.06 | 0.03 | 0.05 | 0.05 |
| 0.05 | 0.07 | 0.05 | 0.05 |
| 0.06 | 0.05 | 0.04 | 0.04 |
| 0.16 | 0.05 | 0.04 | 0.04 |
| 0.11 | 0.04 | 0.05 | 0.05 |
| 0.1 | 0.05 | 0.06 | 0.06 |
| 0.07 | 0.06 | 0.07 | 0.07 |
| 0.08517 | 0.03964 | 0.03314 | 0.03314 |
| 0.08318 | 0.03782 | 0.04375 | 0.04375 |
| 0.08426 | 0.05036 | 0.05712 | 0.05712 |
| 0.08877 | 0.08067 | 0.09252 | 0.09252 |
| 0.10953 | 0.02599 | 0.0934 | 0.0934 |
| 0.10861 | 0.03789 | 0.1044 | 0.1044 |

| GMaxAscAmp3board | GmedAscAmp3board | AddAscAmp3board | GMaxDecAmp4board |
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| 0.07 | 0.07 | 0.1 | 0.07 |
| 0.03 | 0.04 | 0.07 | 0.04 |
| 0.07 | 0.05 | 0.05 | 0.07 |
| 0.05 | 0.03 | 0.06 | 0.04 |
| 0.05 | 0.04 | 0.17 | 0.06 |
| 0.04 | 0.05 | 0.11 | 0.05 |
| 0.05 | 0.09 | 0.13 | 0.06 |
| 0.06 | 0.07 | 0.06 | 0.05 |
| 0.03976 | 0.03346 | 0.0985 | 0.04706 |
| 0.03758 | 0.04288 | 0.07859 | 0.04223 |
| 0.05073 | 0.05704 | 0.07964 | 0.05012 |
| 0.08054 | 0.09386 | 0.09584 | 0.07995 |
| 0.08698 | 0.07034 | 0.12315 | 0.03011 |
| 0.0573 | 0.11398 | 0.1271 | 0.0361 |

| GMedDecAmp4board | AddDecAmp4board | GMaxAscAmp4board | GmedAscAmp4board |
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| 0.08 | 0.08 | 0.07 | 0.07 |
| 0.05 | 0.05 | 0.04 | 0.04 |
| 0.05 | 0.05 | 0.07 | 0.05 |
| 0.05 | 0.05 | 0.04 | 0.05 |
| 0.05 | 0.05 | 0.06 | 0.05 |
| 0.05 | 0.05 | 0.05 | 0.05 |
| 0.05 | 0.05 | 0.05 | 0.04 |
| 0.04 | 0.04 | 0.05 | 0.04 |
| 0.03675 | 0.03675 | 0.04728 | 0.03642 |
| 0.04386 | 0.04386 | 0.04208 | 0.04374 |
| 0.0612 | 0.0612 | 0.05077 | 0.06178 |
| 0.10412 | 0.10412 | 0.07993 | 0.10381 |
| 0.06504 | 0.06504 | 0.09777 | 0.17195 |
| 0.10571 | 0.10571 | 0.05177 | 0.11099 |

| AddAscAmp4board | GMaxDecAmp5board | GMedDecAmp5board | AddDecAmp5board |
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| 0.1 | 0.09 | 0.09 | 0.09 |
| 0.06 | 0.04 | 0.05 | 0.05 |
| 0.05 | 0.08 | 0.05 | 0.05 |
| 0.06 | 0.04 | 0.04 | 0.04 |
| 0.17 | 0.05 | 0.04 | 0.04 |
| 0.11 | 0.04 | 0.06 | 0.06 |
| 0.1 | 0.07 | 0.09 | 0.09 |
| 0.07 | 0.04 | 0.04 | 0.04 |
| 0.09227 | 0.03685 | 0.03567 | 0.03567 |
| 0.0738 | 0.04285 | 0.05165 | 0.05165 |
| 0.0855 | 0.05551 | 0.0675 | 0.0675 |
| 0.11181 | 0.08049 | 0.09635 | 0.09635 |
| 0.12495 | 0.02556 | 0.06581 | 0.06581 |
| 0.10791 | 0.03357 | 0.10842 | 0.10842 |

| GMaxAscAmp5board | GmedAscAmp5board | AddAscAmp5board | GMaxDesAmpboardAVG |
|---|---|---|---|
| | | | 0 |
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| | | | 0 |
| | | | 0 |
| | | | 0 |
| 0.09 | 0.09 | 0.11 | 0.074 |
| 0.04 | 0.05 | 0.06 | 0.034 |
| 0.08 | 0.05 | 0.05 | 0.074 |
| 0.04 | 0.04 | 0.06 | 0.044 |
| 0.05 | 0.04 | 0.19 | 0.054 |
| 0.04 | 0.06 | 0.12 | 0.042 |
| 0.05 | 0.07 | 0.12 | 0.054 |
| 0.04 | 0.04 | 0.06 | 0.058 |
| 0.03668 | 0.03598 | 0.08394 | 0.041384 |
| 0.04304 | 0.05108 | 0.07584 | 0.040332 |
| 0.05568 | 0.06892 | 0.08807 | 0.051476 |
| 0.08086 | 0.09831 | 0.10614 | 0.081192 |
| 0.10143 | 0.14447 | 0.14844 | 0.026652 |
| 0.09279 | 0.11802 | 0.12539 | 0.03473 |

| GMaxDesAmpboardNorm | GMedDesAmpboardAVG | GMedDesAmpboardNorm |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 13.90977444 | 0.076 | 18.38709677 |
| 2.524752475 | 0.048 | 7.407407407 |
| 13.49544073 | 0.05 | 18.24817518 |
| 8.004851425 | 0.038 | 9.844559585 |
| 8.756756757 | 0.046 | 7.286166843 |
| 4.950884086 | 0.05 | 25.55366269 |
| 14.91712707 | 0.056 | 31.69811321 |
| 3.823335531 | 0.056 | 2.849872774 |
| 16.5536 | 0.036406 | 21.41529412 |
| 18.61476923 | 0.04791 | 13.95436893 |
| 13.42852174 | 0.058426 | 20.14689655 |
| 14.24421053 | 0.08901 | 28.10842105 |
| 9.9945 | 0.064644 | 18.46971429 |
| 8.203937008 | 0.104936 | 30.86352941 |

| AddDesAmpboardAVG | AddDesAmpboardNorm | GMaxAscAmpboardAVG |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0.076 | 12.41154056 | 0.072 |
| 0.048 | 12.10084034 | 0.034 |
| 0.05 | 9.855453351 | 0.074 |
| 0.038 | 4.103671706 | 0.044 |
| 0.046 | 4.546952224 | 0.052 |
| 0.05 | 8.138903961 | 0.042 |
| 0.056 | 39.43661972 | 0.05 |
| 0.056 | 20.24096386 | 0.06 |
| 0.036406 | 18.51152542 | 0.041492 |
| 0.04791 | 18.66623377 | 0.040042 |
| 0.058426 | 9.525978261 | 0.05226 |
| 0.08901 | 21.53467742 | 0.08132 |
| 0.064644 | 15.1509375 | 0.096226 |
| 0.104936 | 53.35728814 | 0.066548 |

| GMaxAscAmpboardNorm | GMedAscAmpboardAVG | GMedAscAmpboardNorm |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
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| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 13.53383459 | 0.07 | 16.93548387 |
| 2.524752475 | 0.044 | 6.790123457 |
| 13.49544073 | 0.05 | 18.24817518 |
| 8.004851425 | 0.036 | 9.32642487 |
| 8.432432432 | 0.05 | 7.919746568 |
| 4.950884086 | 0.05 | 25.55366269 |
| 13.8121547 | 0.068 | 38.49056604 |
| 3.955174687 | 0.056 | 2.849872774 |
| 16.5968 | 0.036716 | 21.59764706 |
| 18.48092308 | 0.04731 | 13.77961165 |
| 13.63304348 | 0.058368 | 20.12689655 |
| 14.26666667 | 0.089464 | 28.25178947 |
| 36.08475 | 0.130684 | 37.33828571 |
| 15.72 | 0.112514 | 33.09235294 |

| AddAscAmpboardAVG | AddAscAmpboardNorm | ERConPkTq | ERConPkTqNorm |
|---|---|---|---|
| 0 | 0 | 31.7667 | 0.32415 |
| 0 | 0 | 32.1 | 0.324242424 |
| 0 | 0 | 30.067 | 0.455560606 |
| 0 | 0 | 24.733 | 0.313075949 |
| 0 | 0 | 16.267 | 0.275711864 |
| 0 | 0 | 13.167 | 0.243833333 |
| 0 | 0 | 18.467 | 0.302737705 |
| 0 | 0 | 20.633 | 0.322390625 |
| 0 | 0 | 19.933 | 0.36912963 |
| 0 | 0 | 17.467 | 0.226844156 |
| 0 | 0 | 21.467 | 0.271734177 |
| 0 | 0 | 12.067 | 0.188546875 |
| 0 | 0 | 20.933 | 0.486813953 |
| 0 | 0 | 31 | 0.360465116 |
| 0 | 0 | 16.633 | 0.281915254 |
| 0 | 0 | 17.733 | 0.268681818 |
| 0 | 0 | 25.767 | 0.34356 |
| 0.102 | 16.6575939 | 17.533 | 0.28742623 |
| 0.062 | 15.6302521 | 19.567 | 0.320770492 |
| 0.05 | 9.855453351 | 20.7 | 0.339344262 |
| 0.058 | 6.26349892 | 13.933 | 0.258018519 |
| 0.172 | 17.00164745 | 32.767 | 0.511984375 |
| 0.112 | 18.23114487 | 2.0333 | 0.033332787 |
| 0.112 | 78.87323944 | 12.567 | 0.206016393 |
| 0.066 | 23.85542169 | 31.367 | 0.429684932 |
| 0.089528 | 45.52271186 | 6.8 | 0.119298246 |
| 0.076198 | 29.68753247 | 14.5 | 0.172619048 |
| 0.083722 | 13.65032609 | 8.0667 | 0.136723729 |
| 0.099162 | 23.99080645 | 21.633 | 0.273835443 |
| 0.123262 | 28.88953125 | 37.2 | 0.442857143 |
| 0.115976 | 58.97084746 | 17.4 | 0.271875 |

| ERConAngPkTq | ERConTmPkTq | EREccPkTq | EREccPkTqNorm | EREccAngPkTq |
|---|---|---|---|---|
| 14 | 3 | 56.9 | 0.580612245 | 13.6667 |
| 15 | 1.3333 | 60.733 | 0.613464646 | 15 |
| 14.667 | 2.6667 | 53.6 | 0.812121212 | 14.667 |
| 15 | 2.6667 | 51.9 | 0.656962025 | 15 |
| 15 | 1.6667 | 18.767 | 0.318084746 | 14.667 |
| 15 | 1.6667 | 26.7 | 0.494444444 | 14.667 |
| 12 | 2.6667 | 40.333 | 0.661196721 | 12 |
| 14 | 3.6667 | 48.267 | 0.754171875 | 14 |
| 15 | 3 | 31 | 0.574074074 | 15 |
| 15 | 5.3333 | 32.767 | 0.425545455 | 15 |
| 12.667 | 6.3333 | 58.7 | 0.743037975 | 14 |
| 13.667 | 4 | 35 | 0.546875 | 14.333 |
| 15 | 1.3333 | 34.4 | 0.8 | 14 |
| 12 | 6.3333 | 33.167 | 0.385662791 | 13.667 |
| 14.667 | 2.3333 | 39.733 | 0.673440678 | 14.333 |
| 13 | 5.3333 | 35.6 | 0.539393939 | 13.333 |
| 14 | 3.6667 | 53.167 | 0.708893333 | 14.333 |
| 15 | 1 | 39.8 | 0.652459016 | 15 |
| 14.333 | 2 | 42.167 | 0.691262295 | 12.667 |
| 13.667 | 3.6667 | 30.333 | 0.497262295 | 13 |
| 14.667 | 3.3333 | 34.567 | 0.64012963 | 13 |
| 13 | 3 | 13.067 | 0.204171875 | 13.333 |
| 14.667 | 3.6667 | 24.933 | 0.408737705 | 15 |
| 15 | 1.6667 | 29.233 | 0.479229508 | 15 |
| 14.333 | 3.6667 | 55.2 | 0.756164384 | 15 |
| 13.667 | 4 | 27.633 | 0.484789474 | 14.667 |
| 9 | 1.3333 | 42.467 | 0.505559524 | 9 |
| 10.667 | 8 | 12.067 | 0.204525424 | 12.667 |
| 13.667 | 2.6667 | 45.733 | 0.578898734 | 14 |
| 6 | 1 | 94.333 | 1.123011905 | 4.6667 |
| 14.333 | 2.6667 | 36.467 | 0.569796875 | 14 |

| EREccTmPkTq | IRConPkTq | IRConPkTqNorm | IRConAngPkTq | IRConTmPkTq |
|---|---|---|---|---|
| 4.3333 | 30.067 | 0.306806122 | 1 | 2 |
| 2.6667 | 89.3 | 0.902020202 | 6 | 1.6667 |
| 2.3333 | 85.1 | 1.289393939 | 5 | 1.6667 |
| 2.3333 | 55.3 | 0.7 | 5 | 3.3333 |
| 6 | 24.167 | 0.409610169 | 5 | 1.6667 |
| 4.3333 | 52.367 | 0.969759259 | 6 | 2.3333 |
| 2.6667 | 31.433 | 0.515295082 | 2 | 4 |
| 2 | 74.867 | 1.169796875 | 5 | 1.3333 |
| 1 | 49.733 | 0.920981481 | 3 | 3.3333 |
| 3.3333 | 37.333 | 0.484844156 | 5 | 1 |
| 4 | 49.233 | 0.623202532 | 5 | 1 |
| 2.6667 | 57.667 | 0.901046875 | 4 | 1.3333 |
|  | 54.3 | 1.262790698 | 5 | 3 |
| 4 | 51.067 | 0.593802326 | 5 | 1 |
| 2.6667 | 47.533 | 0.805644068 | 5 | 2.3333 |
| 4.6667 | 53.033 | 0.803530303 | 5 | 3.6667 |
| 2.6667 | 78 | 1.04 | 5 | 4.3333 |
| 1.3333 | 52.7 | 0.863934426 | 5 | 3.3333 |
| 4.6667 | 62.9 | 1.031147541 | 5 | 2 |
| 5.6667 | 40.8 | 0.668852459 | 5 | 1 |
| 6.6667 | 33.567 | 0.621611111 | 6 | 3.6667 |
| 2.6667 | 65.133 | 1.017703125 | 5 | 2 |
| 2 | 57.1 | 0.936065574 | 4 | 4.6667 |
| 1.6667 | 26.4 | 0.432786885 | 5 | 2 |
| 2 | 84.933 | 1.163465753 | 5 | 3.3333 |
| 1.6667 | 50.767 | 0.890649123 | 5 | 4 |
| 1.3333 | 70.1 | 0.83452381 | 5 | 4.3333 |
| 5.3333 | 39.4 | 0.66779661 | 5 | 3.3333 |
| 1.3333 | 44.4 | 0.562025316 | 4 | 3 |
| 3.3333 | 66.133 | 0.787297619 | 5 | 5.3333 |
| 4 | 49.8 | 0.778125 | 5 | 3 |

| IREcPkTq | IREcPkTqNorm | IREcAngPkTq | IREcTmPkTq | ExtCoPkTq | ExtCoPkTqNorm |
|---|---|---|---|---|---|
| 26.367 | 0.26905102 | 1 | 3.3333 | 81.867 | 0.835377551 |
| 63.333 | 0.639727273 | 6 | 1 | 204.7 | 2.067676768 |
| 50.067 | 0.758590909 | 5 | 1.3333 | 79.433 | 1.203530303 |
| 29 | 0.367088608 | 5 |  | 88.067 | 1.114772152 |
| 17.2 | 0.291525424 | 5 | 1 | 69.867 | 1.184186441 |
| 29.567 | 0.547537037 | 6 | 3 | 78.833 | 1.45987037 |
| 14.867 | 0.243721311 | 2 | 4.6667 | 38.967 | 0.638803279 |
| 35.567 | 0.555734375 | 5 | 4 | 135.97 | 2.12453125 |
| 31.6 | 0.585185185 | 3 | 2.6667 | 113.07 | 2.093888889 |
| 23.733 | 0.308220779 | 5 | 4.6667 | 54.767 | 0.71125974 |
| 25.7 | 0.325316456 | 5 | 2 | 120.33 | 1.523164557 |
| 23.8 | 0.371875 | 4 | 1.3333 | 95.867 | 1.497921875 |
| 31.6 | 0.734883721 | 4.6667 | 3.6667 | 37.867 | 0.880627907 |
| 10.167 | 0.11822093 | 5 | 4.3333 | 129.2 | 1.502325581 |
| 26.2 | 0.444067797 | 5 | 3 | 26.433 | 0.448016949 |
| 28.733 | 0.435348485 | 5 |  | 55.333 | 0.838378788 |
| 41.533 | 0.553773333 | 5 | 1.3333 | 124.4 | 1.658666667 |
| 25.267 | 0.414213115 | 5 | 4 | 85.867 | 1.407655738 |
| 38.3 | 0.627868852 | 5 | 1.6667 | 40.167 | 0.65847541 |
| 27.4 | 0.449180328 | 5 | 5 | 75.967 | 1.245360656 |
| 18.833 | 0.348759259 | 6 | 1.3333 | 54.933 | 1.017277778 |
| 43.133 | 0.673953125 | 5 | 2 | 100.43 | 1.56921875 |
| 9.7 | 0.159016393 | 3 | 8.6667 | 51.767 | 0.848639344 |
| 6.3 | 0.103278689 | 5 | 2 | 110.3 | 1.808196721 |
| 56.9 | 0.779452055 | 5 | 1 | 134.9 | 1.847945205 |
| 22.533 | 0.395315789 | 5 | 2 | 49.633 | 0.870754386 |
| 32.7 | 0.389285714 | 5 | 1 | 114.47 | 1.362738095 |
| 23.667 | 0.401135593 | 5 | 3 | 60.767 | 1.029949153 |
| 19.5 | 0.246835443 | 4 | 5 | 47.533 | 0.601683544 |
| 45 | 0.535714286 | 5 | 2.3333 | 154.33 | 1.837261905 |
| 29.8 | 0.465625 | 5 | 1 | 84.233 | 1.316140625 |

| ExCoAngPkTq | ExCoTmPkTq | ExEcPkTq | ExEcPkTqNorm | ExEcAngPkTq | ExEcTmPkTq |
|---|---|---|---|---|---|
| 39 | 2.6667 | 62.7 | 0.639795918 | 39 | 2 |
| 0 | 4.3333 | 126 | 1.272727273 | 0 | 1 |
| 0.66667 | 3.3333 | 49.033 | 0.742924242 | 0 | 1 |
| 40 | 4 | 38.967 | 0.493253165 | 40 | 3.6667 |
| 1.6667 | 3.6667 | 54.467 | 0.923169492 | 1.3333 | 3.6667 |
| -1 | 4.6667 | 39.833 | 0.737648148 | 1 | 1.6667 |
| 1.6667 | 4 | 32.2 | 0.527868852 | 0 | 1 |
| 0 | 2.3333 | 18.6 | 0.290625 | 0.33333 | 4 |
| 0 | 3.3333 | 101.77 | 1.88462963 | 0 | 4.3333 |
| 0 | 3 | 21.767 | 0.282688312 | 0 | 1 |
| 0 | 4.6667 | 92.8 | 1.174683544 | 0 | 1 |
| 40 | 6.6667 | 43.067 | 0.672921875 | 40 | 1 |
| 1 | 3 | 56 | 1.302325581 | 0.33333 | 2 |
| 39 | 6 | 48.867 | 0.56822093 | 39 | 1 |
| 1.6667 | 9.3333 | 53.567 | 0.907915254 | 0.66667 | 6.3333 |
| 2.6667 | 5.3333 | 28.967 | 0.438893939 | 3.6667 | 7 |
| 3.3333 | 6 | 63.433 | 0.845773333 | 0 | 1 |
| 2 | 5.6667 | 44.9 | 0.736065574 | 0.66667 | 2.3333 |
| 40 | 6.6667 | 81.1 | 1.329508197 | 40 | 4.3333 |
| 31 | 3 | 47.967 | 0.786344262 | 31 | 1 |
| 39 | 4.6667 | 41.6 | 0.77037037 | 39 | 3 |
| 0.33333 | 6.3333 | 56.067 | 0.876046875 | 0.33333 | 4.3333 |
| 1 | 2 | 61.9 | 1.014754098 | 1 | 1.6667 |
| 40 | 3.3333 | 33.967 | 0.556836066 | 40 | 3.3333 |
| 2 | 4 | 88.4 | 1.210958904 | 2 | 3 |
| 40 | 6.6667 | 17.733 | 0.311105263 | 40 | 8.3333 |
| 1 | 6 | 42.267 | 0.503178571 | 1 | 3 |
| 2 | 6 | 9.8 | 0.166101695 | 0 | |
| 4 | 6.6667 | 31.867 | 0.403379747 | 1 | 1 |
| 40.333 | 3.3333 | 81.3 | 0.967857143 | 39.667 | 4.6667 |
| 0 | 4.3333 | 37.867 | 0.591671875 | 0 | 3 |

| AbCoPkTq | AbCoPkTqNorm | AbCoAngPkTq | AbCoTmPkTq | AbEcPkTq | AbEcPkTqNorm |
|---|---|---|---|---|---|
| 54.3667 | 0.554762245 | 0 | 3.3333 | 45.1667 | 0.460884694 |
| 38.9 | 0.392929293 | 0 | 1 | 41.933 | 0.423565657 |
| 35.833 | 0.542924242 | 0 | 1 | 56.5 | 0.856060606 |
| 37.8 | 0.478481013 | 0 | 1 | 41.767 | 0.528696203 |
| 21.1 | 0.357627119 | 0 | 1 | 7.1667 | 0.121469492 |
| 32.1 | 0.594444444 | 0 | 1.6667 | 39.067 | 0.723462963 |
| 20.267 | 0.332245902 | 0 | 1 | 8.1667 | 0.133880328 |
| 39.733 | 0.620828125 | 0 | 1 | 64.2 | 1.003125 |
| 23.967 | 0.443833333 | 0 | 1 | 30.6 | 0.566666667 |
| 18.033 | 0.234194805 | 0 | 1 | 27.3 | 0.354545455 |
| 52.667 | 0.666670886 | 0 | 1 | 56.5 | 0.715189873 |
| 11.567 | 0.180734375 | 0 | 1 | 36.6 | 0.571875 |
| 28.033 | 0.651930233 | 0 | 1 | 24.233 | 0.56355814 |
| 4.6667 | 0.054263953 | 0 | 1 | 38.633 | 0.44922093 |
| 25.933 | 0.439542373 | 0 | 1 | 2.9333 | 0.049716949 |
| 21.533 | 0.326257576 | 0 | 1 | 15 | 0.227272727 |
| 43.467 | 0.57956 | 0 | 1 | 66.733 | 0.889773333 |
| 32.967 | 0.540442623 | 0 | 1 | 47.667 | 0.78142623 |
| 32.467 | 0.532245902 | 0 | 1 | 42.033 | 0.689065574 |
| 30.667 | 0.502737705 | -1 | 1 | 37.7 | 0.618032787 |
| 16.533 | 0.306166667 | -1 | 1 | 18.933 | 0.350611111 |
| 25.167 | 0.393234375 | 0 | 2.6667 | 37.1 | 0.5796875 |
| 9.8667 | 0.16174918 | 0 | 1 | 6.9667 | 0.114208197 |
| 14.767 | 0.242081967 | -1 | 1 | 50.833 | 0.833327869 |
| 27.467 | 0.376260274 | -1.6667 | 3 | 36.033 | 0.49360274 |
| 7.2333 | 0.1269 | -0.66667 | 2.6667 | 28.4 | 0.498245614 |
| 26.3 | 0.313095238 | -1 | 1 | 53.8 | 0.64047619 |
| 14.333 | 0.242932203 | 0 | 1.3333 | 24.667 | 0.418084746 |
| 13 | 0.164556962 | -1 | 1.3333 | 9.2667 | 0.1173 |
| 38.233 | 0.455154762 | -0.33333 | 2 | 43.7 | 0.520238095 |
| 13.933 | 0.217703125 | -1 | 2.6667 | 23.2 | 0.3625 |

| AbEccAngPkTq | AbEccTmPkTq |
|---|---|
| 0 | 2.3333 |
| 0 | 1 |
| -1.6667 | 4 |
| 0 | 2 |
| 0 | 3.6667 |
| 0 | 1.3333 |
| 0 | 3.6667 |
| 0 | 2.3333 |
| 0 | 2.6667 |
| -0.33333 | 2 |
| 0 | 2.6667 |
| 0 | 1 |
| -1.3333 | 4.3333 |
| 0 | 1 |
| -0.66667 | 6 |
| -0.33333 | 2 |
| -0.66667 | 4.3333 |
| -0.66667 | 4 |
| -1.6667 | 4 |
| -2 | 3.6667 |
| -1.6667 | 4 |
| 0 | 2.6667 |
| -0.66667 | 4.3333 |
| -2 | 4 |
| -1 | 1 |
| -1.6667 | 5 |
| -2.6667 | 4.6667 |
| 0 | 1.6667 |
| -1 | 2.6667 |
| 0 | 1.6667 |
| -1.3333 | 3.6667 |

# APPENDIX G: SPSS OUTPUTS

# General Linear Model

**Within-Subjects Factors**

Measure: MEASURE_1

| muscle | Dependent Variable |
|---|---|
| 1 | GastAVG |
| 2 | SolAVG |

**Between-Subjects Factors**

| | | Value Label | N |
|---|---|---|---|
| Group | 1.0000 | Normal | 14 |
| | 2.0000 | Valgus | 14 |

**Descriptive Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| GastAVG | Normal | 17.880952 | 7.9255156 | 14 |
| | Valgus | 13.428571 | 7.8451123 | 14 |
| | Total | 15.654762 | 8.0632694 | 28 |
| SolAVG | Normal | 19.857143 | 8.3724357 | 14 |
| | Valgus | 19.880952 | 8.3692632 | 14 |
| | Total | 19.869048 | 8.2143803 | 28 |

**Multivariate Tests[c]**

| Effect | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| muscle | Pillai's Trace | .704 | 61.695[b] | 1.000 | 26.000 | .000 | .704 | 61.695 | 1.000 |
| | Wilks' Lambda | .296 | 61.695[b] | 1.000 | 26.000 | .000 | .704 | 61.695 | 1.000 |
| | Hotelling's Trace | 2.373 | 61.695[b] | 1.000 | 26.000 | .000 | .704 | 61.695 | 1.000 |
| | Roy's Largest Ro | 2.373 | 61.695[b] | 1.000 | 26.000 | .000 | .704 | 61.695 | 1.000 |
| muscle * Grou | Pillai's Trace | .401 | 17.400[b] | 1.000 | 26.000 | .000 | .401 | 17.400 | .980 |
| | Wilks' Lambda | .599 | 17.400[b] | 1.000 | 26.000 | .000 | .401 | 17.400 | .980 |
| | Hotelling's Trace | .669 | 17.400[b] | 1.000 | 26.000 | .000 | .401 | 17.400 | .980 |
| | Roy's Largest Ro | .669 | 17.400[b] | 1.000 | 26.000 | .000 | .401 | 17.400 | .980 |

a. Computed using alpha = .05

b. Exact statistic

c.
Design: Intercept+Group
Within Subjects Design: muscle

**Mauchly's Test of Sphericity[b]**

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[a] Greenhouse-Geisser | Epsilon[a] Huynh-Feldt | Epsilon[a] Lower-bound |
|---|---|---|---|---|---|---|---|
| muscle | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are display the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Group
Within Subjects Design: muscle

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| muscle | Sphericity Assumed | 248.643 | 1 | 248.643 | 61.695 | .000 | .704 | 61.695 | 1.000 |
| | Greenhouse-Geisse | 248.643 | 1.000 | 248.643 | 61.695 | .000 | .704 | 61.695 | 1.000 |
| | Huynh-Feldt | 248.643 | 1.000 | 248.643 | 61.695 | .000 | .704 | 61.695 | 1.000 |
| | Lower-bound | 248.643 | 1.000 | 248.643 | 61.695 | .000 | .704 | 61.695 | 1.000 |
| muscle * Group | Sphericity Assumed | 70.127 | 1 | 70.127 | 17.400 | .000 | .401 | 17.400 | .980 |
| | Greenhouse-Geisse | 70.127 | 1.000 | 70.127 | 17.400 | .000 | .401 | 17.400 | .980 |
| | Huynh-Feldt | 70.127 | 1.000 | 70.127 | 17.400 | .000 | .401 | 17.400 | .980 |
| | Lower-bound | 70.127 | 1.000 | 70.127 | 17.400 | .000 | .401 | 17.400 | .980 |
| Error(muscle) | Sphericity Assumed | 104.786 | 26 | 4.030 | | | | | |
| | Greenhouse-Geisse | 104.786 | 26.000 | 4.030 | | | | | |
| | Huynh-Feldt | 104.786 | 26.000 | 4.030 | | | | | |
| | Lower-bound | 104.786 | 26.000 | 4.030 | | | | | |

a. Computed using alpha = .05

**Tests of Within-Subjects Contrasts**

Measure: MEASURE_1

| Source | muscle | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| muscle | Linear | 248.643 | 1 | 248.643 | 61.695 | .000 | .704 | 61.695 | 1.000 |
| muscle * Group | Linear | 70.127 | 1 | 70.127 | 17.400 | .000 | .401 | 17.400 | .980 |
| Error(muscle) | Linear | 104.786 | 26 | 4.030 | | | | | |

a. Computed using alpha = .05

**Tests of Between-Subjects Effects**

Measure: MEASURE_1
Transformed Variable: Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|
| Intercept | 17667.175 | 1 | 17667.175 | 137.787 | .000 | .841 | 137.787 | 1.000 |
| Group | 68.643 | 1 | 68.643 | .535 | .471 | .020 | .535 | .109 |
| Error | 3333.738 | 26 | 128.221 | | | | | |

a. Computed using alpha = .05

# Estimated Marginal Means

**1. Grand Mean**

Measure: MEASURE_1

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| 17.762 | 1.513 | 14.652 | 20.872 |

**2. Group**

Measure: MEASURE_1

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Normal | 18.869 | 2.140 | 14.470 | 23.268 |
| Valgus | 16.655 | 2.140 | 12.256 | 21.053 |

**3. muscle**

Measure: MEASURE_1

| muscle | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 15.655 | 1.490 | 12.592 | 18.718 |
| 2 | 19.869 | 1.582 | 16.617 | 23.121 |

**4. Group * muscle**

Measure: MEASURE_1

| Group | muscle | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Normal | 1 | 17.881 | 2.107 | 13.549 | 22.213 |
| | 2 | 19.857 | 2.237 | 15.259 | 24.456 |
| Valgus | 1 | 13.429 | 2.107 | 9.097 | 17.761 |
| | 2 | 19.881 | 2.237 | 15.282 | 24.480 |

# Oneway

**Descriptives**

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound | | |
| HipERAVG | Normal | 17 | 3.921569 | 17.5144898 | .2478877 | 64.916449 | 82.926688 | 42.6667 | 107.0000 |
| | Valgus | 14 | 4.428571 | 7.0169862 | .8753684 | 70.377084 | 78.480059 | 63.3333 | 86.0000 |
| | Total | 31 | 4.150538 | 13.6016989 | .4429372 | 69.161394 | 79.139681 | 42.6667 | 107.0000 |
| HipABAVG | Normal | 17 | 6.882353 | 5.3384626 | .2947674 | 34.137569 | 39.627137 | 24.3333 | 45.0000 |
| | Valgus | 14 | 5.285714 | 3.9696652 | .0609376 | 32.993698 | 37.577731 | 31.3333 | 44.6667 |
| | Total | 31 | 6.161290 | 4.7624076 | .8553536 | 34.414425 | 37.908156 | 24.3333 | 45.0000 |

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| HipERAVG | Between Groups | 1.973 | 1 | 1.973 | .010 | .920 |
| | Within Groups | 5548.213 | 29 | 191.318 | | |
| | Total | 5550.186 | 30 | | | |
| HipABAVG | Between Groups | 19.572 | 1 | 19.572 | .859 | .362 |
| | Within Groups | 660.844 | 29 | 22.788 | | |
| | Total | 680.416 | 30 | | | |

# T-Test

**Group Statistics**

| | Group | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| HipABAVG | Normal | 17 | 36.882353 | 5.3384626 | 1.2947674 |
| | Valgus | 14 | 35.285714 | 3.9696652 | 1.0609376 |
| HipERAVG | Normal | 17 | 73.921569 | 17.5144898 | 4.2478877 |
| | Valgus | 14 | 74.428571 | 7.0169862 | 1.8753684 |
| GastAVG | Normal | 14 | 17.880952 | 7.9255156 | 2.1181831 |
| | Valgus | 14 | 13.428571 | 7.8451123 | 2.0966945 |
| SolAVG | Normal | 14 | 19.857143 | 8.3724357 | 2.2376276 |
| | Valgus | 14 | 19.880952 | 8.3692632 | 2.2367797 |

**Independent Samples Test**

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Confidence Interval of the Difference | |
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| HipABAV( | Equal variances assumed | 1.031 | .318 | .927 | 29 | .362 | .5966387 | .7228318 | -1.92695 | 1202252 |
| | Equal variances not assumed | | | .954 | 28.748 | .348 | .5966387 | .6739209 | -1.82822 | 0214957 |
| HipERAV( | Equal variances assumed | 6.408 | .017 | -.102 | 29 | .920 | -.5070028 | .9919466 | -10.7167 | 7026743 |
| | Equal variances not assumed | | | -.109 | 21.824 | .914 | -.5070028 | .6434424 | -10.1414 | 1274008 |
| GastAVG | Equal variances assumed | .093 | .763 | 1.494 | 26 | .147 | .4523810 | .9804073 | -1.67393 | 10.57870 |
| | Equal variances not assumed | | | 1.494 | 25.997 | .147 | .4523810 | .9804073 | -1.67396 | 10.57873 |
| SolAVG | Equal variances assumed | .399 | .533 | -.008 | 26 | .994 | -.0238095 | .1638838 | -6.52727 | 4796467 |
| | Equal variances not assumed | | | -.008 | 26.000 | .994 | -.0238095 | .1638838 | -6.52727 | 4796467 |

# T-Test

**Paired Samples Statistics**

| | | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Pair 1 | GastAVG | 13.428571 | 14 | 7.8451123 | 2.0966945 |
| | SolAVG | 19.880952 | 14 | 8.3692632 | 2.2367797 |

**Paired Samples Correlations**

| | | N | Correlation | Sig. |
|---|---|---|---|---|
| Pair 1 | GastAVG & SolAVG | 14 | .930 | .000 |

**Paired Samples Test**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference Lower | Upper | | | |
| Pair 1 | GastAVG - SolA | -6.45238 | 3.0734795 | .8214219 | -8.22696 | -4.67781 | -7.855 | 13 | .000 |

# Oneway

**Descriptives**

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound | | |
| ERConPkTqNorm | Normal | 17 | .315258 | .0753943 | .0182858 | .276494 | .354023 | .1885 | .4868 |
| | Valgus | 14 | .271699 | .1335344 | .0356886 | .194599 | .348799 | .0333 | .5120 |
| | Total | 31 | .295586 | .1060385 | .0190451 | .256691 | .334482 | .0333 | .5120 |
| EREccPkTqNorm | Normal | 17 | .605175 | .1431187 | .0347114 | .531590 | .678760 | .3181 | .8121 |
| | Valgus | 14 | .556857 | .2291982 | .0612558 | .424522 | .689192 | .2042 | 1.1230 |
| | Total | 31 | .583354 | .1851635 | .0332563 | .515436 | .651273 | .2042 | 1.1230 |
| IRConPkTqNorm | Normal | 17 | .805796 | .2927646 | .0710058 | .655270 | .956321 | .3068 | 1.2894 |
| | Valgus | 14 | .803999 | .2006404 | .0536234 | .688153 | .919845 | .4328 | 1.1635 |
| | Total | 31 | .804984 | .2513124 | .0451370 | .712802 | .897166 | .3068 | 1.2894 |
| IREccPkTqNorm | Normal | 17 | .444110 | .1804319 | .0437612 | .351340 | .536879 | .1182 | .7586 |
| | Valgus | 14 | .427831 | .1876576 | .0501536 | .319481 | .536181 | .1033 | .7795 |
| | Total | 31 | .436758 | .1808061 | .0324737 | .370438 | .503078 | .1033 | .7795 |
| ExtConPkTqNorm | Normal | 17 | 1.281353 | .5213672 | .1264501 | 1.013291 | 1.549415 | .4480 | 2.1245 |
| | Valgus | 14 | 1.244378 | .4238226 | .1132714 | .999670 | 1.489086 | .6017 | 1.8479 |
| | Total | 31 | 1.264655 | .4723985 | .0848453 | 1.091378 | 1.437932 | .4480 | 2.1245 |
| ExtEccPkTqNorm | Normal | 17 | .806239 | .4145150 | .1005347 | .593115 | 1.019363 | .2827 | 1.8846 |
| | Valgus | 14 | .730298 | .3345796 | .0894202 | .537118 | .923479 | .1661 | 1.3295 |
| | Total | 31 | .771943 | .3763289 | .0675907 | .633905 | .909982 | .1661 | 1.8846 |
| AbConPkTqNorm | Normal | 17 | .438308 | .1749017 | .0424199 | .348381 | .528234 | .0543 | .6667 |
| | Valgus | 14 | .326804 | .1420702 | .0379699 | .244775 | .408833 | .1269 | .5404 |
| | Total | 31 | .387951 | .1680570 | .0301839 | .326308 | .449595 | .0543 | .6667 |
| AbEccPkTqNorm | Normal | 17 | .508174 | .2769238 | .0671639 | .365793 | .650555 | .0497 | 1.0031 |
| | Valgus | 14 | .501200 | .2165695 | .0578806 | .376157 | .626244 | .1142 | .8333 |
| | Total | 31 | .505025 | .2474600 | .0444451 | .414256 | .595794 | .0497 | 1.0031 |

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| ERConPkTqNorm | Between Groups | .015 | 1 | .015 | 1.309 | .262 |
| | Within Groups | .323 | 29 | .011 | | |
| | Total | .337 | 30 | | | |
| EREccPkTqNorm | Between Groups | .018 | 1 | .018 | .514 | .479 |
| | Within Groups | 1.011 | 29 | .035 | | |
| | Total | 1.029 | 30 | | | |
| IRConPkTqNorm | Between Groups | .000 | 1 | .000 | .000 | .985 |
| | Within Groups | 1.895 | 29 | .065 | | |
| | Total | 1.895 | 30 | | | |
| IREccPkTqNorm | Between Groups | .002 | 1 | .002 | .060 | .808 |
| | Within Groups | .979 | 29 | .034 | | |
| | Total | .981 | 30 | | | |
| ExtConPkTqNorm | Between Groups | .010 | 1 | .010 | .046 | .833 |
| | Within Groups | 6.684 | 29 | .230 | | |
| | Total | 6.695 | 30 | | | |
| ExtEccPkTqNorm | Between Groups | .044 | 1 | .044 | .305 | .585 |
| | Within Groups | 4.204 | 29 | .145 | | |
| | Total | 4.249 | 30 | | | |
| AbConPkTqNorm | Between Groups | .095 | 1 | .095 | 3.682 | .065 |
| | Within Groups | .752 | 29 | .026 | | |
| | Total | .847 | 30 | | | |
| AbEccPkTqNorm | Between Groups | .000 | 1 | .000 | .006 | .939 |
| | Within Groups | 1.837 | 29 | .063 | | |
| | Total | 1.837 | 30 | | | |

## Oneway

**Descriptives**

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound | | |
| ERConTmPkT | Normal | 17 | 3.352941 | 1.6349808 | .3965411 | 2.512312 | 4.193571 | 1.3333 | 6.3333 |
| | Valgus | 14 | 2.976200 | 1.7805440 | .4758704 | 1.948144 | 4.004256 | 1.0000 | 8.0000 |
| | Total | 31 | 3.182800 | 1.6839899 | .3024535 | 2.565107 | 3.800493 | 1.0000 | 8.0000 |
| EREccTmPkT | Normal | 16 | 3.229169 | 1.2395829 | .3098957 | 2.568642 | 3.889696 | 1.0000 | 6.0000 |
| | Valgus | 14 | 3.119050 | 1.8332602 | .4899594 | 2.060557 | 4.177543 | 1.3333 | 6.6667 |
| | Total | 30 | 3.177780 | 1.5180521 | .2771571 | 2.610930 | 3.744630 | 1.0000 | 6.6667 |
| IRConTmPkTc | Normal | 17 | 2.294112 | 1.1110650 | .2694729 | 1.722855 | 2.865369 | 1.0000 | 4.3333 |
| | Valgus | 14 | 3.214279 | 1.1810949 | .3156609 | 2.532335 | 3.896222 | 1.0000 | 5.3333 |
| | Total | 31 | 2.709671 | 1.2163714 | .2184668 | 2.263502 | 3.155840 | 1.0000 | 5.3333 |
| IREccTmPkTq | Normal | 15 | 2.755553 | 1.3479478 | .3480386 | 2.009085 | 3.502022 | 1.0000 | 4.6667 |
| | Valgus | 14 | 2.857143 | 2.1630790 | .5781072 | 1.608218 | 4.106068 | 1.0000 | 8.6667 |
| | Total | 29 | 2.804597 | 1.7559904 | .3260792 | 2.136654 | 3.472540 | 1.0000 | 8.6667 |
| ExtConTmPkT | Normal | 17 | 4.490194 | 1.7642959 | .4279046 | 3.583077 | 5.397311 | 2.3333 | 9.3333 |
| | Valgus | 14 | 4.904764 | 1.5821169 | .4228385 | 3.991277 | 5.818251 | 2.0000 | 6.6667 |
| | Total | 31 | 4.677419 | 1.6699658 | .2999347 | 4.064871 | 5.289968 | 2.0000 | 9.3333 |
| ExtEccTmPkT | Normal | 17 | 2.509806 | 1.9759540 | .4792392 | 1.493864 | 3.525748 | 1.0000 | 7.0000 |
| | Valgus | 13 | 3.307685 | 1.9122394 | .5303598 | 2.152130 | 4.463239 | 1.0000 | 8.3333 |
| | Total | 30 | 2.855553 | 1.9567736 | .3572563 | 2.124882 | 3.586225 | 1.0000 | 8.3333 |
| AbConTmPkT | Normal | 17 | 1.176471 | .5787576 | .1403693 | .878901 | 1.474040 | 1.0000 | 3.3333 |
| | Valgus | 14 | 1.619050 | .7937605 | .2121414 | 1.160746 | 2.077354 | 1.0000 | 3.0000 |
| | Total | 31 | 1.376345 | .7083765 | .1272282 | 1.116511 | 1.636180 | 1.0000 | 3.3333 |
| AbEccTmPkTc | Normal | 17 | 2.725488 | 1.4153696 | .3432775 | 1.997772 | 3.453204 | 1.0000 | 6.0000 |
| | Valgus | 14 | 3.357157 | 1.2227414 | .3267914 | 2.651167 | 4.063147 | 1.0000 | 5.0000 |
| | Total | 31 | 3.010758 | 1.3484797 | .2421941 | 2.516132 | 3.505384 | 1.0000 | 6.0000 |

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| ERConTmPkTq | Between Groups | 1.090 | 1 | 1.090 | .376 | .544 |
| | Within Groups | 83.985 | 29 | 2.896 | | |
| | Total | 85.075 | 30 | | | |
| EREccTmPkTq | Between Groups | .091 | 1 | .091 | .038 | .847 |
| | Within Groups | 66.739 | 28 | 2.384 | | |
| | Total | 66.830 | 29 | | | |
| IRConTmPkTq | Between Groups | 6.501 | 1 | 6.501 | 4.976 | .034 |
| | Within Groups | 37.886 | 29 | 1.306 | | |
| | Total | 44.387 | 30 | | | |
| IREccTmPkTq | Between Groups | .075 | 1 | .075 | .023 | .880 |
| | Within Groups | 86.263 | 27 | 3.195 | | |
| | Total | 86.338 | 28 | | | |
| ExtConTmPkTq | Between Groups | 1.320 | 1 | 1.320 | .465 | .501 |
| | Within Groups | 82.344 | 29 | 2.839 | | |
| | Total | 83.664 | 30 | | | |
| ExtEccTmPkTq | Between Groups | 4.690 | 1 | 4.690 | 1.235 | .276 |
| | Within Groups | 106.350 | 28 | 3.798 | | |
| | Total | 111.040 | 29 | | | |
| AbConTmPkTq | Between Groups | 1.504 | 1 | 1.504 | 3.218 | .083 |
| | Within Groups | 13.550 | 29 | .467 | | |
| | Total | 15.054 | 30 | | | |
| AbEccTmPkTq | Between Groups | 3.063 | 1 | 3.063 | 1.725 | .199 |
| | Within Groups | 51.489 | 29 | 1.775 | | |
| | Total | 54.552 | 30 | | | |

# General Linear Model

**Within-Subjects Factors**

Measure: MEASURE_1

| phase | Dependent Variable |
|---|---|
| 1 | GMaxDes AmpNorm |
| 2 | GMaxAsc AmpNorm |

**Between-Subjects Factors**

| | | Value Label | N |
|---|---|---|---|
| Group | 1.0000 | Normal | 16 |
| | 2.0000 | Valgus | 13 |

**Descriptive Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| GMaxDesAmpNorm | Normal | 10.984009 | 12.5250030 | 16 |
| | Valgus | 11.370089 | 5.6519150 | 13 |
| | Total | 11.157080 | 9.8878250 | 29 |
| GMaxAscAmpNorm | Normal | 11.521487 | 8.0315153 | 16 |
| | Valgus | 11.395781 | 5.7234116 | 13 |
| | Total | 11.465136 | 6.9713218 | 29 |

**Multivariate Tests[c]**

| Effect | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Pillai's Trace | .001 | .024[b] | 1.000 | 27.000 | .877 | .001 | .024 | .053 |
| | Wilks' Lambda | .999 | .024[b] | 1.000 | 27.000 | .877 | .001 | .024 | .053 |
| | Hotelling's Trac | .001 | .024[b] | 1.000 | 27.000 | .877 | .001 | .024 | .053 |
| | Roy's Largest R | .001 | .024[b] | 1.000 | 27.000 | .877 | .001 | .024 | .053 |
| phase * Grou | Pillai's Trace | .001 | .020[b] | 1.000 | 27.000 | .888 | .001 | .020 | .052 |
| | Wilks' Lambda | .999 | .020[b] | 1.000 | 27.000 | .888 | .001 | .020 | .052 |
| | Hotelling's Trac | .001 | .020[b] | 1.000 | 27.000 | .888 | .001 | .020 | .052 |
| | Roy's Largest R | .001 | .020[b] | 1.000 | 27.000 | .888 | .001 | .020 | .052 |

a. Computed using alpha = .05

b. Exact statistic

c.
Design: Intercept+Group
Within Subjects Design: phase

**Mauchly's Test of Sphericity[b]**

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[a] | | |
|---|---|---|---|---|---|---|---|
| | | | | | Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Group
Within Subjects Design: phase

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Sphericity Assumed | 1.137 | 1 | 1.137 | .024 | .877 | .001 | .024 | .053 |
| | Greenhouse-Geisser | 1.137 | 1.000 | 1.137 | .024 | .877 | .001 | .024 | .053 |
| | Huynh-Feldt | 1.137 | 1.000 | 1.137 | .024 | .877 | .001 | .024 | .053 |
| | Lower-bound | 1.137 | 1.000 | 1.137 | .024 | .877 | .001 | .024 | .053 |
| phase * Group | Sphericity Assumed | .939 | 1 | .939 | .020 | .888 | .001 | .020 | .052 |
| | Greenhouse-Geisser | .939 | 1.000 | .939 | .020 | .888 | .001 | .020 | .052 |
| | Huynh-Feldt | .939 | 1.000 | .939 | .020 | .888 | .001 | .020 | .052 |
| | Lower-bound | .939 | 1.000 | .939 | .020 | .888 | .001 | .020 | .052 |
| Error(phase) | Sphericity Assumed | 1257.722 | 27 | 46.582 | | | | | |
| | Greenhouse-Geisser | 1257.722 | 27.000 | 46.582 | | | | | |
| | Huynh-Feldt | 1257.722 | 27.000 | 46.582 | | | | | |
| | Lower-bound | 1257.722 | 27.000 | 46.582 | | | | | |

a. Computed using alpha = .05

**Tests of Within-Subjects Contrasts**

Measure: MEASURE_1

| Source | phase | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Linear | 1.137 | 1 | 1.137 | .024 | .877 | .001 | .024 | .053 |
| phase * Group | Linear | .939 | 1 | .939 | .020 | .888 | .001 | .020 | .052 |
| Error(phase) | Linear | 1257.722 | 27 | 46.582 | | | | | |

a. Computed using alpha = .05

**Tests of Between-Subjects Effects**

Measure: MEASURE_1

Transformed Variable: Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|
| Intercept | 7349.919 | 1 | 7349.919 | 69.890 | .000 | .721 | 69.890 | 1.000 |
| Group | .243 | 1 | .243 | .002 | .962 | .000 | .002 | .050 |
| Error | 2839.411 | 27 | 105.163 | | | | | |

a. Computed using alpha = .05

# Estimated Marginal Means

**1. Grand Mean**

Measure: MEASURE_1

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| 11.318 | 1.354 | 8.540 | 14.096 |

**2. Group**

Measure: MEASURE_1

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Normal | 11.253 | 1.813 | 7.533 | 14.972 |
| Valgus | 11.383 | 2.011 | 7.256 | 15.509 |

**3. phase**

Measure: MEASURE_1

| phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 11.177 | 1.880 | 7.321 | 15.034 |
| 2 | 11.459 | 1.325 | 8.739 | 14.178 |

**4. Group * phase**

Measure: MEASURE_1

| Group | phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Normal | 1 | 10.984 | 2.517 | 5.820 | 16.148 |
| | 2 | 11.521 | 1.775 | 7.880 | 15.163 |
| Valgus | 1 | 11.370 | 2.792 | 5.641 | 17.099 |
| | 2 | 11.396 | 1.969 | 7.356 | 15.436 |

# General Linear Model

**Within-Subjects Factors**

Measure: MEASURE_1

| phase | Dependent Variable |
|---|---|
| 1 | GMedDes AmpNorm |
| 2 | GMedAsc AmpNorm |

**Between-Subjects Factors**

| | | Value Label | N |
|---|---|---|---|
| Group | 1.0000 | Normal | 16 |
| | 2.0000 | Valgus | 13 |

**Descriptive Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| GMedDesAmpNorm | Normal | 14.985443 | 10.0408630 | 16 |
| | Valgus | 19.024160 | 9.7204132 | 13 |
| | Total | 16.795903 | 9.9339103 | 29 |
| GMedAscAmpNorm | Normal | 15.499042 | 11.0197818 | 16 |
| | Valgus | 19.028615 | 9.7469128 | 13 |
| | Total | 17.081264 | 10.4384500 | 29 |

**Multivariate Tests[c]**

| Effect | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Pillai's Trace | .004 | .101[b] | 1.000 | 27.000 | .753 | .004 | .101 | .061 |
| | Wilks' Lambda | .996 | .101[b] | 1.000 | 27.000 | .753 | .004 | .101 | .061 |
| | Hotelling's Trace | .004 | .101[b] | 1.000 | 27.000 | .753 | .004 | .101 | .061 |
| | Roy's Largest R | .004 | .101[b] | 1.000 | 27.000 | .753 | .004 | .101 | .061 |
| phase * Grou | Pillai's Trace | .004 | .098[b] | 1.000 | 27.000 | .757 | .004 | .098 | .060 |
| | Wilks' Lambda | .996 | .098[b] | 1.000 | 27.000 | .757 | .004 | .098 | .060 |
| | Hotelling's Trace | .004 | .098[b] | 1.000 | 27.000 | .757 | .004 | .098 | .060 |
| | Roy's Largest R | .004 | .098[b] | 1.000 | 27.000 | .757 | .004 | .098 | .060 |

a. Computed using alpha = .05

b. Exact statistic

c.
Design: Intercept+Group
Within Subjects Design: phase

**Mauchly's Test of Sphericity[b]**

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[a] | | |
|---|---|---|---|---|---|---|---|
| | | | | | Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Group
Within Subjects Design: phase

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Sphericity Assumed | .962 | 1 | .962 | .101 | .753 | .004 | .101 | .061 |
| | Greenhouse-Geisser | .962 | 1.000 | .962 | .101 | .753 | .004 | .101 | .061 |
| | Huynh-Feldt | .962 | 1.000 | .962 | .101 | .753 | .004 | .101 | .061 |
| | Lower-bound | .962 | 1.000 | .962 | .101 | .753 | .004 | .101 | .061 |
| phase * Group | Sphericity Assumed | .930 | 1 | .930 | .098 | .757 | .004 | .098 | .060 |
| | Greenhouse-Geisser | .930 | 1.000 | .930 | .098 | .757 | .004 | .098 | .060 |
| | Huynh-Feldt | .930 | 1.000 | .930 | .098 | .757 | .004 | .098 | .060 |
| | Lower-bound | .930 | 1.000 | .930 | .098 | .757 | .004 | .098 | .060 |
| Error(phase) | Sphericity Assumed | 257.040 | 27 | 9.520 | | | | | |
| | Greenhouse-Geisser | 257.040 | 27.000 | 9.520 | | | | | |
| | Huynh-Feldt | 257.040 | 27.000 | 9.520 | | | | | |
| | Lower-bound | 257.040 | 27.000 | 9.520 | | | | | |

a. Computed using alpha = .05

**Tests of Within-Subjects Contrasts**

Measure: MEASURE_1

| Source | phase | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Linear | .962 | 1 | .962 | .101 | .753 | .004 | .101 | .061 |
| phase * Group | Linear | .930 | 1 | .930 | .098 | .757 | .004 | .098 | .060 |
| Error(phase) | Linear | 257.040 | 27 | 9.520 | | | | | |

a. Computed using alpha = .05

**Tests of Between-Subjects Effects**

Measure: MEASURE_1

Transformed Variable: Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|
| Intercept | 16845.691 | 1 | 16845.691 | 85.005 | .000 | .759 | 85.005 | 1.000 |
| Group | 205.414 | 1 | 205.414 | 1.037 | .318 | .037 | 1.037 | .166 |
| Error | 5350.643 | 27 | 198.172 | | | | | |

a. Computed using alpha = .05

# Estimated Marginal Means

**1. Grand Mean**

Measure: MEASURE_1

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| 17.134 | 1.858 | 13.321 | 20.947 |

**2. Group**

Measure: MEASURE_1

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Normal | 15.242 | 2.489 | 10.136 | 20.348 |
| Valgus | 19.026 | 2.761 | 13.362 | 24.691 |

**3. phase**

Measure: MEASURE_1

| phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 17.005 | 1.848 | 13.213 | 20.797 |
| 2 | 17.264 | 1.955 | 13.252 | 21.276 |

**4. Group * phase**

Measure: MEASURE_1

| Group | phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Normal | 1 | 14.985 | 2.475 | 9.907 | 20.064 |
| | 2 | 15.499 | 2.618 | 10.127 | 20.871 |
| Valgus | 1 | 19.024 | 2.746 | 13.390 | 24.658 |
| | 2 | 19.029 | 2.905 | 13.069 | 24.989 |

# General Linear Model

**Within-Subjects Factors**

Measure: MEASURE_1

| phase | Dependent Variable |
|---|---|
| 1 | AddDes AmpNorm |
| 2 | AddAsc AmpNorm |

**Between-Subjects Factors**

| | | Value Label | N |
|---|---|---|---|
| Group | 1.0000 | Normal | 16 |
| | 2.0000 | Valgus | 13 |

**Descriptive Statistics**

| | Group | Mean | Std. Deviation | N |
|---|---|---|---|---|
| AddDesAmpNorm | Normal | 29.680102 | 39.0152292 | 16 |
| | Valgus | 18.848112 | 14.2616026 | 13 |
| | Total | 24.824383 | 30.5398423 | 29 |
| AddAscAmpNorm | Normal | 18.024013 | 7.6244966 | 16 |
| | Valgus | 35.598841 | 33.7813601 | 13 |
| | Total | 25.902384 | 24.4814316 | 29 |

**Multivariate Tests[c]**

| Effect | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Pillai's Trace | .007 | .196[b] | 1.000 | 27.000 | .661 | .007 | .196 | .071 |
| | Wilks' Lambda | .993 | .196[b] | 1.000 | 27.000 | .661 | .007 | .196 | .071 |
| | Hotelling's Trac | .007 | .196[b] | 1.000 | 27.000 | .661 | .007 | .196 | .071 |
| | Roy's Largest R | .007 | .196[b] | 1.000 | 27.000 | .661 | .007 | .196 | .071 |
| phase * Grou | Pillai's Trace | .184 | 6.095[b] | 1.000 | 27.000 | .020 | .184 | 6.095 | .663 |
| | Wilks' Lambda | .816 | 6.095[b] | 1.000 | 27.000 | .020 | .184 | 6.095 | .663 |
| | Hotelling's Trac | .226 | 6.095[b] | 1.000 | 27.000 | .020 | .184 | 6.095 | .663 |
| | Roy's Largest R | .226 | 6.095[b] | 1.000 | 27.000 | .020 | .184 | 6.095 | .663 |

a. Computed using alpha = .05

b. Exact statistic

c.
Design: Intercept+Group
Within Subjects Design: phase

**Mauchly's Test of Sphericity**[b]

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[a] | | |
|---|---|---|---|---|---|---|---|
| | | | | | Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displ the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Group
Within Subjects Design: phase

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Sphericity Assume | 93.081 | 1 | 93.081 | .196 | .661 | .007 | .196 | .071 |
| | Greenhouse-Geis | 93.081 | 1.000 | 93.081 | .196 | .661 | .007 | .196 | .071 |
| | Huynh-Feldt | 93.081 | 1.000 | 93.081 | .196 | .661 | .007 | .196 | .071 |
| | Lower-bound | 93.081 | 1.000 | 93.081 | .196 | .661 | .007 | .196 | .071 |
| phase * Grou | Sphericity Assume | 2893.880 | 1 | 2893.880 | 6.095 | .020 | .184 | 6.095 | .663 |
| | Greenhouse-Geis | 2893.880 | 1.000 | 2893.880 | 6.095 | .020 | .184 | 6.095 | .663 |
| | Huynh-Feldt | 2893.880 | 1.000 | 2893.880 | 6.095 | .020 | .184 | 6.095 | .663 |
| | Lower-bound | 2893.880 | 1.000 | 2893.880 | 6.095 | .020 | .184 | 6.095 | .663 |
| Error(phase) | Sphericity Assume | 12819.595 | 27 | 474.800 | | | | | |
| | Greenhouse-Geis | 12819.595 | 27.000 | 474.800 | | | | | |
| | Huynh-Feldt | 12819.595 | 27.000 | 474.800 | | | | | |
| | Lower-bound | 12819.595 | 27.000 | 474.800 | | | | | |

a. Computed using alpha = .05

**Tests of Within-Subjects Contrasts**

Measure: MEASURE_1

| Source | phase | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| phase | Linear | 93.081 | 1 | 93.081 | .196 | .661 | .007 | .196 | .071 |
| phase * Grou | Linear | 2893.880 | 1 | 2893.880 | 6.095 | .020 | .184 | 6.095 | .663 |
| Error(phase) | Linear | 12819.595 | 27 | 474.800 | | | | | |

a. Computed using alpha = .05

**Tests of Between-Subjects Effects**

Measure: MEASURE_1
Transformed Variable: Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|
| Intercept | 37421.498 | 1 | 37421.498 | 37.394 | .000 | .581 | 37.394 | 1.000 |
| Group | 163.050 | 1 | 163.050 | .163 | .690 | .006 | .163 | .068 |
| Error | 27020.104 | 27 | 1000.745 | | | | | |

a. Computed using alpha = .05

# Estimated Marginal Means

### 1. Grand Mean

Measure: MEASURE_1

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| 25.538 | 4.176 | 16.969 | 34.107 |

### 2. Group

Measure: MEASURE_1

| Group | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Normal | 23.852 | 5.592 | 12.378 | 35.326 |
| Valgus | 27.223 | 6.204 | 14.494 | 39.953 |

### 3. phase

Measure: MEASURE_1

| phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 24.264 | 5.712 | 12.544 | 35.984 |
| 2 | 26.811 | 4.336 | 17.914 | 35.709 |

### 4. Group * phase

Measure: MEASURE_1

| Group | phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Normal | 1 | 29.680 | 7.649 | 13.986 | 45.374 |
| | 2 | 18.024 | 5.807 | 6.110 | 29.938 |
| Valgus | 1 | 18.848 | 8.486 | 1.437 | 36.259 |
| | 2 | 35.599 | 6.442 | 22.381 | 48.817 |

# General Linear Model

**Within-Subjects Factors**

Measure: MEASURE_1

| board | phase | Dependent Variable |
|---|---|---|
| 1 | 1 | GMaxDes AmpNorm |
| | 2 | GMaxAsc AmpNorm |
| 2 | 1 | GMaxDes Ampboard Norm |
| | 2 | GMaxAsc Ampboard Norm |

# Group = Valgus

**Multivariate Tests[b,c]**

| Effect | | Value | F | Hypothesis df | Error df | Sig. |
|---|---|---|---|---|---|---|
| board | Pillai's Trace | .011 | .134[a] | 1.000 | 12.000 | .721 |
| | Wilks' Lambda | .989 | .134[a] | 1.000 | 12.000 | .721 |
| | Hotelling's Trace | .011 | .134[a] | 1.000 | 12.000 | .721 |
| | Roy's Largest Root | .011 | .134[a] | 1.000 | 12.000 | .721 |
| phase | Pillai's Trace | .113 | 1.525[a] | 1.000 | 12.000 | .241 |
| | Wilks' Lambda | .887 | 1.525[a] | 1.000 | 12.000 | .241 |
| | Hotelling's Trace | .127 | 1.525[a] | 1.000 | 12.000 | .241 |
| | Roy's Largest Root | .127 | 1.525[a] | 1.000 | 12.000 | .241 |
| board * phase | Pillai's Trace | .106 | 1.430[a] | 1.000 | 12.000 | .255 |
| | Wilks' Lambda | .894 | 1.430[a] | 1.000 | 12.000 | .255 |
| | Hotelling's Trace | .119 | 1.430[a] | 1.000 | 12.000 | .255 |
| | Roy's Largest Root | .119 | 1.430[a] | 1.000 | 12.000 | .255 |

a. Exact statistic

b.
Design: Intercept
Within Subjects Design: board+phase+board*phase

c. Group = Valgus

**Mauchly's Test of Sphericity[b,c]**

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[a] | | |
|---|---|---|---|---|---|---|---|
| | | | | | Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| board | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| board * phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: board+phase+board*phase

c. Group = Valgus

**Tests of Within-Subjects Effects[a]**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| board | Sphericity Assumed | 2.550 | 1 | 2.550 | .134 | .721 |
| | Greenhouse-Geisse | 2.550 | 1.000 | 2.550 | .134 | .721 |
| | Huynh-Feldt | 2.550 | 1.000 | 2.550 | .134 | .721 |
| | Lower-bound | 2.550 | 1.000 | 2.550 | .134 | .721 |
| Error(board) | Sphericity Assumed | 228.463 | 12 | 19.039 | | |
| | Greenhouse-Geisse | 228.463 | 12.000 | 19.039 | | |
| | Huynh-Feldt | 228.463 | 12.000 | 19.039 | | |
| | Lower-bound | 228.463 | 12.000 | 19.039 | | |
| phase | Sphericity Assumed | 20.663 | 1 | 20.663 | 1.525 | .241 |
| | Greenhouse-Geisse | 20.663 | 1.000 | 20.663 | 1.525 | .241 |
| | Huynh-Feldt | 20.663 | 1.000 | 20.663 | 1.525 | .241 |
| | Lower-bound | 20.663 | 1.000 | 20.663 | 1.525 | .241 |
| Error(phase) | Sphericity Assumed | 162.606 | 12 | 13.550 | | |
| | Greenhouse-Geisse | 162.606 | 12.000 | 13.550 | | |
| | Huynh-Feldt | 162.606 | 12.000 | 13.550 | | |
| | Lower-bound | 162.606 | 12.000 | 13.550 | | |
| board * phase | Sphericity Assumed | 19.829 | 1 | 19.829 | 1.430 | .255 |
| | Greenhouse-Geisse | 19.829 | 1.000 | 19.829 | 1.430 | .255 |
| | Huynh-Feldt | 19.829 | 1.000 | 19.829 | 1.430 | .255 |
| | Lower-bound | 19.829 | 1.000 | 19.829 | 1.430 | .255 |
| Error(board*phase | Sphericity Assumed | 166.412 | 12 | 13.868 | | |
| | Greenhouse-Geisse | 166.412 | 12.000 | 13.868 | | |
| | Huynh-Feldt | 166.412 | 12.000 | 13.868 | | |
| | Lower-bound | 166.412 | 12.000 | 13.868 | | |

a. Group = Valgus

**Tests of Within-Subjects Contrasts[a]**

Measure: MEASURE_1

| Source | board | phase | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| board | Linear | | 2.550 | 1 | 2.550 | .134 | .721 |
| Error(board) | Linear | | 228.463 | 12 | 19.039 | | |
| phase | | Linear | 20.663 | 1 | 20.663 | 1.525 | .241 |
| Error(phase) | | Linear | 162.606 | 12 | 13.550 | | |
| board * phase | Linear | Linear | 19.829 | 1 | 19.829 | 1.430 | .255 |
| Error(board*phase) | Linear | Linear | 166.412 | 12 | 13.868 | | |

a. Group = Valgus

**Tests of Between-Subjects Effects[a]**

Measure: MEASURE_1

Transformed Variable: Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 7002.385 | 1 | 7002.385 | 59.407 | .000 |
| Error | 1414.464 | 12 | 117.872 | | |

a. Group = Valgus

# Estimated Marginal Means

**1. Grand Mean[a]**

Measure: MEASURE_1

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| 11.604 | 1.506 | 8.324 | 14.885 |

a. Group = Valgus

**2. board[a]**

Measure: MEASURE_1

| board | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 11.383 | 1.577 | 7.946 | 14.820 |
| 2 | 11.826 | 1.667 | 8.194 | 15.457 |

a. Group = Valgus

**3. phase[a]**

Measure: MEASURE_1

| phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 10.974 | 1.450 | 7.815 | 14.133 |
| 2 | 12.235 | 1.718 | 8.491 | 15.978 |

a. Group = Valgus

**4. board * phase[a]**

Measure: MEASURE_1

| board | phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| 1 | 1 | 11.370 | 1.568 | 7.955 | 14.786 |
| | 2 | 11.396 | 1.587 | 7.937 | 14.854 |
| 2 | 1 | 10.578 | 1.403 | 7.520 | 13.636 |
| | 2 | 13.074 | 2.386 | 7.875 | 18.273 |

a. Group = Valgus

# General Linear Model

**Within-Subjects Factors**

Measure: MEASURE_1

| board | phase | Dependent Variable |
|---|---|---|
| 1 | 1 | GMedDes AmpNorm |
| | 2 | GMedAsc AmpNorm |
| 2 | 1 | GMedDes Ampboard Norm |
| | 2 | GMedAsc Ampboard Norm |

# Group = Valgus

**Descriptive Statistics[a]**

| | Mean | Std. Deviation | N |
|---|---|---|---|
| GMedDesAmpNorm | 19.024160 | 9.7204132 | 13 |
| GMedAscAmpNorm | 19.028615 | 9.7469128 | 13 |
| GMedDesAmpboard Norm | 18.142014 | 9.4341316 | 13 |
| GMedAscAmpboardNorm | 20.258858 | 11.8490756 | 13 |

a. Group = Valgus

**Multivariate Tests[c,d]**

| Effect | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| board | Pillai's Trace | .002 | .022[b] | 1.000 | 12.000 | .885 | .002 | .022 | .052 |
| | Wilks' Lambda | .998 | .022[b] | 1.000 | 12.000 | .885 | .002 | .022 | .052 |
| | Hotelling's Trac | .002 | .022[b] | 1.000 | 12.000 | .885 | .002 | .022 | .052 |
| | Roy's Largest R | .002 | .022[b] | 1.000 | 12.000 | .885 | .002 | .022 | .052 |
| phase | Pillai's Trace | .145 | 2.034[b] | 1.000 | 12.000 | .179 | .145 | 2.034 | .259 |
| | Wilks' Lambda | .855 | 2.034[b] | 1.000 | 12.000 | .179 | .145 | 2.034 | .259 |
| | Hotelling's Trac | .169 | 2.034[b] | 1.000 | 12.000 | .179 | .145 | 2.034 | .259 |
| | Roy's Largest R | .169 | 2.034[b] | 1.000 | 12.000 | .179 | .145 | 2.034 | .259 |
| board * phas | Pillai's Trace | .140 | 1.955[b] | 1.000 | 12.000 | .187 | .140 | 1.955 | .251 |
| | Wilks' Lambda | .860 | 1.955[b] | 1.000 | 12.000 | .187 | .140 | 1.955 | .251 |
| | Hotelling's Trac | .163 | 1.955[b] | 1.000 | 12.000 | .187 | .140 | 1.955 | .251 |
| | Roy's Largest R | .163 | 1.955[b] | 1.000 | 12.000 | .187 | .140 | 1.955 | .251 |

a. Computed using alpha = .05

b. Exact statistic

c.
Design: Intercept
Within Subjects Design: board+phase+board*phase

d. Group = Valgus

**Mauchly's Test of Sphericity[b,c]**

Measure: MEASURE_1

| Within Subjects Eff | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[a] | | |
|---|---|---|---|---|---|---|---|
| | | | | | Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| board | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| board * phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent v proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: board+phase+board*phase

c. Group = Valgus

**Tests of Within-Subjects Effects[b]**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| board | Sphericity Assum | .394 | 1 | .394 | .022 | .885 | .002 | .022 | .052 |
| | Greenhouse-Geis | .394 | 1.000 | .394 | .022 | .885 | .002 | .022 | .052 |
| | Huynh-Feldt | .394 | 1.000 | .394 | .022 | .885 | .002 | .022 | .052 |
| | Lower-bound | .394 | 1.000 | .394 | .022 | .885 | .002 | .022 | .052 |
| Error(board) | Sphericity Assum | 215.282 | 12 | 17.940 | | | | | |
| | Greenhouse-Geis | 215.282 | 12.000 | 17.940 | | | | | |
| | Huynh-Feldt | 215.282 | 12.000 | 17.940 | | | | | |
| | Lower-bound | 215.282 | 12.000 | 17.940 | | | | | |
| phase | Sphericity Assum | 14.625 | 1 | 14.625 | 2.034 | .179 | .145 | 2.034 | .259 |
| | Greenhouse-Geis | 14.625 | 1.000 | 14.625 | 2.034 | .179 | .145 | 2.034 | .259 |
| | Huynh-Feldt | 14.625 | 1.000 | 14.625 | 2.034 | .179 | .145 | 2.034 | .259 |
| | Lower-bound | 14.625 | 1.000 | 14.625 | 2.034 | .179 | .145 | 2.034 | .259 |
| Error(phase) | Sphericity Assum | 86.289 | 12 | 7.191 | | | | | |
| | Greenhouse-Geis | 86.289 | 12.000 | 7.191 | | | | | |
| | Huynh-Feldt | 86.289 | 12.000 | 7.191 | | | | | |
| | Lower-bound | 86.289 | 12.000 | 7.191 | | | | | |
| board * phase | Sphericity Assum | 14.502 | 1 | 14.502 | 1.955 | .187 | .140 | 1.955 | .251 |
| | Greenhouse-Geis | 14.502 | 1.000 | 14.502 | 1.955 | .187 | .140 | 1.955 | .251 |
| | Huynh-Feldt | 14.502 | 1.000 | 14.502 | 1.955 | .187 | .140 | 1.955 | .251 |
| | Lower-bound | 14.502 | 1.000 | 14.502 | 1.955 | .187 | .140 | 1.955 | .251 |
| Error(board*pha | Sphericity Assum | 89.006 | 12 | 7.417 | | | | | |
| | Greenhouse-Geis | 89.006 | 12.000 | 7.417 | | | | | |
| | Huynh-Feldt | 89.006 | 12.000 | 7.417 | | | | | |
| | Lower-bound | 89.006 | 12.000 | 7.417 | | | | | |

a. Computed using alpha = .05

b. Group = Valgus

**Tests of Within-Subjects Contrasts**[b]

Measure: MEASURE_1

| Source | board | phase | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| board | Linear | | .394 | 1 | .394 | .022 | .885 | .002 | .022 | .052 |
| Error(board) | Linear | | 215.282 | 12 | 17.940 | | | | | |
| phase | | Linear | 14.625 | 1 | 14.625 | 2.034 | .179 | .145 | 2.034 | .259 |
| Error(phase) | | Linear | 86.289 | 12 | 7.191 | | | | | |
| board * phase | Linear | Linear | 14.502 | 1 | 14.502 | 1.955 | .187 | .140 | 1.955 | .251 |
| Error(board*ph | Linear | Linear | 89.006 | 12 | 7.417 | | | | | |

a. Computed using alpha = .05

b. Group = Valgus

**Tests of Between-Subjects Effects**[b]

Measure: MEASURE_1

Transformed Variable: Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|
| Intercept | 18996.771 | 1 | 18996.771 | 49.171 | .000 | .804 | 49.171 | 1.000 |
| Error | 4636.130 | 12 | 386.344 | | | | | |

a. Computed using alpha = .05

b. Group = Valgus

# Estimated Marginal Means

**1. Grand Mean**[a]

Measure: MEASURE_1

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| 19.113 | 2.726 | 13.175 | 25.052 |

a. Group = Valgus

**2. board**[a]

Measure: MEASURE_1

| board | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 19.026 | 2.699 | 13.145 | 24.908 |
| 2 | 19.200 | 2.874 | 12.938 | 25.463 |

a. Group = Valgus

**3. phase[a]**

Measure: MEASURE_1

| phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 18.583 | 2.642 | 12.826 | 24.340 |
| 2 | 19.644 | 2.855 | 13.422 | 25.865 |

a. Group = Valgus

**4. board * phase[a]**

Measure: MEASURE_1

| board | phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| 1 | 1 | 19.024 | 2.696 | 13.150 | 24.898 |
| | 2 | 19.029 | 2.703 | 13.139 | 24.919 |
| 2 | 1 | 18.142 | 2.617 | 12.441 | 23.843 |
| | 2 | 20.259 | 3.286 | 13.099 | 27.419 |

a. Group = Valgus

# General Linear Model

**Within-Subjects Factors**

Measure: MEASURE_1

| board | phase | Dependent Variable |
|---|---|---|
| 1 | 1 | AddDes AmpNorm |
| | 2 | AddAsc AmpNorm |
| 2 | 1 | AddDes Ampboard Norm |
| | 2 | AddAsc Ampboard Norm |

# Group = Valgus

**Descriptive Statistics[a]**

| | Mean | Std. Deviation | N |
|---|---|---|---|
| AddDesAmpNorm | 18.848112 | 14.2616026 | 13 |
| AddAscAmpNorm | 35.598841 | 33.7813601 | 13 |
| AddDesAmpboardNorm | 18.090004 | 14.0836079 | 13 |
| AddAscAmpboardNorm | 28.494032 | 20.9464810 | 13 |

a. Group = Valgus

**Multivariate Tests[c,d]**

| Effect | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| board | Pillai's Trace | .166 | 2.390[b] | 1.000 | 12.000 | .148 | .166 | 2.390 | .296 |
| | Wilks' Lambda | .834 | 2.390[b] | 1.000 | 12.000 | .148 | .166 | 2.390 | .296 |
| | Hotelling's Trace | .199 | 2.390[b] | 1.000 | 12.000 | .148 | .166 | 2.390 | .296 |
| | Roy's Largest R | .199 | 2.390[b] | 1.000 | 12.000 | .148 | .166 | 2.390 | .296 |
| phase | Pillai's Trace | .477 | 10.951[b] | 1.000 | 12.000 | .006 | .477 | 10.951 | .859 |
| | Wilks' Lambda | .523 | 10.951[b] | 1.000 | 12.000 | .006 | .477 | 10.951 | .859 |
| | Hotelling's Trace | .913 | 10.951[b] | 1.000 | 12.000 | .006 | .477 | 10.951 | .859 |
| | Roy's Largest R | .913 | 10.951[b] | 1.000 | 12.000 | .006 | .477 | 10.951 | .859 |
| board * phas | Pillai's Trace | .124 | 1.700[b] | 1.000 | 12.000 | .217 | .124 | 1.700 | .225 |
| | Wilks' Lambda | .876 | 1.700[b] | 1.000 | 12.000 | .217 | .124 | 1.700 | .225 |
| | Hotelling's Trace | .142 | 1.700[b] | 1.000 | 12.000 | .217 | .124 | 1.700 | .225 |
| | Roy's Largest R | .142 | 1.700[b] | 1.000 | 12.000 | .217 | .124 | 1.700 | .225 |

a. Computed using alpha = .05

b. Exact statistic

c.
Design: Intercept
Within Subjects Design: board+phase+board*phase

d. Group = Valgus

**Mauchly's Test of Sphericity[b,c]**

Measure: MEASURE_1

| Within Subjects Eff | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[a] Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
|---|---|---|---|---|---|---|---|
| board | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| board * phase | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent v
proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests
the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: board+phase+board*phase

c. Group = Valgus

**Tests of Within-Subjects Effects**[b]

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| board | Sphericity Assume | 200.933 | 1 | 200.933 | 2.390 | .148 | .166 | 2.390 | .296 |
| | Greenhouse-Geiss | 200.933 | 1.000 | 200.933 | 2.390 | .148 | .166 | 2.390 | .296 |
| | Huynh-Feldt | 200.933 | 1.000 | 200.933 | 2.390 | .148 | .166 | 2.390 | .296 |
| | Lower-bound | 200.933 | 1.000 | 200.933 | 2.390 | .148 | .166 | 2.390 | .296 |
| Error(board) | Sphericity Assume | 1008.777 | 12 | 84.065 | | | | | |
| | Greenhouse-Geiss | 1008.777 | 12.000 | 84.065 | | | | | |
| | Huynh-Feldt | 1008.777 | 12.000 | 84.065 | | | | | |
| | Lower-bound | 1008.777 | 12.000 | 84.065 | | | | | |
| phase | Sphericity Assume | 2396.488 | 1 | 2396.488 | 10.951 | .006 | .477 | 10.951 | .859 |
| | Greenhouse-Geiss | 2396.488 | 1.000 | 2396.488 | 10.951 | .006 | .477 | 10.951 | .859 |
| | Huynh-Feldt | 2396.488 | 1.000 | 2396.488 | 10.951 | .006 | .477 | 10.951 | .859 |
| | Lower-bound | 2396.488 | 1.000 | 2396.488 | 10.951 | .006 | .477 | 10.951 | .859 |
| Error(phase) | Sphericity Assume | 2626.032 | 12 | 218.836 | | | | | |
| | Greenhouse-Geiss | 2626.032 | 12.000 | 218.836 | | | | | |
| | Huynh-Feldt | 2626.032 | 12.000 | 218.836 | | | | | |
| | Lower-bound | 2626.032 | 12.000 | 218.836 | | | | | |
| board * phase | Sphericity Assume | 130.912 | 1 | 130.912 | 1.700 | .217 | .124 | 1.700 | .225 |
| | Greenhouse-Geiss | 130.912 | 1.000 | 130.912 | 1.700 | .217 | .124 | 1.700 | .225 |
| | Huynh-Feldt | 130.912 | 1.000 | 130.912 | 1.700 | .217 | .124 | 1.700 | .225 |
| | Lower-bound | 130.912 | 1.000 | 130.912 | 1.700 | .217 | .124 | 1.700 | .225 |
| Error(board*phas | Sphericity Assume | 924.341 | 12 | 77.028 | | | | | |
| | Greenhouse-Geiss | 924.341 | 12.000 | 77.028 | | | | | |
| | Huynh-Feldt | 924.341 | 12.000 | 77.028 | | | | | |
| | Lower-bound | 924.341 | 12.000 | 77.028 | | | | | |

a. Computed using alpha = .05

b. Group = Valgus

**Tests of Within-Subjects Contrasts**[b]

Measure: MEASURE_1

| Source | board | phase | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| board | Linear | | 200.933 | 1 | 200.933 | 2.390 | .148 | .166 | 2.390 | .296 |
| Error(board) | Linear | | 1008.777 | 12 | 84.065 | | | | | |
| phase | | Linear | 2396.488 | 1 | 2396.488 | 10.951 | .006 | .477 | 10.951 | .859 |
| Error(phase) | | Linear | 2626.032 | 12 | 218.836 | | | | | |
| board * phase | Linear | Linear | 130.912 | 1 | 130.912 | 1.700 | .217 | .124 | 1.700 | .225 |
| Error(board*pha | Linear | Linear | 924.341 | 12 | 77.028 | | | | | |

a. Computed using alpha = .05

b. Group = Valgus

**Tests of Between-Subjects Effects[b]**

Measure: MEASURE_1

Transformed Variable: Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|
| Intercept | 33173.597 | 1 | 33173.597 | 20.711 | .001 | .633 | 20.711 | .986 |
| Error | 19220.971 | 12 | 1601.748 | | | | | |

a. Computed using alpha = .05

b. Group = Valgus

# Estimated Marginal Means

**1. Grand Mean[a]**

Measure: MEASURE_1

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| 25.258 | 5.550 | 13.165 | 37.350 |

a. Group = Valgus

**2. board[a]**

Measure: MEASURE_1

| board | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 27.223 | 6.541 | 12.972 | 41.475 |
| 2 | 23.292 | 4.696 | 13.060 | 33.524 |

a. Group = Valgus

**3. phase[a]**

Measure: MEASURE_1

| phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | 18.469 | 3.921 | 9.926 | 27.012 |
| 2 | 32.046 | 7.393 | 15.939 | 48.153 |

a. Group = Valgus

**4. board * phase[a]**

Measure: MEASURE_1

| board | phase | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| 1 | 1 | 18.848 | 3.955 | 10.230 | 27.466 |
| | 2 | 35.599 | 9.369 | 15.185 | 56.013 |
| 2 | 1 | 18.090 | 3.906 | 9.579 | 26.601 |
| | 2 | 28.494 | 5.810 | 15.836 | 41.152 |

a. Group = Valgus

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