5-2020

Electromyographic (EMG) Activity of the Hip Abductors During Various Hip Exercises

Heather Harrower
University of North Dakota

Natalie Murphy
University of North Dakota

Trista Saulter
University of North Dakota

Katelyn Voll
University of North Dakota

Electromyographic (EMG) Activity of the Hip Abductors During Various Hip Exercises

By

Heather Harrower, B.S
University of North Dakota 2018

Natalie Murphy, B.S
University of North Dakota 2018

Trista Saulter
North Dakota State University 2017

Katelyn Voll, B.S
University of North Dakota 2018

A Scholarly Project Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota

In partial fulfillment of the requirements for the degree of
Doctor of Physical Therapy

Grand Forks, North Dakota
May, 2020

This Scholarly Project, submitted by Heather Harrower, Natalie Murphy, Trista Saulter, and Katelyn Voll, in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Advisor and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

Graduate School Advisor

Chairperson, Physical Therapy

PERMISSION

Title Electromyographic (EMG) Activity of the Hip Abductors During Various Hip Exercises

Department Physical Therapy

Degree Doctor of Physical Therapy

In presenting this Scholarly Project in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, we agree that the Department of Physical Therapy shall make it freely available for inspection. We further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised our work or, in his absence, by the Chairperson of the department. It is understood that any copying or publication or other use of this Scholarly Project or part thereof for financial gain shall not be allowed without our written permission. It is also understood that due recognition shall be given to us and the University of North Dakota in any scholarly use which may be made of any material in this Scholarly Project.

Heather Harrower 9/24/19
Heather Harrower Date

Natalie Murphy 9/24/19
Natalie Murphy Date

Trista Saulter 9/24/19
Trista Saulter Date

Katelyn Voll 9/24/19
Katelyn Voll Date

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Firstly, we would like to thank Dr. David Relling for his great direction, assistance, and supervision for the entirety of this scholarly project. Furthermore, we would like to thank Dr. Renee Mabey for providing her service and expertise in statistical analysis. Lastly, we would like to thank all-of our participants who took time out of their day, and showed us their upmost support, patience, and cooperation. We are very appreciative for all those who helped complete our research.

ABSTRACT

Background and Purpose: The purpose of the study was to record, compare, and analyze muscle recruitment patterns during different hip abduction exercises. This was done by examining the patterns for gluteus maximus, gluteus medius, and tensor fascia latae when performing the following exercises: Standing hip abduction with a blue resistance band around bilateral ankles, sidelying hip abduction utilizing constant effort to move a small, medium, or large ball up and down the wall, and basic sidelying hip abduction with no ball. All exercises were done with participants' dominant lower extremity.

Case Description: Fifteen, healthy, University of North Dakota Physical Therapy students with mean age being 23, were recruited to perform the five different exercises. All participants met the inclusion criteria for healthy adults over the age of 18. The exclusion criteria for this study included hip or low back pain in the past three months or allergic reactions to adhesives. Each subject also completed a subject questionnaire and data collection.

Intervention: The sequence of exercises was randomly assigned for each participant. EMG equipment was used to measure muscle activity during all exercises. Five repetitions were completed to a 50 beat per minute metronome, and three sets of each exercise were fully completed by all participants.

Outcomes: Gluteus medius showed no significant difference between the ball sizes, but there was a significantly higher EMG response for standing and large ball conditions when compared to the no ball/sidelying condition. The gluteus maximus showed the lowest EMG activity with no ball and significantly higher EMG activity in each of the other experimental conditions. Interestingly, there was no statistical difference in EMG activity between the different balls and standing conditions. The tensor fascia latae EMG muscle activity was significantly higher in the standing abduction with the resistance band when compared to all other conditions.

Discussion: Our results yield trends that could be explained by the level of mental concentration needed to complete the activity, the position of the hip in each position, and biomechanics for each hip muscle. More extensive and specific research utilizing EMG activity of the hip muscles with a larger population is needed for a clearer understanding.

CHAPTER I: INTRODUCTION

Adequate strength of the hip musculature is an important factor in injury prevention, and is linked to increased function and quality of life across the lifespan. Hip abductor weakness and abnormal hip kinematics have been associated with lower extremity injuries, including ankle instability,[1] anterior cruciate ligament (ACL) injuries,[2] as well as lower extremity overuse injuries. Side-to-side asymmetry in hip-extensor strength also has been observed in females with lower extremity injuries and low back pain.[3] Strengthening the hip musculature following lower extremity injuries provides significant benefits regarding early rehabilitation outcomes.[4] Many of the muscles that have attachments near the hip also have attachments near the knee which intricately links the two joints, especially during rehabilitation. When the knee is injured, the leg relies on the ankle and hip for additional balance and support commonly referred to as hip or ankle strategies. Thus, it is important to strengthen the hip when the knee or ankle are injured.

In the elderly population, lower extremity weakness and balance deficits are well documented risk factors contributing to falls. Falls, especially in the elderly, have a large impact on quality of life, mortality, and economic impact. One of four Americans aged 65 and older falls each year. Falls result in more than 2.8 million injuries treated in emergency departments annually, including more than 28,000 deaths. Older adult falls result in more than $31 billion in annual Medicare costs.[5] Among risk factors for falls, proposed mechanisms of injury involve weakness of the hip joint and protective stepping response using ankle and hip strategies. When the ankle strategy is delayed or absent, the hip strategy is utilized to stabilize the hip joint. Weak hip muscles impair the hip strategy, causing the person to take more steps which increases their risk of fall. In community-dwelling older adults, medial to lateral postural sway has been associated with falls. One of the first protective responses is a stepping response. This can be in the anterior to posterior direction or medial to lateral.[6] The hip abductors are an important muscle group for stabilizing the hip joint. If the person is unable to adequately stabilize using an ankle strategy, the hip strategy is employed, resulting in a stepping response to preserve balance and prevent a fall.[7] Weakness around the hip joint can impair the use of this strategy, increasing the risk of a fall. Falls occur as a result of a complex interaction of risk factors including biological, behavioral, environmental and socioeconomic.[8] Because of the hip joints central location and dominant role in kinesiology, pathology of this joint can greatly affect normal functioning. There are powerful muscles, specifically the gluteus maximus, gluteus medius, and tensor fascia latae, that when weakened can negatively affect body mechanics and our ability to move properly. Some of these limitations include difficulty walking, running, driving, lifting, negotiating stairs, and completing activities of daily living.[9] Understanding the anatomy and recruitment patterns behind these muscles, can help guide rehabilitation and wellness programs.

The gluteus maximus muscle originates from the ilium, sacrum/coccyx and sacrotuberous ligament. Eighty percent of the gluteus maximus inserts into the lateral tibial condyle via the iliotibial tract; the remainder inserts into the femur's gluteal tuberosity.[10] This muscle is a strong hip extensor and lateral rotator. This muscle is very active when the body is accelerated up and forward such as pushing off into a sprint or climbing a hill.[11] During the gait cycle, the gluteus maximus is active during late swing, at which time its activity is needed to decelerate the flexing hip and initiate extension at the joint. The function of gluteus maximus during stance phase is to help support the body weight from heel contact to mid stance.[12]

The gluteus medius muscle originates at the superior ilium between the posterior and anterior gluteal lines and inserts on the lateral and superior surfaces of the femur's greater trochanter. Anatomically, the gluteus medius is divided into three parts: 1) anterior, 2) middle, and 3) posterior. This muscle is involved in several motions at the hip including flexion, abduction, extension, internal rotation and external rotation. It is in an optimal position to abduct the femur and stabilize the pelvis during weight bearing activities. Specifically, the greatest gluteus medius activation is observed during the stance phase of gait.[13] During this phase of gait, the gluteus medius works to prevent lateral drop of the pelvis on the side contralateral to the stance leg. Weakness or poor recruitment of the gluteus medius can result in instability and improper body mechanics. This can be a leading factor contributing to an abundance of lower extremity injuries.

The tensor fascia latae (TFL) originates on the iliac crest and the anterior superior iliac spine and shares a common insertion with gluteus maximus onto the lateral tibial condyle via the iliotibial tract. This shared insertion enables the two muscles to work together to provide lateral bracing of the knee. This is important in single leg stance and balancing on one foot.[14] The tensor fascia latae (TFL) has three common actions with the gluteus medius and minimus including: flexion, abduction, and internal rotation. These common actions help enhance the entire movement at the hip. Different exercises have been evaluated that activate the gluteal muscles along with TFL, to help determine the balance among their muscle activation.[15] Due to the tendency for TFL to become overactive, it is critical to minimize activation of TFL and maximize activation of gluteus medius and minimus during rehabilitation.[16] For example, using elastic resistance during clam exercises resulted in lower activation of TFL compared to the gluteal muscles. This supports the use of resistance and positioning to optimize gluteal function and eliminate overactive TFL.[15]

Exercises to strengthen musculature of the hip have been used in rehabilitation, injury prevention and fall prevention programs for years. It has been proposed that the minimum effort to obtain a strengthening stimulus is approximately 40-60% of a maximum voluntary isometric contraction.[17] Understanding correct positioning for eliciting the best response from the targeted muscle is essential for desired patient outcomes. Sufficient strength in hip musculature contributes to proper movement of individuals of all age groups, and has been studied in settings ranging from rehabilitation of high level athletes to fall prevention programs for the geriatric population. Fall prevention programs and injury rehabilitation interventions require multi-faceted rehabilitation. However, this study focuses primarily on strengthening musculature surrounding the hip joint, specifically gluteus maximus, gluteus medius and tensor fascia latae. Understanding the importance of strength and balance between the hip muscles has led to important research on different methods of activating and strengthening the hip musculature. There have been studies investigating the activation of gluteus medius during a variety of open- and closed-chain exercises, however the determination of an exercise shown to effectively recruit multiple hip muscles would be clinically significant.[18] Therefore, our study aims to determine activation of the hip muscles during novel exercises of hip abduction while rolling a ball up the wall using the heel.

CHAPTER II: METHODS

This project was reviewed and approved by the University of North Dakota Institutional Review Board (IRB-201804-302) prior to initiation of the study (see Appendix).

Subjects

Subjects were recruited from a sample of convenience in the Department of Physical Therapy at the University of North Dakota. The subjects participating in this study were obtained on a voluntary basis and all subjects completed an informed consent form prior to participation (see Appendix). The inclusion criteria to participate in this study included healthy adults over the age of 18. The exclusion criteria included hip or low back pain in the past three months and allergic reactions to adhesives. Each subject completed a subject questionnaire and data collection. The subjects attended one session of approximately thirty minutes of testing in the Department of Physical Therapy at the University of North Dakota campus in the School of Medicine and Health Sciences. The testing was completed in a private research room for the confidentiality and privacy of the subjects. Subjects did not receive compensation for participating in this study.

Instrumentation

Instrumentation for this study included electromyography (EMG) hardware and software. The EMG data collection was performed using self-adhesive pre-gelled EMG surface electrodes. These electrodes were placed over standard electrode sites on the dominant side of each test subject. Muscle activity was collected unilaterally on the gluteus maximus, gluteus medius and tensor fascia latae muscles. The EMG data was collected using the Noraxon EMG software myoMUSCLE module for the myoResearch 3.12 software and the TeloMyo DTS telemetry system. Data analysis for the EMG data was performed on a laptop computer (Dell Technologies, Inc) using Noraxon myoResearch 3.12 software (Noraxon, USA, Scottsdale, AZ).

Procedure

Prior to initiation of this study, the EMG equipment was set up and tested by the researchers to ensure proper signal transmission and reception. The subjects were tested independently in the Department of Physical Therapy located at the University of North Dakota School of Medicine and Health Sciences. The purpose and procedure for the study was explained to each participant prior to signing a statement of informed consent, completing the intake survey, and initiation of data collection.

The dominant lower extremity of each subject was used to perform each exercise. Data was collected only for the muscles on the dominant side. Lower extremity dominance was determined by asking each subject to stand in place and kick a ball placed in front of them towards a wall three times. The lower extremity self-selected by the subject to kick the ball two out of three times was considered the dominant side for the purposes of this study. These methods are similar to those used in other studies. [19, 20]

The collection of EMG data required electrode site preparation, electrode placement, connection of hardware and testing of equipment before testing began. The electrode site preparation was performed in a standardized fashion including removal of excess hair from the electrode sites with an electric razor, gently rubbing the skin surface with 400 grit sandpaper, and cleaning the area with isopropyl alcohol. Electrode placement was determined by using standard electrode placement recommendations (see Figure 1).[21] Standard silver/silver chloride electrodes were placed in a bipolar configuration at the appropriate sites using an inter-electrode distance of approximately 1.5 cm. The Noraxon skin impedance analyzer was used to assess electrode placement and ensure low (<50kOhm) impedance (Noraxon, USA, Scottsdale AZ). The electrodes were connected to the TeleMyo DTS transmitter. The EMG signals were transmitted to the TeleMyo DTS receiver and stored on a laptop computer (Dell Technologies, Inc.). The raw EMG data was later analyzed for intensity of activation of the muscles using the myoResearch 3.12 software. (Noraxon, USA, Scottsdale AZ).

Figures

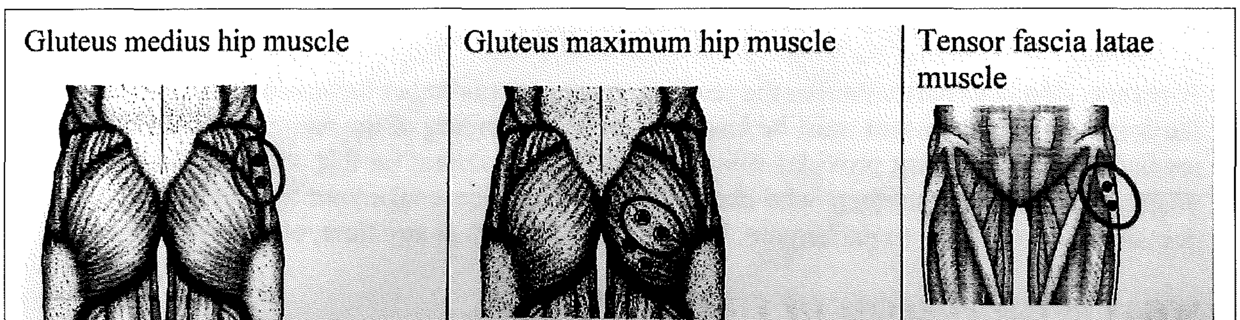


Figure 1. EMG Electrode placement for the gluteus maximus, gluteus medius and tensor fascia latae muscles on the subject's dominant lower extremity

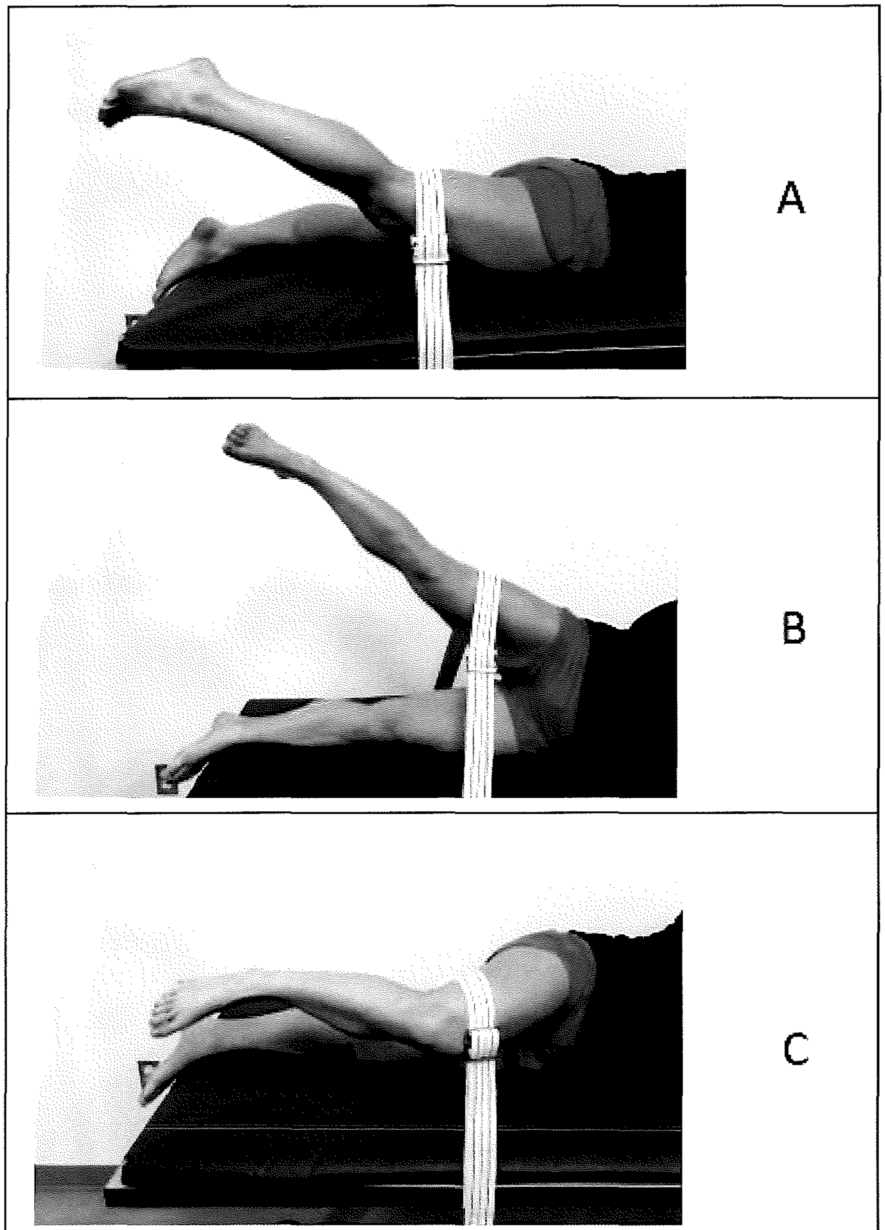
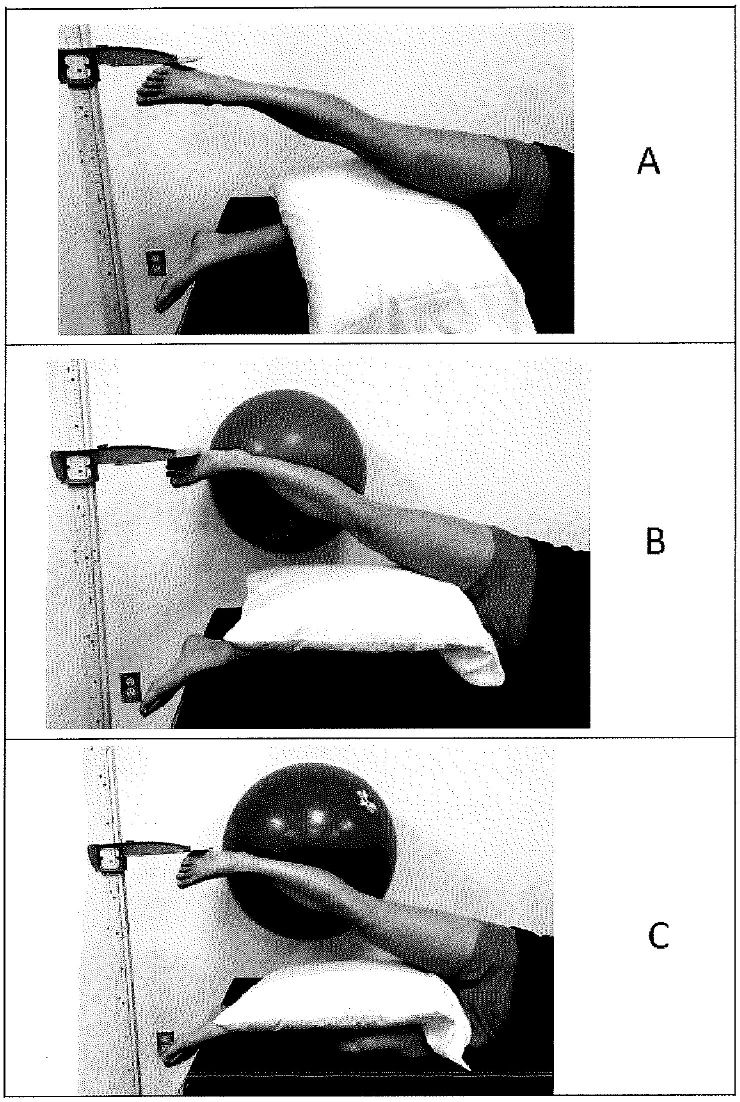


Figure 2: Maximal Voluntary Contraction (MVC) positions. A. MVC position for gluteus maximus. B. MVC position for gluteus medius. C. MVC position for tensor fascia latae



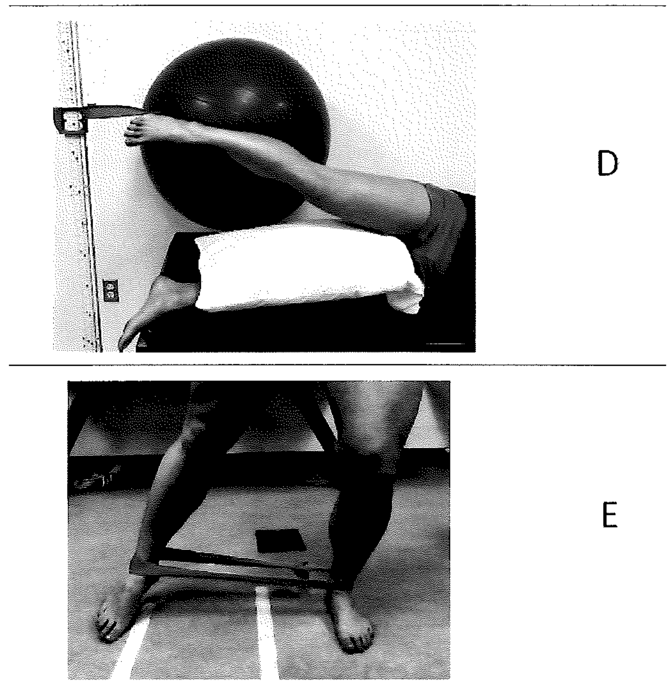


Figure 3: Hip abduction exercise positions for hip abduction. A. Sidelying hip abduction. B. Hip abduction with three ball sizes (B. small, C. Medium, and D. Large). E. Standing hip abduction with resistance band.

To begin, subjects performed mild muscle contractions to assure accurate electrode placement. The subjects were instructed in performing isometric maximal voluntary contractions (MVCs) for a duration of 5 seconds in standardized positions for two trials with one minute rest in between (see Figure 2). For gluteus maximus, the subject lay prone on the examination table with a belt fixed around the distal thigh. The subject performed a MVC at 10 degrees of hip extension. For the gluteus medius, the subject lay on their non-dominant side with a belt placed around the distal thigh. The subject performed a MVC at 30 degrees of hip abduction. For the tensor fascia latae, the subject lay on their non-dominant side with a belt placed around their distal thigh. The subject performed a MVC at 45 degrees of hip flexion and abducted to neutral.

Next, the subjects were randomly assigned a series of five different experimental positions: hip abduction in standing with a 24 in. blue resistance band that was looped and placed at the ankles (Thera-Band, USA, Akron OH), sidelying with a small ball, sidelying with a medium ball (Valeo), sidelying with a large ball (Physio Gymnic, Italy), and sidelying with no ball (See Figure 3). The circumferences of the small, medium, and large balls measured approximately 148 cm, 188 cm, and 208 cm, respectively. These sizes reflect the measured circumferences, rather than the diameter listed on the ball, to account for variations in inflation level. Standard sizes for fully inflated small, medium and large balls are 172.7 cm, 204.1 cm, 235.5 cm, respectively. In each sidelying position, the subject performed two trials of five repetitions of hip abduction through an excursion of 12" to a metronome of fifty beats per minute. For standing abduction, the subject placed a blue resistance band around their ankles and stepped 12 inches laterally using tape strips as a marker for five repetitions using a metronome of fifty beats per minute. The EMG activity was collected during the five repetitions of hip abduction (standing) or hip abduction and extension (sidelying). At least one minute of rest separated each of the trials. Following the completion of data collection in all experimental positions, the electrodes were removed from the subjects and the sites were cleaned with isopropyl alcohol to remove any remaining gel and adhesive.

Data Analysis

Raw EMG data was analyzed using the Noraxon MyoResearch 3.12 Software Program. The EMG data were normalized to the maximal voluntary contractions, rectified, and smoothed using the root mean square (RMS) option set at 50 millisecond collection frames. Composite data is presented as the average +/- SD of two trials for each exercise for all subjects within an experimental condition.

Statistical Analysis

Data are presented as mean±standard deviation. The data did not follow a normally distributed curve resulting in the use of non-parametric statistical analysis. The Friedman Test, an alternative to the Repeated-Measures ANOVA, was used to identify differences between the five conditions of standing, sidelying no ball, and sidelying with the small, medium, and large ball sizes. When significance was found across a muscle group, a Bonferroni correction was applied for pairwise comparisons.

CHAPTER III RESULTS

Fifteen subjects participated in the study including ten females and five males. The data and analysis of the genders are combined for reporting purposes. The average age of the subjects was 23 years old.

The average height of the subjects was 67.0 inches while the average weight was 162 lbs (see Figure 4). The EMG means and standard deviations across the various experimental conditions are reported for the gluteus maximus, gluteus medius and tensor fascia latae (see Table 1). The data lacked a normal distribution, therefore non-parametric tests were used to identify differences in EMG activity across the five test positions in each muscle. Friedman's test, a non-parametric alternative to the repeated-measures ANOVA, with a Bonferroni correction was applied to determine significance. The Friedman's Test identified significant differences between conditions for the gluteus medius (=24.6 (4, n=15), $p<0.001$), gluteus maximus (=18.24 (4, n=15), $p=0.001$), and tensor fascia latae (=28.96 (4 (n=15)), $p<0.001$).

Additional analysis identified several significant and interesting findings within each of the hip muscles under study (see Table 1). Notably, each of the muscles achieved the highest EMG activation in the standing hip abduction condition. The standing hip abduction EMG activity was significantly higher than the sidelying/no ball hip abduction activity in all muscles. It is interesting to note that the gluteus medius muscle was the only "mixed" response to the different trials. The gluteus medius activity typically increased with an expanding ball size. The greatest EMG activity occurred in standing but was not significantly different from the small, medium or large ball conditions. At the same time, the sidelying/no ball condition resulted in the lowest gluteus medius EMG activity but was not significantly different from the small and medium sized ball conditions. Comparatively, the gluteus maximus activity followed a similar upward trend although only the sidelying/no ball condition was significantly different compared to all other trials. The tensor fascia latae results were reversed, demonstrating significantly higher EMG activity only in the standing condition.

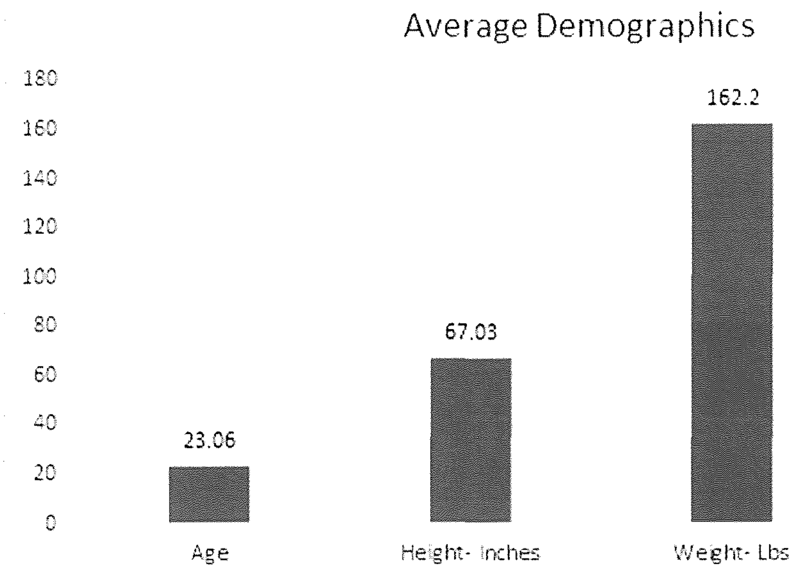


Figure 4: Average demographics of the 15 subjects (10 females, 5 males) for the age in years, height in inches, and weight in pounds.

Table 1 Mean EMG activity for the five experimental conditions in each muscle.

Condition	Mean EMG	Standard Deviation	N	Significance/ Difference
Gluteus Medius				
Sidelying/ No Ball	33.37	15.17	15	a
Small ball	42.83	16.63	15	a,b
Medium ball	45.26	19.59	15	a,b
Large ball	44.61	15.36	15	b
Standing	52.41	17.17	15	b
Gluteus Maximus				
Sidelying/ No Ball	28.70	38.63	15	a
Small ball	45.71	46.96	15	b
Medium ball	46.77	57.66	15	b
Large ball	44.15	52.66	15	b
Standing	55.41	46.70	15	b
Tensor Fascia Latae				
Sidelying/ No Ball	62.12	41.76	15	a
Small ball	63.65	37.77	15	a
Medium ball	70.29	46.59	15	a
Large ball	66.75	39.73	15	a
Standing	101.54	52.26	15	b
Letters a & b identify significance between conditions for a muscle. Conditions with the same letter are statistically similar while conditions with different letters are significantly different from each other.				

CHAPTER IV DISCUSSION

The purpose of this study was to compare muscle recruitment patterns during hip abduction exercises in sidelying using no ball, a small, medium, and large ball compared to using a resistance band in standing as a method of measured overload. Fifteen subjects performed these five different types of exercises to determine the level of gluteus medius, gluteus maximus, and tensor fascia latae muscle activity. We observed increased gluteus medius, gluteus maximus, and tensor fascia latae EMG activity as the participants completed sidelying abduction with no ball, a small ball, and then a medium ball. However, this EMG activity then decreased while using the large ball. EMG activity in standing abduction with a blue resistance band was the highest for all three muscles. Particularly, the tensor fascia latae activity was substantially higher in standing than in sidelying.

The original hypothesis of the study predicted an increase in EMG activity with increasing ball size. Intuitively, a larger ball was hypothesized to require greater force and control, thereby resulting in higher levels of EMG activation from the gluteus medius and gluteus maximus muscles. It was also hypothesized that tensor fascia latae muscle activity would decrease from standing to sidelying due to the position of the hip being flexed in standing to extended in sidelying. As aforementioned, the EMG activity for the gluteus medius was mixed with the activity significantly higher in the standing and large ball conditions. EMG activity for the TFL was significantly higher in standing compared the sidelying/no ball condition. Gluteus maximus EMG activity was significantly higher in all conditions compared to the sidelying/no ball condition. The trends seen throughout the results could be explained by the level of mental concentration needed to complete the activity, the position of the hip in each position and biomechanics of each muscle group.

During the study, it was noted that several subjects required greater concentration when performing the exercises that required the addition of a ball or a resistance band compared to using no ball. Completing exercises with multiple components and added cueing requires greater concentration. Due to this increase in concentration, EMG readings were higher than hypothesized in standing and while using a ball. A 2015 study by Calatayud et al.[22] evaluated whether focusing on using specific muscles during bench press can activate specific musculature selectively. In the study, 18 resistance-trained men participated in three different bench press conditions at 20, 40, 50, 60, and 80% of their one-repetition maximum (1RM). The bench press conditions included a regular bench press, bench press focusing on the pectoralis muscles, and bench press focusing on the triceps brachii muscle group. Surface EMG signals were recorded for the triceps brachii and pectoralis major muscle groups. The study found that focusing on the muscle group increased the muscle activity for the relative loads between 20-60% of 1RM. Research concluded that resistance-trained individuals can increase muscle activity when focusing on using specific muscles at intensities up to 60% of 1RM.

Not only does concentrating on the exercise have a potential impact on EMG activity, so does external cueing. In a 2011 study by Stoate and Wulf, [23] thirty trained swimmers were instructed to swim three lengths of the pool (75 yards) using the front crawl with one minute breaks under three different focus conditions (control, internal, and external). For the control trial, the swimmers were not given any verbal instructions. For the internal focus trial, the swimmers were instructed to focus on pulling their hands back. For the external focus trial, the swimmers were instructed to focus on pushing the water back. The study reported that the swimmers had faster times during the control and external focus trials, and significantly slower times during the internal focus trial. During our study, we provided participants with instructions while completing the exercises and completed each set to the rhythm of a metronome at 50 beats per minute. The cuing was kept consistently external with instructions of "roll the ball up and down the wall with your ankle" as the focus was then on the ball and the wall, not the muscle group doing the work. This external impact could have an impact on levels of EMG activity. Although the amount of mental concentration and cueing may have a significant impact on EMG muscle activity during exercises, body positioning, biomechanics, and technique may be significant factors as well.

The understanding of muscle activation in the hip, specifically the tensor fascia latae, can help us determine optimal positioning for minimizing or maximizing activation. There is no clear understanding on why tensor fascia latae activation is better in standing, however, several studies have noted the effects of positioning to minimize or maximize TFL activation. Berry et al.,[24] found that TFL was activated more in "upright" versus "squat" positioning for standing hip abduction. When considering why this occurs, it is crucial to consider the anatomy and biomechanics. Tensor fascia latae is a hip flexor, while also a contributing hip abductor in the upright standing position, biomechanically. Berry et al., [24] notes during the upright standing position the TFL works to balance the pelvis on top of the stationary lower extremity. Therefore, TFL may act as a flexion counterbalance to the gluteal muscles in standing, however, in a squat position the flexor moment from the bodies center of mass minimizes the need for a TFL flexor moment.[24] Findings from Willcox et al, [25] further supports our results by exhibiting no effect on TFL through hip positioning in sidelying clam exercises. However, Lee et al., [26] demonstrated that neutral, medial, and lateral rotation at the hip did have an effect. TFL activation was much greater in lateral rotation, and less activation was noted in medial and neutral rotation compared with the gluteus medius.[26] These explanations signify that our findings of higher activation for TFL in standing, and decreased TFL activity in sidelying are presumably due to both biomechanical and positional influences. Hip positioning in sidelying plays an important role, but has less of an influence than biomechanics, upright standing, and weight bearing.

In addition to body positioning, placement of the resistance band in standing may have had an effect on EMG muscle activity. A separate study concluded that as a resistance band is moved distally during standing hip abduction exercises, EMG activity changes for the gluteus medius, gluteus maximus and TFL. EMG activity of the TFL was highest with the resistance band around the ankles, compared to around the knees or feet.[27] This may explain why in our study, the TFL EMG activation was highest during standing abduction with resistance at the ankles. In addition to band placement, different exercise technique for hip abduction seemingly contributes to EMG activity of hip abductor muscles. In our study, standing abduction was completed as a lateral step with a resistance band around the ankles. Results from a study by Bolgla (2005), found non-weight bearing standing hip abduction required the least activation of the hip abductors compared to weight bearing standing abduction. Furthermore, EMG activity of the gluteus medius muscle was lower in non-weight bearing sidelying compared to weight bearing in standing hip abduction.[28] This reinforces our findings of higher EMG activity of the hip abductor muscles during standing hip abduction compared to all other positions.

This research study was completed to compare muscle recruitment patterns during hip abduction exercises. This research can help determine what exercises are best for recruiting hip abductor musculature. There are multiple benefits to strengthening these specific muscles. Benefits including faster rehabilitation, injury prevention, fall prevention and enhancement of walking, running and everyday activities. Therefore, strengthening of this musculature is beneficial for individuals across the lifespan. We found standing abduction with a resistive band around the ankles recruits all three of the hip abductor muscles, particularly the TFL. To maximize gluteus medius and gluteus maximus activation while minimizing contribution of the TFL, we found that sidelying hip abduction with a medium sized ball produced the highest activity. Based on our findings in the clinic, maximal activation of TFL is achieved more successfully with standing resistance. If the objective was to minimize TFL activation, while increasing gluteus medius and gluteus maximus muscle activity, sidelying hip abduction exercises would be best. This can be done with the use of resistance or rolling a ball up the wall, compared to straight sidelying hip abduction. It is clear that further research is needed, possibly with more subjects, additional exercises addressing specific biomechanics and positioning of the hip abductor muscles, and more detailed instructions as per the performance of the exercises. In conclusion, strengthening of the hip musculature is beneficial. Future researchers should attempt to illuminate optimal exercises and positions to achieve the goal of efficient gluteus medius, gluteus maximus and tensor fascia latae muscle recruitment.

APPENDIX

UNIVERSITY OF NORTH DAKOTA

UND.edu

DIVISION OF RESEARCH & ECONOMIC DEVELOPMENT

Institutional Review Board
Twamley Hall, Room 106
264 Centennial Dr Stop 7134
Grand Forks, ND 58202-7134
Phone: 701.777.4279
Fax: 701.777.6708
Email: UND.irb@research.UND.edu

April 30, 2018

Principal Investigator:	David Relling, PT, Ph.D.
Project Title:	Electromyography (EMG) Activity of the Gluteus Medius During Various Hip Exercises
IRB Project Number:	IRB-201804-302
Project Review Level:	Expedited 4
Date of IRB Approval:	04/26/2018
Expiration Date of This Approval:	04/25/2019
Consent Form Approval Date:	04/26/2018

The application form and all included documentation for the above-referenced project have been reviewed and approved via the procedures of the University of North Dakota Institutional Review Board.

Attached is your original consent form that has been stamped with the UND IRB approval and expiration dates. Please maintain this original on file. ***You must use this original, stamped consent form to make copies for participant enrollment. No other consent form should be used.*** It must be signed by each participant prior to initiation of any research procedures. In addition, each participant must be given a copy of the consent form.

Prior to implementation, submit any changes to or departures from the protocol or consent form to the IRB for approval. No changes to approved research may take place without prior IRB approval.

You have approval for this project through the above-listed expiration date. When this research is completed, please submit a termination form to the IRB. If the research will last longer than one year, an annual review and progress report must be submitted to the IRB prior to the submission deadline to ensure adequate time for IRB review.

The forms to assist you in filing your project termination, annual review and progress report, adverse event/unanticipated problem, protocol change, etc. may be accessed on the IRB website: http://und.edu/research/resources/human-subjects/

Sincerely,

Michelle L. Bowles, M.P.A., CIP
IRB Manager

MLB/sb
Enclosures

Cc: Chair, Physical Therapy

Research Project Review and Progress Report

University of North Dakota Institutional Review Board

Institutional Review Board FEB 28 2019 University of North Dakota

DATE: 2/1/2019 **DEPARTMENT:** Physical Therapy

PRINCIPAL INVESTIGATOR: Relling, David

PROJECT TITLE: Electromyography (EMG) Activity of the Gluteus Medius During Various Hip Exercises

PROPOSAL NUMBER: IRB-201804-302

IF MEDICAL COMPONENT, PLEASE GIVE PHYSICIAN'S NAME: ______

IRB USE ONLY

☐ FULL BOARD REVIEW REQUIRED, EVEN THOUGH ORIGINAL APPROVAL WAS EXPEDITED

☒ CONTINUED APPROVAL, "EXPEDITED" CATEGORY #4

☐ NEXT REVIEW REQUIRED BEFORE: MAR 6 2020

☐ CONTINUED APPROVAL, BASED ON FULL BOARD REVIEW

☐ NEXT REVIEW REQUIRED BEFORE: ______

☐ SUSPEND APPROVAL, PENDING INVESTIGATION

☐ APPROVAL TERMINATED

COMMENTS OF REVIEWER: ______

Signature of Chair/Vice Chair or Designee: [signature]

cc: Chair, Physical Therapy

Approval Date: 03/07/19

1. Is project complete? Yes ☐ No ☒
2. Is project ongoing? Yes ☒ No ☐

   If No, explain below and indicate if continued approval and continuing review is desired.

3. How many subjects have been enrolled in the research project?

   15 since the date of last approval, and

   15 since the initial approval

4. Is the research permanently closed to the enrollment of new subjects? Yes ☐ No ☒

   Have all subjects completed all research-related interventions? Yes ☐ No ☒

   Does the research remain active only for long-term follow-up of subjects? Yes ☐ No ☒

5. Is data analysis complete? Yes ☐ No ☒

*** If the research is permanently closed to the enrollment of new subjects, all subjects have completed all research-related interventions, the research does not need to remain active for long-term follow-up of subjects, and all data analysis is complete, please sign here that you would like the IRB to terminate approval for this project, and finish filling out the rest of this form.

Please terminate IRB approval for this research project ______ ______

Signature of Principal Investigator Date

6. Has any additional grant money been awarded for this project in the past year? Yes ☐ No ☒
If yes, submit a copy of the grant along with this completed form.

7. Describe any adverse events and/or unanticipated problems involving risks to subjects or others that have occurred since the last approval. If you did not report the adverse event or unanticipated problem previously, a separate Unanticipated Problem/Adverse Event Form must be submitted to RD&C with this form.

No adverse events or unanticipated problems.

8. Have any additional risks with this research been identified? Yes ☐ No ☒
Describe all benefits experienced by participants, and include a current risk/benefit assessment based on study results.

Benefits are to participate in different exercises for hip strengthening and contributing to research to help fall prevention.

9. Have there been any changes or deviations from the approved protocol since the most recent approval? Yes ☐ No ☒ If Yes, elaborate below, and submit a separate Protocol Change Form to the RD&C indicating proposed protocol changes.

a. Have any of these changes been implemented already? Yes ☐ No ☐
If yes, please describe fully.

b. Are any protocol changes being planned for later implementation? Yes ☒ No ☐
If yes, please describe fully. A separate Protocol Change Form must be submitted to RD&C for approval before the proposed protocol changes can be implemented.

Adding one additional muscle and one additional exercise to the protocol. I will submit a Protocol Change Form.

10. Have any subjects withdrawn from the research? Yes ☐ No ☒
If yes, state how many have withdrawn and describe the circumstances.

Continue to the next page →

11. Have there been any complaints about the research since the last IRB review? Yes ☐ No ☒
If yes, please report and summarize the complaints and your response/action.

12. Summarize any multi-site trial reports relevant to your research.
No multisite trials completed on this subject.

13. Summarize any recent literature, findings, or other information relevant to your research, especially information about risks associated with the research.
No additional research has been found specifically addressing the exercises and emg activity in this study.

14. Have all PI's involved with the research completed the IRB Educational Requirements?
Yes ☒ No ☐ (Educational requirements must be completed before the IRB can grant continued approval for the research project.)

15. On a separate piece of paper, provide a thorough protocol summary (approximately 300 words) giving a concise summary of the protocol's progress to date and the reasons for continuing the study or reasons for asking the IRB to terminate approval. The summary should include, for instance, an explanation of any complaints about the research, relevant multi-site trial reports, participant benefits, or a current risk-benefit assessment based on study results. Sufficient information is required in the summary so that the IRB can determine whether the proposed research continues to fulfill the criteria for approval.

See attached.

16. A copy of the current informed consent document(s) (with the IRB Approval stamp), as well as a clean copy of the consent document(s) (with no IRB Approval stamp) must be submitted with this report.

Completed.

17. Have there been any changes in the conflict of interest statement or situation for the Principal Investigators, research staff involved in the study, or each individual's respective family members in the last 12 months?
Yes ☒ No ☐ If yes, please describe fully on a separate sheet of paper.
See attached, Change in research staff.

Signature of Principal Investigator [signature] Date 2/28/19

Current Email Address: david.relling@und.edu

Current Mailing Address: Stop 9037 Dept. of Physical Therapy

This completed form should be returned to the IRB, University of North Dakota, 264 Centennial Drive Stop 7134, Grand Forks, ND 58202-7134.

Date 2/28/2019

Project Title: Electromyography (EMG) activity of the gluteus medius during various hip exercises.

Proposal Number: IRB-201804-302

Progress Report:

15. The study has obtained 15 subjects. I wish to continue the project to obtain 30-40 subjects. I feel that 30-40 subjects for an EMG study will provide adequate power and confidence in the results. There have been no complaints or concerns about the protocol, the sites of the electrode placement, or the exercises. There have been no observed or reported skin irritation from the research project.

A protocol change will be submitted to add one additional muscle (tensor fascia lata) to be studied and one additional exercise. The additional exercise will be hip abduction in sidelying. Abduction in sidelying will have the subject lay on their side and then lift the top leg into the air 20-40 degrees. The subject will then bring the leg back to its resting position. The subjects already perform hip abduction in sidelying with a ball behind their heel. The addition of this exercise will provide a standard for comparison to the exercise in standing and the exercises with the ball behind the subjects heel.

17. Key personnel will change. Graduate Students Taylor Doeden, Mitchell Karbo, Kalie Maiden, and Analise Richtsmeier will graduate and will no longer be involved in the study. A new key personnel form is attached. New personnel are graduate students

PROTOCOL CHANGE FORM
UNIVERSITY OF NORTH DAKOTA INSTITUTIONAL REVIEW BOARD

Please complete this form and attach revised research documents for any proposed change to your protocol, consent forms, or any supportive materials (such as advertisements, questionnaires, surveys, etc.). All changes must be highlighted. Any proposed change in protocol affecting human participants must be reviewed and approved by the IRB prior to implementation, except where an immediate change is necessary to eliminate a hazard to the participant.

Principal Investigator: David Relling, PT, PhD

Telephone: 777-4091 E-mail Address: David.relling@und.edu

Complete Mailing Address: 1301 N Columbia Rd Rm E321 Stop 9037 Grand Forks ND 58202-9037

School/College: School of Medicine & Health Sciences Department: Physical Therapy

Project Title: Electromyography (EMG) Activity of the Gluteus Medius during Various Hip Exercises

Proposal Number: IB-201804-302 **Approval Date:** 4/26/2018

THE CURRENT STATUS OF THE PROJECT IS (Check one)

x Project currently in progress. Number of subjects enrolled is: **15**

___ Project not yet started. No subjects enrolled.

___ Project closed to subject entry.

1. Briefly describe and explain the reason for the revision or amendment and the justification for the change. Include a copy of affected protocol pages and consent form with specific changes highlighted.

The requested change is to add the tensor fascia lata muscle for EMG data collection and a sidelying hip abduction exercise. The tensor fascia lata muscle is important for stabilizing hip movement, especially rotation, when subjects are performing exercises of the hip. Our initial protocol did not include this muscle as the study was focused on mainly hip abduction muscles (moving the leg to the side) instead of rotation. The addition of this muscle will provide more detail to the use of muscle during the different exercises in this study. The sidelying hip abduction is a common exercise for strengthening the hip. The person lays on one side and then uses the hip muscles on the outside of the hip to lift the top leg into the air. I missed this additional activity as a baseline for the hip exercises already approved for the study.

2. Does the change affect the study or subject participation (procedures, risks, costs, etc.)? ___ Yes X No

Please explain: The hip abduction exercise is commonly performed at fitness facilities and rehabilitation settings. The exercise is less strenuous than the hip abduction with a ball that is currently approved for the study. Note, the study has received no complaints of soreness or discomfort with the current list of exercises.

3. Does the change affect the consent document? x Yes ___ No

If yes, include the revised consent form(s) with the changes highlighted, and a clean copy of the revised consent form(s).

By signing below, you are verifying that the information provided in the Human Subjects Review Form and attached information is accurate and that the project will be completed as indicated.

Signatures:

Principal Investigator Date:

Student Adviser (if applicable) Date:

ID #: _2019-______

TITLE: Electromyography (EMG) Activity of the Gluteus Medius during various hip exercises

Subject Questionnaire and Data Collection

DOB:________________ Height (in) ___________________

Gender:___M / F________ Weight (lbs)___________________

Hand Dominance: R/L

1) Have you had any injuries to your legs? YES/NO
   If YES, please explain: ___________________________________

2) Have you had any injuries to your pelvis or back? YES/NO
   If YES, please explain:____________________________________

3) Have you experienced itching, rash or irritation from bandages or adhesives on tape? YES/NO
   If YES, please explain:____________________________________

POSITION	Sequence of Testing (1-4)	
Standing hip abduction		
Sidelying hip abduction, NO ball		
Sidelying hip abduction, small ball		
Sidelying hip abduction, medium ball		
Sidelying hip abduction, large ball		

NOTES:

INFORMED CONSENT

TITLE: Electromyography (EMG) activity of the Gluteus Medius during various hip exercises

PROJECT DIRECTOR: David Relling, PT, Ph.D.

PHONE # (701)777-4091

DEPARTMENT: Physical Therapy

STATEMENT OF RESEARCH

A person who is to participate in the research must give his or her informed consent to such participation. This consent must be based on an understanding of the nature and risks of the research. This document provides information that is important for this understanding. Research projects include only subjects who choose to take part. Please take your time in making your decision as to whether to participate. If you have questions at any time, please ask.

WHAT IS THE PURPOSE OF THIS STUDY?

You are invited to take part in a research study conducted by David Relling, a faculty member of the Department of Physical Therapy at the University of North Dakota. The purpose of this study is to better understand the effect of hip exercises on the activation and use of hip muscles. You were selected because you are over the age of 18, do not have any recent hip injuries or diseases and do not have any allergies to adhesives like tape.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 30 people will take part in this study at the University of North Dakota.

HOW LONG WILL I BE IN THIS STUDY?

Your participation in the study will last for 1 session of approximately 1 hour. You will need to visit the physical therapy department (1301 N Columbia Rd, Room E312, and its research lab) where the study will take place.

WHAT WILL HAPPEN DURING THIS STUDY?

You will complete a form that asks about your age, height, weight, gender, hip injuries and allergies to tape. The information is needed to determine eligibility to participate in the study. Following completion of the form, the researchers will prepare to collect information regarding your muscles' activity using electromyography (EMG). EMG uses small, adhesive-backed electrodes attached to the skin and a device that can detect the electrical activity present in

Date__________
Subject Initials: _________

muscles at rest and in action. The device does not give off an electrical current or shock to your body—it only detects electrical activity present in muscles over which electrodes are attached. (See Figure 1 for sites of muscles and electrode placement) The researchers will clip any hair present over areas of muscle on which electrodes are to be placed. This will be followed by rubbing the skin lightly with sandpaper and an alcohol wipe in order to improve the ability to detect electrical activity. The electrodes will convey electrical information to the device for actual measurement. Once electrodes are in place, you will be asked to perform five different exercises. Standing hip movements with resistive band at your ankles, laying on your side and lifting your leg into the air, laying on your side while lifting your leg and moving one of three different sized balls. You will be asked to perform the sidelying exercise with all three balls.

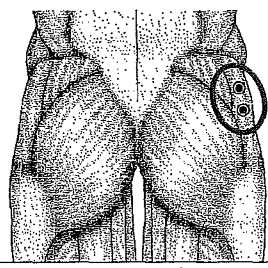
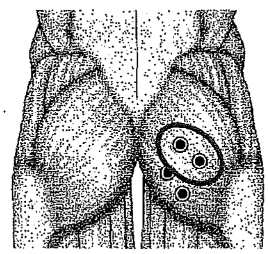
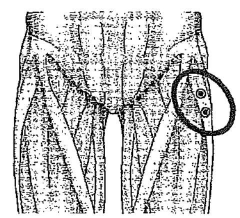
Gluteus medius hip muscle	Gluteus maximum hip muscle	Tensor fascia latae muscle
		

Figure 1 EMG sites for electrode placement on hip muscles.

WHAT ARE THE RISKS OF THE STUDY?

There may be some risk from being in this study, such as the small risk of mild skin irritation at the site of the electrode that reads the muscle activity, a common short-lasting occurrence in studies using EMG. Steps will be taken to ensure your modesty and comfort by covering areas where electrode application may approach more personal body areas.

If you are pregnant or become pregnant during the study, we foresee no additional risks to you or the baby during the course of the research.

WHAT ARE THE BENEFITS OF THIS STUDY?

You may not benefit personally from being in this study. However, we hope that, in the future, other people might benefit from this study because results from this research may help the understanding of the best exercises to activate and strengthen muscles that minimize the risk of falling.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY? WILL I BE PAID?

You will not have any costs for being in this research study other than perhaps traveling or parking costs. You will not be paid for being in this research study.

WHO IS FUNDING THE STUDY?

The University of North Dakota and the research team are receiving no payments from other agencies, organizations, or companies to conduct this research study.

CONFIDENTIALITY

The records of this study will be kept private to the extent permitted by law. In any report about this study that might be published, you will not be identified. Your study record may be reviewed by Government agencies, the UND Research Development and Compliance office, and the University of North Dakota Institutional Review Board.

Any information that is obtained in this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of coding data and computer files with an independent number for each subject. You should know, however, that there are some circumstances in which we may have to show your information to other people. For example the law may require us to show your information to a court or to tell authorities if we believe you have abused a child, or you pose a danger to yourself or someone else. Confidentiality will be maintained by means of storing of all records and research information in separate locked file cabinets in Room E336 of the Physical Therapy Department. All collected research information and records will be destroyed by shredding after 3 years.

If we write a report or article about this study, we will describe the study results in a summarized manner so that you cannot be identified.

COMPENSATION FOR INJURY

In the event that this research activity results in an injury, treatment will be available including first aid, emergency treatment and follow-up care as needed. Payment for any such treatment is to be provided by you (you will be billed) or your third-party payer, if any (such as health insurance, Medicare, etc.) No funds have been set aside to compensate you in the event of injury. Also, the study staff cannot be responsible if you knowingly and willingly disregard the directions they give you.

IS THIS STUDY VOLUNTARY?

Your participation is voluntary. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Your decision whether or not to participate will not affect your current or future relations with the University of North Dakota.

Date__________
Subject Initials: ________

CONTACTS AND QUESTIONS

The researcher conducting this study is David Relling. You may ask any questions you have now or anytime during your participation in the study. If you later have questions, concerns, or complaints about the research please contact David Relling in the Physical Therapy Department at 777-2831 during the day and at (701)741-3481 after hours. If you have questions regarding your rights as a research subject, or if you have any concerns or complaints about the research, you may contact the University of North Dakota Institutional Review Board at (701) 777-4279.

- You may also call this number about any problems, complaints, or concerns you have about this research study.
- You may also call this number if you cannot reach research staff, or you wish to talk with someone who is independent of the research team.
- General information about being a research subject can be found by clicking "Information for Research Participants" on the web site: http://und.edu/research/resources/human-subjects/research-participants.cfm

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You may receive a copy of this form by requesting one.

Subjects Name: ____

___________________________________ ____________________

Signature of Subject Date

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative.

___________________________________ ____________________

Signature of Person Who Obtained Consent Date

REFERENCES

1. Hollman JH, Kolbeck KE et al. Correlations between hip strength and static foot and knee posture. *J Sport Rehabil.* 2006;15(1):12– 23. Accessed June 28, 2019.
2. Nadler SF, Malanga GA et al. The relationship between lower extremity injury, low back pain, and hip muscle strength in male and female collegiate athletes. *Clin J Sport Med.* 2000;10:89–97. Accessed July 2, 2019.
3. Reiman MP, Bolgla LA et al. A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. *Physiother Theory Prac* 2012; 28(4):257–68. 10.3109/09593985.2011.604981
4. Garrison JC, Bothwell J et al. Effects of hip strengthening on early outcomes following anterior cruciate ligament reconstruction. *Int J Sports Phys Ther*. 2014;9(2):157–167.
5. Take a Stand on Falls. Centers for Disease Control and Prevention. Published September 22, 2017. Accessed July 2, 2019.
6. Hilliard, MJ., Martinez, KM et al. (2008). Lateral balance factors predict future falls in community-living older adults. Archives of Physical Medicine and Rehabilitation, 89(9), 1708–1713. doi:10.1016/ j.apmr.2008.01.023 S0003-9993(08)00395-X [pii].
7. Friel K, McLean N et al. Ipsilateral hip abductor weakness after inversion ankle sprain. *J Athl Train.* 2006;41(1):74-78. Accessed June 26, 2019.
8. Kalache A, Fu D et al. World Health Organisation Global Report on Falls Prevention in Older Age. 2008. Accessed September 19, 2019.
9. Choi H, Hayward RA, Langa KM. Fall associated difficulty with activities of daily living (ADL) in functionally independent older adults aged 65 to 69 in the united states: A cohort study. *J Am Geriatr Soc.* 2013;61(1). doi: 10.1111/jgs.12071.
10. Reiman MP, Bolgla LA Lorenz D. Hip functions influence on knee dysfunction: a proximal link to a distal problem. *J Sport Rehabilitation.* 2009. Accessed September 10, 2019.
11. Neumann DA 2010 Kinesiology of the hip: A focus on muscular actions. *Journal of Orthopedic and Sports Physical Therapy* 40: 82–94. Accessed June 27, 2019.
12. Choi H, Hayward RA, Langa KM. Fall associated difficulty with activities of daily living (ADL) in functionally independent older adults aged 65 to 69 in the united states: A cohort study. *J Am Geriatr Soc.* 2013;61(1). doi: 10.1111/jgs.12071.
13. Gottschalk F, Kourosh S, Leveau B 1989 The functional anatomy of tensor fascia latae and gluteus medius and minimus. *Journal of Anatomy.* 166: 179–189. Accessed June 29, 2019.
14. Neumann DA, Kelly ER et al. *Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation.* 3rd ed. St. Louis, MO: Elsevier; 2017. Accessed June 28, 2019.
15. Ramskov D, Barton C et al. High eccentric hip abduction strength reduces the risk of developing patellofemoral pain among novice runners initiating a self-structured running

program: A 1-year observational study. *J Orthop Sports Phys Ther.* 2015;45(3):153-161. doi: 10.2519/jospt.2015.5091.

16. Weiland S, Smit IH et al. The effect of asymmetric movement support on muscle activity during lokomat guided gait in able-bodied individuals. *PLoS One.* 2018;13(6):e0198473 .doi: 10.1371/journal.pone.O198473.
17. Macadam P, Cronin J et al. An Examination of the gluteal muscle activity associated with dynamic hip abduction and hip external rotation exercise: A systematic review. *Int J Sports Phys Ther.* 2015;10(5):573–591. Accessed July 2, 2019.
18. Selkowitz DM, Beneck GJ et al. Which exercises target the gluteal muscles while minimizing activation of the tensor fascia latae? Electromyographic assessment using fine- wire electrodes. *J Orthop Sports Phys Ther.* 2013;43:54-64. Accessed July 3, 2019.
19. Falls. *World Health Organization.* Updated 2018. Accessed Jul 2, 2019.
20. Brophy R, Silvers HJ et al. Gender influences: The role of leg dominance in ACL injury among soccer players. *Br J Sports Med.* 2010;44(10):694-697. doi: 10.1136/bjsm.2008.051243.
21. Criswell, E. (2011). *Cram's Introduction to Surface Electromyography.* Sudbury MA, Jones and Bartlett Publishers.
22. Calatayud J, Vinstrup J et al. Importance of mind-muscle connection during progressive resistance training. *PubMed.* Published December 23, 2015. Accessed September 9, 2019.
23. Stoate I, Wulf G. Does the Attentional Focus Adopted by Swimmers Affect Their Performance? - Isabelle Stoate, Gabriele Wulf, 2011. *SAGE Journals.* Accessed September 10, 2019.
24. Berry JW, Lee TS, et al. Resisted Side Stepping: The Effect of Posture on Hip Abductor Muscle Activation. *Journal of Orthopaedic & Sports Physical Therapy.* 2015;45(9):675-682. doi:10.2519/jospt.2015.5888.
25. Willcox EL, Burden AM. The Influence of Varying Hip Angle and Pelvis Position on Muscle Recruitment Patterns of the Hip Abductor Muscles During the Clam Exercise. *Journal of Orthopaedic & Sports Physical Therapy.* 2013;43(5):325-331. doi:10.2519/jospt.2013.4004.
26. Lee J-H, Cynn H-S et al. Effects of Different Hip Rotations on Gluteus Medius and Tensor Fasciae Latae Muscle Activity During Isometric Side-Lying Hip Abduction. *Journal of Sport Rehabilitation.* 2013;22(4):301-307. doi:10.1123/jsr.22.4.301.
27. Cambridge ED, Sidorkewicz N et al. Progressive hip rehabilitation: the effects of resistance band placement on gluteal activation during two common exercises. *Clin Biomech.* 2012; 27: 719– 724. Accessed September 19, 2019.
28. Bolgla LA, Uhl TL. Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. *Journal of Orthopaedic & Sports Physical Therapy.* 2005;35(8),487-494. doi: 10.2519/jospt.2005.35.8.487