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Electromyography Measures of Selected Gluteus and Hip
Muscle Activation of Recreational Athletes During
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Kimberly Sue Sieve

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Tracey Covassin
Major Professor's Signature

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ELECTROMYOGRAPHY MEASURES OF GLUTEUS AND HIP MUSCLE ACTIVATION OF RECREATIONAL ATHLETES DURING NON-WEIGHT-BEARING EXERCISES.

By

KIMBERLY SUE SIEVE

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ABSTRACT

ELECTROMYOGRAPHY MEASURES OF SELECTED GLUTEUS AND HIP MUSCLE ACTIVATION OF RECREATIONAL ATHLETES DURING NON-WEIGHT-BEARING EXERCISES

By

Kimberly Sue Sieve

Purpose: The purpose of this study is to determine the muscle activation levels of the gluteus and hip muscles during 3 non-weight-bearing exercises, and examine gender differences in hip and gluteus muscle activation.

Methods: A total of 30 participants (15 male, 15 female) volunteered for this study. Surface EMG was utilized to measure muscle activation of the gluteus maximus, gluteus medius, tensor fascia latae (TFL), and lateral hamstring. Data were collected during maximum voluntary contractions (MVC), and 3 non-weight-bearing exercises.

Results: TFL and gluteus medius produced the greatest activation across all exercises. TFL activation was significantly greater during side-lying hip abduction with external rotation ($p = .025$). Females demonstrated significantly greater TFL activation across all exercises.

Conclusion: Results suggest non-weight-bearing exercises may be used to activate and strengthen the gluteus medius and TFL. Clinicians may utilize results from this study when developing rehabilitation protocols.

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CHAPTER 1

INTRODUCTION

Overview of Problem

As long as people are active, there will be injuries, and as long as there are injuries, rehabilitation will be needed. However, rehabilitation of athletic injuries can be very difficult when the source of the injury is unknown or unidentified. Some injuries are caused by an existing condition, such as muscle weakness or tightness, which may predispose a person to injury. Gluteus medius weakness is one predisposing factor that has been frequently cited in numerous research studies related to lower extremity injuries (Bolgla & Uhl, 2005; Brindle, Mattacola, & McCory, 2003; Earl, 2004; Earl, Hertel, & Denegar, 2005; Mascal, Landel, & Powers, 2003). The gluteus medius is the target of rehabilitation for various lower extremity problems ranging from knee and hip to low back injuries. However, the question remains if the exercises that are being used to strengthen the gluteus medius are effectively activating the muscle.

The primary function of the gluteus medius is hip abduction, although the anterior fibers assist with internal rotation and flexion of the hip and the posterior fibers assist with external rotation and extension of the hip. The upper fibers of the gluteus maximus, as well as the tensor fasciae latae (TFL) also assist in hip abduction. In a case study conducted by Mascal et al. (2003), subjects with patellofemoral pain exhibited significant weakness in gluteus maximus, and lateral rotators of the hip as well as gluteus medius weakness. Therefore, one must wonder if it is exclusively gluteus medius weakness that is contributing to lower extremity injuries or if it is overall hip muscle weakness.

Previous research has focused on a variety of strengthening exercises for the gluteus medius, TFL, and hip abductors in general. The side-lying hip abduction exercise as well as side-lying hip abduction with external rotation have been tested and found to be effective in activating the gluteus medius (Bolgla & Uhl, 2005; Schmitz, Riemann, & Thompson, 2002). One exercise that has been documented in rehabilitation practices, but has not been tested in research is the clamshell (Greenman, 2003; Mascal et al., 2003). The clamshell is an abduction external rotation maneuver. The clamshell exercise is designed to strengthen the gluteus medius; however, if there is a strength deficit the subject may rely more on the TFL or lateral rotators of the hip. It is also possible that if the subject is allowing the pelvis to rotate, or not executing the exercise properly, the lateral rotators, such as, the lateral hamstring and gluteus maximus may be activated to a greater extent. To date, no research pertaining to the level of gluteus and hip muscle activation during the clamshell exercise has been documented.

Very little research has investigated the differences between males and females of muscle activation during exercises for selected gluteus muscles and other hip musculature. Several studies have investigated the activation of hip musculature during dynamic activity such as single-leg landing or squatting (Russell, Palmieri, Zinder, & Ingersoll, 2006; Zeller, McCrory, Kibler, & Uhl, 2003; Zazulak, Ponce, Straub, Medvecky, Avedisian, & Hewett, 2005). However, research studies do not demonstrate a general consensus on activation of hip musculature during dynamic activity. Furthermore, these studies focused on the impact that the muscle activation levels had on anterior cruciate ligament injury, not the muscle activation levels of specific exercises used to strengthen the hip and gluteus muscles.

Significance of Problem

In the most extreme cases of gluteus medius weakness, a Trendelenburg gait may develop or be exacerbated

(Petrofsky, 2001). A Trenelenburg gait is marked by a drop in the hip opposite the affected side during the weight bearing phase of the gait cycle (Petrofsky, 2001). The drop in the opposite hip creates an abnormal gait and thus changes the entire kinetic chain. In less severe cases, it can still cause problems for the lower extremity. Gluteus medius weakness has been linked to the cause of patellofemoral pain, general anterior knee pain, low back pain, iliotibial (IT) band syndrome, and overall mal-alignment of the lower extremity (Brindle et al., 2003). Various treatment techniques have been used in the correction of these problems, and gluteus medius and hip abductor strengthening is one that has been utilized in all of these problems. Clinically the clamshell, side-lying hip abduction, and side-lying hip abduction with external rotation have been used to strengthen the gluteus medius, but no research has been conducted to compare the differences in muscle activation during each of these exercises.

By examining the muscle activation of the gluteus medius and TFL during the side-lying abduction, clamshell, and side-lying abduction with external rotation, it is possible to determine which exercise activates the gluteus medius and TFL to the greatest degree. By also testing the gluteus maximus, and lateral hamstring one is able to determine the contribution of each of these muscles during the exercises. It is crucial to determine which of the gluteus and hip muscles are activated to the greatest degree during each exercise. Providing the best care possible to an athlete is the ultimate goal of any health care provider. If it is possible to determine the most effective method for activating, and thus strengthening the gluteus and hip muscles, it may increase the potential to reduce the amount of time that athletes miss due to secondary injury caused by this muscle weakness.

Statement of the Problem

The purpose of this study was to determine if the type of rehabilitation exercises utilized, clamshell, side-lying hip abduction, or side-lying hip abduction with external rotation affects the level of selected gluteus and hip muscle activation. A secondary purpose was to determine if there were differences present between males and females in the levels of gluteus and hip muscle activation during each exercise.

Need for the Study

Knowledge about which exercises elicit the greatest level of gluteus and hip muscle activation may help in the development of rehabilitation and strengthening programs.

Despite the fact that the clamshell exercise has been recommended as a rehabilitation exercise, there is little credible research to demonstrate the muscle activation levels associated with this exercise. Other studies have examined various gluteus medius exercises, including side-lying hip abduction (Bolgla & Uhl, 2005; Mascal et al., 2003) and side-lying hip abduction with external rotation (Earl, 2004) but no research to my knowledge has studied muscle activation during the clamshell exercise compared to other exercises. This study may provide some verification for the use of the clamshell exercise in current rehabilitation protocols and allow clinicians, athletes, and coaches to implement the exercises that result in high levels of activation.

Research Questions

Which of the selected gluteus and hip muscles (gluteus maximus, gluteus medius, TFL, lateral hamstring) have the greatest activation during each of the following exercises: the clamshell, side-lying hip abduction, and side-lying hip abduction with external rotation?

Do male and female recreational athletes differ in selected gluteus and hip muscle activation during the clamshell, side-lying hip abduction, and side-lying hip abduction with external rotation exercises?

Definition of Terms

Recreational athlete: Someone who participates in physical activity for at least 20 minutes, at least 3 times per week and does not have a professional training regimen.

Clamshell: A hip strengthening exercise completed with the participant in a lateral recumbent position with the knees flexed 90 degrees and the knees flexed to 45 degrees. Participant maintains the feet together and lifts the top knee (Greenman, 2003).

Side-lying hip abduction: A hip strengthening exercise completed with the participant lying on their side with the legs parallel and the knees and hips extended. Participant abducts the upper leg and then returns to the starting position (Bolgla & Uhl, 2005).

Lateral Recumbent Position: Side-lying with the shoulders and pelvis perpendicular to the table and the hips slightly flexed to 45 degrees (Greenman, 2003).

Electromyograph (EMG): Recording device used to measure the electrical impulse of the muscle to allow detection of contraction or enervation.

CHAPTER 2

LITERATURE REVIEW

This section will outline background information pertaining to the gluteus and hip muscles anatomy and function, gluteus and hip weakness, gluteus and hip EMG research, measures of muscle activation, and differences between males and females in hip and gluteus muscle activation.

Gluteus and Hip Anatomy and Function

Gluteus medius muscle function. To understand the rehabilitation and strengthening exercises utilized for the gluteus medius, it is important to first understand how the muscle functions. The gluteus medius is commonly referred to as a primary abductor of the hip joint (Schmitz et al., 2002). The gluteus medius originates on the outer surface of the iliac crest and creates a fan shape before inserting on the greater trochanter of the femur (Earl, 2004; Kendall, McCreary, & Provance, 1993). Although the primary function of the gluteus medius is abduction, the anterior fibers have also been shown to perform internal rotation, and assist in hip flexion, while the posterior fibers externally rotate the hip and assist in extension (Bewyer & Bewyer, 2003; Earl, 2004; Kendall et al., 1993). According to Hertel, Sloss, and Earl (2005) and Schmitz et al. (2002)

the gluteus medius serves a dynamic role as a pelvic stabilizer during stationary weight-bearing activities, and serves as a pelvic rotator during movement activities. Therefore, it is evident that the gluteus medius is an important muscle for overall stabilization and proper movement of the pelvis.

Gluteus maximus muscle function. The gluteus maximus is a relatively large muscle that serves numerous functions for the body. Containing many fibers, the gluteus maximus originates on the illium, the lower part of the sacrum, and the sacrotuberous ligament (Kendall et al., 1993). The majority of the muscle fibers insert into the iliotibial tract of fascia lata, while fewer fibers also insert into the gluteal tuberosity of the femur (Kendall et al., 1993). The gluteus maximus is a strong hip extensor and also aids in lateral rotation of the hip. The upper fibers also assist in abduction, creating a function similar to the gluteus medius (Mascal et al., 2003), while the lower fibers assist in adduction. According to Nadler, Malanga, Bartoli, Feinberg, Prybicien, and Deprince (2002) the gluteus maximus provides pelvic stability when the center of gravity is shifted and during trunk rotation. Therefore, similar to the gluteus medius, adequate gluteus maximus strength is also crucial for pelvic stabilization.

Tensor fascia latae (TFL) muscle function. The TFL originates on the anterior portion of the iliac crest and the iliac spine, and inserts into the IT band in the middle third of the thigh (Kendall et al., 1993). Similar to the anterior fibers of the gluteus medius, the tensor fascia latae is a strong hip abductor, and also assists in hip flexion and medial rotation (Kendall et al., 1993). Mascal et al. (2003) suggest that the TFL is more active in hip abduction when the hip and knee are in an extended position. In situations when the TFL is preferentially utilized for abduction over the gluteus medius, weakness and atrophy may develop in the gluteus medius (Bewyer & Bewyer, 2003).

Lateral hamstring muscle function. The short head of the biceps femoris originates on the linea aspera and the supracondylar line while the long head originates on the sacrotuberous ligament and the ischial tuberosity (Kendall et al., 1993). The biceps femoris inserts on the lateral aspect of the head of the fibula and the lateral tibial condyle (Kendall et al., 1993). Both portions of the muscle flex and laterally rotate the knee joint and the long head also assists in extension and lateral rotation of the hip joint. The lateral hamstring is important in providing lateral stability for the knee as well as preventing unwanted pelvic tilts and rotations (Kendall et al., 1993).

Gluteus and Hip Muscle Weakness

Although the gluteus medius is one of many pelvic stabilizing muscles, it has become the target of rehabilitation programs for numerous lower extremity injuries and dysfunctions. Weakness or dysfunction of the gluteus medius creates a problem in the kinetic chain of the lower extremity which may cause pain at locations remote to the gluteus medius (Brindle et al., 2003). Brindle et al. (2003) found that subjects with anterior knee pain demonstrated a decrease in musculature strength as well as differences in gluteus medius timing characteristics. However, when Boling, Bolgla, Mattacola, Uhl, and Hosey (2006) conducted a study similar to Brindle et al. (2003), they found no significant difference in gluteus medius timing characteristics in subjects with patellofemoral pain compared to healthy subjects. This study did not measure hip muscle strength. It was clinically demonstrated by Mascal et al. (2003) that dysfunction of the gluteus medius along with the hip extensors and external rotators was connected to malalignment of the lower extremity which has been linked to patellofemoral pain.

Nyland, Kuzemchek, Parks, and Carbon (2004) also suggested a link between patellofemoral pain and inability to stabilize the pelvis. The hip abductors, mainly gluteus medius, gluteus maximus, and TFL, aid in maintaining the horizontal pelvic alignment during single leg support. The inability to control the hip and patellofemoral joint during dynamic activity increases femoral anteversion, which is associated with the cause of patellofemoral joint pain and dysfunction (Nyland et al., 2004). Similarly, Earl et al. (2005) found that when gluteus medius dysfunction was present with other lower extremity malalignments such as increased Q angle, or delayed VMO activation, patellofemoral pain was accurately predicted in a significant number of participants. The majority of research seems to support a connection between hip musculature weakness and patellofemoral pain.

Strength deficits in the hip abductors, such as the gluteus medius, have also been linked to iliotibial band syndrome (Fredericson, Cookingham, Chaudhari, Dowdell, Oestreicher, & Sahrmann, 2000). Weakness in the gluteus medius increases adduction and internal rotation at the hip due to the inability to control the abduction and external rotation movement (Fredericson et al., 2000). Fredericson et al. (2000) found that after a six week rehabilitation program focusing on gluteus medius strengthening, long-distance runners with IT band syndrome had an increase in strength, a decrease in pain, and were able to return to running. The inability of the gluteus medius to fire properly or with adequate strength places more stress on the IT band, resulting in an increased valgus force at the knee and the discomfort and tightness associated with IT band syndrome (Fredericson et al., 2000; Greenman, 2003).

A Trendelenburg gait may also develop if the gluteus medius does not function properly or is markedly weak. Kendall et al. (1993) describe a Trendelenburg gait as the affected hip going into an adducted position, or the unaffected hip dropping, during the weight-bearing phase of gait. In a similar manner, gluteus medius weakness may be linked to low back pain and sacroiliac joint dysfunctions due to the lack of pelvic control and stabilization (Earl, 2004; Nadler et al., 2002). Nadler et al. (2002) stated that weakness in the gluteus maximus as well as gluteus medius is associated with low back pain. Specifically, females with asymmetric hip extensor (gluteus maximus) strength were more likely to report low back pain.

Gluteus and Hip Muscle EMG during Activity

To my knowledge, no previous research has been done to compare the clamshell exercise to the side-lying hip abduction and side-lying hip abduction with external rotation exercises. Many studies have examined the side-lying hip abduction exercise (Bolgla & Uhl, 2005; Mascal et al., 2003), but the clamshell has only been demonstrated clinically as a rehabilitation exercise (Greenman, 2003; Mascal et al., 2003). Furthermore, the comparison of muscle activation between males and females during these exercises makes this study unique.

In a case study of two females suffering from patellofemoral pain, Mascal et al. (2003) utilized clamshell exercises as a part of the rehabilitation program. Both participants in the study demonstrated weakness of the hip abductors, extensors, and external rotators at the beginning of the study. The participants then began a 14 week training program focusing on the hip, trunk, and pelvis. The exercises progressed from non-weight-bearing to weight-bearing, and then to functional activities. At the end of the training, participants demonstrated a 50% and 90% increase in gluteus medius force production and 55% and 110% increase in gluteus maximus force production respectively. More importantly, the participants were able to return to their normal activity levels, pain free.

In an effort to measure the activation of the gluteus medius during various rehabilitation exercises, Bolgla and Uhl (2005) conducted a study of 16 healthy male and female participants. The six rehabilitation exercises consisted of three weight-bearing (contralateral pelvic drop, weight-bearing contralateral hip abduction with hip at 0° and 20° of flexion), and three non-weight-bearing activities (side-lying hip abduction, standing ipsilateral hip abduction with the hip at 0° and 20° of flexion). The subjects performed 15 repetitions of each exercise with 3 minutes of rest between each different exercise. This study revealed that the weight-bearing exercises and the non-weight-bearing side-lying hip abduction had approximately the same EMG amplitudes. Overall, pelvic drop produced the greatest muscle activation level, while the non-weight-bearing standing hip abduction required significantly lower levels of gluteus medius activation. These results indicate that both weight-bearing and non-weight-bearing exercises may be beneficial for rehabilitation and strengthening of the gluteus medius dependent on the injuries and needs of the patients.

As previously mentioned, the gluteus medius also aides in hip rotation. Earl (2004) conducted a study to examine which combination of hip abduction and rotation elicited the greatest activation of the gluteus medius. The participants completed five trials of three standing exercises (hip abduction, hip abduction with internal rotation, hip abduction with external rotation). Earl (2004) utilized a pulley system with weights to induce the internal and external rotation. This study revealed the greatest activation of the middle and anterior portions of the gluteus medius during hip abduction with internal rotation. This study did not examine the posterior fibers of the gluteus medius, which are known to aid in external rotation, therefore it would make sense that the greatest activation was found with internal rotation.

The activation of the gluteus medius muscle may be affected by more than just the type of exercise utilized. Cynn, Oh, Kwon, and Yi (2006) investigated the effects of lumbar stabilization on muscle activation during side-lying hip abduction. Eighteen healthy male and female participants were involved in this study. The participants performed side-lying abduction with and without lumbar stabilization from a pressure biofeedback unit. Surface EMG activity was recorded for the quadratus lumborum, gluteus medius, internal oblique, external oblique, rectus abdominis, and multifidus. Results of this study revealed that the lumbar stabilization significantly decreased the amount of quadratus lumborum activation, while significantly increasing the gluteus medius and internal oblique activation levels. Overall, females in this study also demonstrated significantly higher muscle activation levels in the gluteus medius, external oblique, and rectus abdominis. The results indicate that the inability to stabilize the lumbar spine may affect the potential for gluteus medius activation.

Measures of Muscle Activation Using Surface EMG

The measurement of muscle activation of the gluteus and hip muscles has almost exclusively been done with surface EMG methods. Cram, Kasman, and Holtz (1998) report that there are both advantages and disadvantages to using surface EMG. Numerous advantages include relative ease of performance; the procedure is safe and non-invasive to the participant while still providing a good measurement of the muscle activation. A disadvantage of surface EMG is the possibility of "cross-talk", which refers to the energy from one muscle crossing over to the recording area of another muscle. To decrease the amount of "cross-talk" electrode placement needs to be as accurate as possible for each specific muscle. Merletti, Rainoldi, and Farina (2001) reported that misalignment between the muscle fibers and the electrodes, among other factors, can skew the EMG readings.

As described previously, Bolgla and Uhl (2005) investigated gluteus medius muscle activation during three weight-bearing, and three non-weight-bearing exercises. Two surface EMG electrodes were placed over the muscle belly of the gluteus medius one-third the distance between the iliac crest and the greater trochanter. A ground electrode was placed over the acromion process. A Myopac transmitter belt was worn by participants, Datapac software was used for data analysis, and the data was normalized to a percentage of pretesting maximum voluntary isometric contraction. It was found that the weight-bearing exercises and the non-weight-bearing side-lying hip abduction had the greatest muscle activation.

Earl (2004) looked at the difference in gluteus medius activation during standing hip abduction plus internal or external rotation. There were 20 healthy male and female participants in this study. Two 10mm-diameter surface EMG electrodes were placed parallel to the muscle fibers midway between the iliac crest and the greater trochanter and another pair of electrodes were placed just anterior to the first pair. The ground electrode was placed on the fibular head. Participants completed 5 repetitions of each of three exercises with a 2.26 kilogram load and with 2 minutes of rest between exercises. The participants then repeated the same exercises with a 4.53 kilogram load. A cable column was used to provide resistance for the exercises. The Standard Myopac System and Datapac 2K2 software was used to collect data. Data was not normalized; rather, raw data was used for analysis. This study revealed the greatest activation of gluteus medius with abduction and internal rotation, and greater activation with a heavier load.

Neumann and Cook (1985) studied the muscle activation of the gluteus medius during the stance phase of gait while carrying a load equal to 10% or 20% of body weight in a contralateral or ipsilateral position and either anterior or posterior to the chest. There were 24 healthy participants in this study. Unlike many other studies, the researchers placed the surface EMG electrodes perpendicular to the muscle fibers with a ground electrode over the proximal medial tibia. All data was normalized to a percentage of maximum voluntary isometric contraction. There were 10 total control and experimental conditions. In regards to carrying position, the study revealed the greatest gluteus medius activation with a contralateral rather an ipsilateral carrying position and an anterior rather than a posterior carrying position. The 20% body weight load also revealed greater muscle activation in all carrying positions than the 10% body weight; particularly in the anterior and contralateral positions.

Nyland et al. (2004) conducted a study on the influences of femoral anteversion on vastus medialis and gluteus medius to composite hip abductor EMG amplitude ratios. The study included 18 athletically active females and utilized surface EMG measures of the gluteus medius, vastus medialis, gluteus maximus, and tensor fascia lata in an isometric hip abduction-external rotation maneuver. Pairs of 10mm surface electrodes were placed parallel to the muscle fibers. The researchers also describe how manual pressure and verbal cues were provided to the participants to maintain the proper position and elicit maximum effort. The vastus medialis and gluteus medius EMG amplitudes were normalized to the composite mean hip abductor amplitude (gluteus maximus, gluteus medius, and tensor fascia lata). This normalization was done to decrease the possibility of crosstalk between the hip abductor muscles.

Results revealed that subjects with greater femoral anteversion showed decreased levels of gluteus medius and vastus medialis activation. Also, TFL demonstrated the greatest activation level across all participants. In those subjects with less femoral anteversion, the gluteus medius demonstrated the second greatest activation, while the gluteus maximus demonstrated the second greatest activation in those with increased femoral anteversion.

Differences between Males and Females in Gluteus and Hip Muscle Activation

To date, almost no research has been conducted comparing differences between males and females in muscle activation of the gluteus and hip muscles during non-weight-bearing exercises. Researchers have examined gender differences present in hip muscle activation during dynamic activities such as landing and squatting. In a study of Division 1 collegiate athletes, Zazulak et al. (2005) found that females had lower gluteus maximus activation in the postcontact phase of landing, greater rectus femoris activation before contact, and no significant difference in gluteus medius activation when compared to males in a single-leg landing task. In a similar study of a single-leg drop jump, Russell et al. (2006) found that females seemed to land in a more knee valgus position and males landed in a more knee varus position. There was no statistically significant difference in gluteus medius muscle activation at any phase of the activity between males and females.

Zeller et al. (2003) examined male and female differences during the single leg squat. Analysis of each individual muscle revealed that there were differences in the EMG muscle activation between males and females but the only difference that was statistically significant was females had a higher activation of rectus femoris compared to males. Analysis of all eight muscles together revealed that overall women had significantly higher activation levels then men. Results did display greater activation of the gluteus maximus for women and greater activation of the gluteus medius and biceps femoris for men, although not statistically significant. Because of the important roles that the hip and gluteus muscles play in pelvic stabilization, it is important to examine whether differences between males and females exist in the activation of these muscles during the exercises that are used to strengthen them.

Summary

Previous research has linked hip abductor weakness, particularly the gluteus medius, to numerous lower extremity injuries. The current study compared three non-weight-bearing exercises used to strengthen the gluteus and hip muscles. To date, the majority of research has examined the side-lying hip abduction exercise, while the hip abduction with external rotation exercise has been studied in a standing position. However, the clamshell exercise has only been associated with rehabilitation programs or examined as an isometric exercise. Finally, there is very little research pertaining to the differences between males and females in muscle activation during these non-weight-bearing exercises. Previous studies have examined muscle activation during squatting and landing, but not specifically during non-weight-bearing exercises. The current study examined the clamshell exercise as an isotonic exercise and compared the activation levels between males and females.

CHAPTER 3

METHODS

The primary purpose of this study was to determine if the type of exercise utilized, clamshell, side-lying hip abduction, or side-lying hip abduction with external rotation affects the level of selected gluteus and hip muscle activation. A secondary purpose was to determine if there were differences present between males and females in the levels of muscle activation during each exercise.

Research Design

A counterbalanced, within-subject experimental design was used to compare three different hip abduction exercises. The dependent variable was EMG muscle recruitment for gluteus medius, gluteus maximus, lateral hamstring, and tensor fascia latae(TFL). The independent variables were the exercises and gender. Exercise has three levels (clamshell, side-lying hip abduction, side-lying hip abduction with external rotation) and gender has two levels (male and female).

Participants

Thirty recreational athletes from a large Midwestern University between the ages of eighteen and thirty (15 male, 15 female) volunteered to participate in this study. All participants were recreational athletes; defined as a person who participates in physical activity for at least 20 minutes, at least 3 times per week and does not have a professional training regimen. The participants reported no history of a lower extremity, hip, or pelvis injury within the last 6 months. Injury could have possibly influenced the muscle activation levels. Participants with previous hip surgery were excluded from the study. Participants with an allergy to adhesives were also excluded from the study due to the use of self-adhesive electrodes.

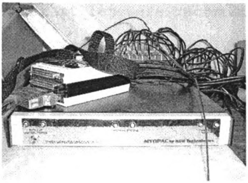
Electromyography

The Myopac System attached an eight-channel FM transmitter was utilized to measure the EMG activity of the gluteus medius, gluteus maximus, lateral hamstring, and TFL muscles (see Figure 1). Each channel of the transmitter was equipped with two leads, and each of the leads has a clip that attached to the surface electrodes.

During the maximum voluntary contractions (MVC) and exercise trials, the signals from the surface electrodes attached to the muscles were passed to a battery operated Myopac eight-channel FM transmitter belt unit (RUN Technologies, Mission Viejo, CA). The raw digital signal was sampled at a rate of 960 Hz. The signal was then amplified by a gain of 1000 V with a single-ended amplifier with impedance greater than ten MOmega (RUN Technologies, Mission Viejo, CA). Unit specifications for the Myopac included a notch Butterworth filter (60.0 Hz) and common mode rejection ratio of 130 dB at direct current with a minimum of 85 dB across the entire frequency of 10-500 Hz (RUN Technologies, Mission Viejo, CA). A Datapac receiving unit with a sixth order filter with an amplifier gain of 2000 further amplified the signal (RUN Technologies, Mission Viejo, CA). The analog signal was converted to a digital signal by an analog-to-digital converter card and was stored in the Datapac Software, version 3.00 (RUN Technologies, Mission Viejo, CA).

EMG data was measured by raw voltage using Datapac 2K2 (RUN Technologies, Mission Viejo, CA). EMG raw scores were then divided by a reference contraction to produce normalized data. Each participant performed a MVC for each muscle pre and post-exercise. Each MVC lasted five seconds. Reference contractions were than obtained by averaging the pre and post-exercise MVCs.

Figure 1 Myopac EMG System



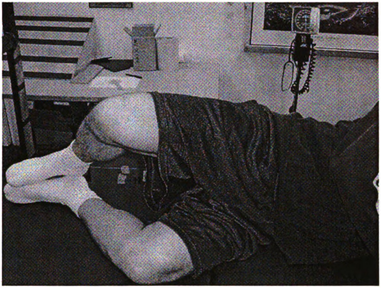
Procedures

Prior to data collection, this study was approved by the Biomedical Institutional Review Board (BIRB) at Michigan State University. Each participant completed an informed consent and a health history questionnaire prior to participating in this study (See Appendices A & B). Participants wore comfortable clothing such as athletic shorts, and t-shirt that allowed researchers access to the testing area and allowed the participants to perform the necessary exercises. Only the participant and the researchers were present in the testing area. A researcher of the same sex as the participant was available to prepare the participant for testing. Data collection was completed in the Athletic Training Research Laboratory at Michigan State University. Participants were required to attend one testing session for approximately 60 minutes.

The participants’ name, age, and side of their dominant leg were recorded and their height and weight was measured and recorded. The dominant leg was determined by asking the participants which leg they would kick a ball with. The participants were randomly assigned to the order in which they completed the exercises.

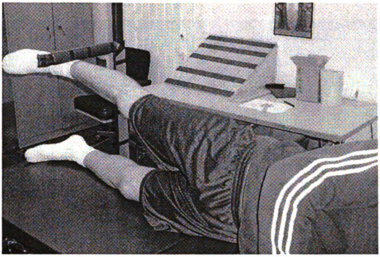
The exercises were then demonstrated to the participants. During the clamshell exercise the participants were side-lying with the knees flexed to 90 degrees, the hips flexed to 45 degrees, the spine in a neutral position, and the hips and shoulders perpendicular to the table with the feet together (Nyland, et al., 2004). The arm on the non-dominant side rested under the participants’ head while the arm on the dominant side rested on the table in front of the body. Maintaining the feet together and the pelvic and shoulder position, the participants slowly raised the knee on the dominant leg toward the ceiling as far as they could without the hips or shoulders rotating, and then slowly return to the starting position (Greenman, 2003; Mascal et al., 2003 [see Figure 2]).

Figure 2 Clamshell exercise



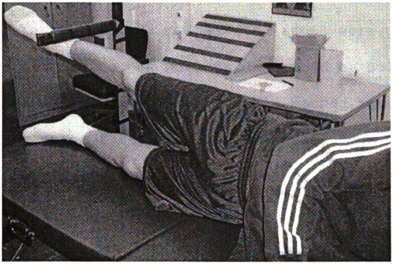
The side-lying hip abduction exercise was executed with the participants in a side-lying position with hips and knees extended and the legs parallel, with the shoulders and pelvis perpendicular to the table. The arm and hand on the dominant side rested on the table in front of the body while the participants abducted the dominant leg 18 inches above the height of the table, maintaining the perpendicular hip and shoulder position. A bar was placed 18 inches above the height of the table and participants were instructed to raise the leg until they contacted the bar and then slowly return to the starting position (Bolgla & Uhl, 2005; Greenman, 2003 [see Figure 3]).

Figure 3 Side-lying hip abduction exercise



The side-lying hip abduction with external rotation exercise involved the same basic technique as the side-lying hip abduction exercise except that the dominant leg was externally rotated as far as the participants could without rotating the hips or shoulders throughout the exercise. The same bar, 18 inches above the height of the table, was utilized for this exercise (see Figure 4).

Figure 4 Side-lying abduction with external rotation exercise



After demonstration the participants completed 5 practice repetitions to familiarize them with the exercises. The practice session was followed by 5 minutes of rest to reduce the effects of fatigue (Bolgla & Uhl, 2005).

During the rest time the participants were prepared for surface electrode placement. The skin on the dominant leg and hip was cleansed with 70% isopropyl alcohol, shaved, and abraded slightly using a fine grain emery board to decrease skin impedance during testing (Schmitz, et al., 2002). Two self-adhesive Ag/AgCl bipolar, 10mm-diameter surface electrodes (Blue Sensor N-00-S; Ambu Inc, Glen Burnie, MD) were placed over the muscle belly of the gluteus medius, gluteus maximus, TFL, and lateral hamstring.

The gluteus medius electrodes were positioned according to the methods described by Bolgla and Uhl (2005) and Cram et al. (1998). This method involved locating the placement for electrodes on the gluteus medius by palpating the iliac crest and the greater trochanter and placing the electrodes over the proximal one-third of the distance between these landmarks to minimize the amount of crosstalk that may occur. According to Cram et al. (1998), the electrodes for the gluteus maximus were positioned at an oblique angle over the muscle belly, half the distance between the trochanter and the sacrum. To identify the placement of the electrodes for the TFL, the anterior superior iliac spine (ASIS) was palpated and the electrodes were placed parallel to the muscle fibers about 2cm below the ASIS (Cram et al., 1998). Finally, electrodes for the lateral hamstring were placed over the muscle belly on the posterior, lateral aspect of the thigh, parallel to the muscle fibers and approximately two-thirds the distance between the trochanter and the posterior aspect of the knee (Cram et al., 1998). An interelectrode distance of approximately 20mm was used for all electrode placements. An additional Ambu surface electrode was placed over the medial tibial shaft of the dominant leg as a ground electrode.

Each participant performed one five second MVC for each of the four muscles muscle prior to exercise. To test the gluteus medius, the participants were positioned in a side-lying position with the hip abducted 30 degrees, slightly extended and externally rotated. The researcher then applied manual pressure to the distal thigh (Kendall et al., 1993; Neumann & Cook, 1985 [see Figure 5]). To test the gluteus maximus the participants were in a prone position with the knee flexed and the hip extended and the researcher then applied pressure over the distal thigh in the direction of hip flexion (Kendall et al., 1993 [see Figure 6]). The lateral hamstring was also tested in a prone position; with the knee flexed to 70 degrees and the hip slightly externally rotated, the researcher applied pressure in the direction of knee extension (Kendall et al., 1993 [see Figure 7]). The TFL was tested with the participants in a supine position with the knee extended and the hip abducted, flexed, and slightly internally rotated, while the researcher applied pressure in the direction of hip extension and adduction (Kendall et al., 1993 [see Figure 8]).

Figure 5 Gluteus Medius MVC

Figure 6 Gluteus Maximus MVC

Figure 7 Lateral Hamstring MVC

Figure 8 TFL MVC

The participants then performed 10 repetitions of the first exercise, clamshell, side-lying hip abduction, or side-lying hip abduction with external rotation. During the exercises, participants were given verbal cues if the researcher observed incorrect performance of the exercise. The participants rested 3 minutes between exercises to reduce the possible effects of fatigue (Bolgla & Uhl, 2005). Following the rest period, the participants complete 10 repetitions of the second exercise. Following another 3-minute rest period the participants completed 10 repetitions of the third and final exercise. After the final exercise was completed the participants had another 3-minute rest and then post-exercise MVCs were determined in the same manner as the pre-exercise MVCs.

Data management

Data was recorded using the Datapac 2K2 software (RUN Technologies, Mission Viejo, CA) for EMG raw data extraction and analysis. The data was then transferred to a Microsoft Excel spreadsheet and then imported to an SPSS data file for statistical analysis. All data files were kept on a password protected personal computer in a locked office. A backup of the data was kept on a USB travel drive that was kept in a locked desk in a locked office. All consent forms were also kept in a locked desk in a locked office and only authorized researchers had access to the consent forms and data files. Issuing a participant number to each person to insure that their name was not linked to their data after the testing procedures were complete, insured participant privacy.

Data Analyses

Means and standard deviations were calculated for descriptive statistics. For clarification, the results section is limited to values based on reference contractions and normalized data. Activation levels for each muscle during each exercise were calculated by averaging the activation levels across the 10 repetitions of each exercise. The average activation level was then divided by the reference contraction (average of pre and post-exercise MVCs) to produce the normalized data.

Participants with an increased value for normalized data, when comparing the three exercises, indicates a greater amount of activity for that specific muscle. Normalizing the data to the reference contractions aided in examining muscle activation patterns during the exercises and across males and females.

A 3 exercise (clamshell, hip-abduction, hip-abduction with external rotation) X 2 gender (male, female) X 4 muscle repeated measures analysis of variance (ANOVA) was conducted to determine the amount of muscle activation involved during the non-weight-bearing exercises. The level of significance was set at $p \leq .05$. Independent t-tests with Bonferroni Correction were utilized to determine which muscles demonstrated significant differences between genders. After applying the Bonferroni Correction, the level of significance for gender was set at $p \leq .0125$. All analysis was conducted using SPSS version 15.1 for Windows (SPSS Inc., Chicago, IL).

Chapter 4

RESULTS

The primary purpose of this study was to determine the muscle activation levels of the gluteus maximus, gluteus medius, TFL, and lateral hamstring during three non-weight-bearing exercises. A secondary purpose was to examine if differences between males and females exist in the muscle activation during the side-lying hip abduction, side-lying hip abduction with external rotation, and clamshell exercises. For clarity, the results section is separated into participant demographics, reference contractions, muscle activation patterns across the three exercises, and muscle activation levels within each exercise. All analysis of variance (ANOVA) and Pairwise Comparison results are available in Appendix C.

Participant Demographics

A total of 30 collegiate, recreational athletes volunteered to participate in this study (see Table 4-1). There were 15 male participants (age = 23.53 ± 2.59 years, height = 70.23 ± 2.16 inches, weight = 187.93 ± 35.62 lbs.) and 15 female participants (age = 21.07 ± 1.10 years, height = 65.23 ± 2.89 inches, weight = 146.8 ± 24.68 lbs.).

Table 4-1 Participant Demographic Information

Participants	N	Age (years)	Height (in.)	Weight (lbs)
Male	15			
Mean		23.53	70.23	187.93
SD		±2.59	±2.16	±35.62
Female	15			
Mean		21.07	65.23	146.80
SD		±1.10	±2.89	±24.68
Total	30			
Mean		22.30	67.73	167.37
SD		±2.32	±3.57	±36.66

Reference Contraction Results

Reference contractions were calculated by averaging pre- and post- MVC tests for each of the four muscles (see Table 4-2). On average, females produced the greatest reference contraction for lateral hamstring (0.3236) and TFL (0.3126). Females had the lowest muscle activation for the gluteus maximus (0.1077). Males produced the greatest MVC for TFL (0.4907) and had the lowest muscle activation for the gluteus maximus (0.1749).

Table 4-2 Reference Contractions by Gender (N=30)

Muscle	Min	Max	Mean	SD
Gluteus Maximus				
Male	0.0635	0.4705	0.1749	0.0727
Female	0.0234	0.2595	0.1077	0.0596
Gluteus Medius				
Male	0.0782	0.6679	0.2373	0.1689
Female	0.0922	0.4832	0.2716	0.1078
TFL				
Male	0.1332	0.9153	0.4907	0.2508
Female	0.0435	0.7953	0.3126	0.1974
Lat Hamstring				
Male	0.0718	0.5395	0.2242	0.1115
Female	0.0775	0.5455	0.3236	0.1550

Min = minimum MVC, Max = maximum MVC, Mean = average of reference contractions, SD = standard deviation

Muscle Activation for Gluteus Maximus

A 2 gender X 3 exercise (side-lying abduction, clamshell, side-lying abduction with external rotation) repeated measures analysis of variance (ANOVA) was conducted to determine the amount of gluteus maximus muscle activation during the three exercises (see Table 4-3). Results revealed significant differences within-participants for exercise [$F_{(2,56)}$= 7.60, p = .001]. The clamshell (p = .001) and side-lying abduction with external rotation (p = .001) produced significantly greater muscle activation compared to side-lying abduction. There was no significant differences for the interaction between gender and exercise [$F_{(2,56)}$= 0.54, p = .568].

Table 4-3 Normalized Descriptive Statistics for Gluteus Maximus across Three Exercises

Exercise	N	Mean	SD
Side-lying Abduction			
Male	15	0.0657	0.4019
Female	15	0.1683	0.1850
Clamshell			
Male	15	0.1177	0.0575
Female	15	0.2577	0.1815
Side-lying Abduction ER			
Male	15	0.0897	0.0602
Female	15	0.2146	0.2439

Note: Mean = average muscle activation level based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Muscle Activation for Gluteus Medius

A 2 gender X 3 exercise (side-lying abduction, clamshell, side-lying abduction with external rotation) repeated measures ANOVA was utilized to determine the amount of gluteus medius muscle activation during each of the three exercises (see Table 4-4). Results indicated no significant differences within-participants for exercise [$F_{(2,56)}$= 1.620, p = .207]. There was also no significant differences for the interaction between gender and exercise [$F_{(2,56)}$= .744, p = .480].

Table 4-4 Normalized Descriptive Statistics for Gluteus Medius across Three Exercises

Exercise	N	Mean	SD
Side-lying Abduction			
Male	15	0.6890	1.064
Female	15	0.3364	0.089
Clamshell			
Male	15	0.3796	0.2205
Female	15	0.2362	0.1795
Side-lying Abduction ER			
Male	15	0.4176	0.1098
Female	15	0.3342	0.1711

Note: Mean = average muscle activation level based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Muscle Activation for TFL

A 2 gender X 3 exercise (side-lying abduction, clamshell, side-lying abduction with external rotation) repeated measures ANOVA was performed to determine the amount of TFL muscle activation during the three exercises (see Table 4-5). Results revealed significant differences within-participants for exercise [$F_{(2,56)}$= 32.184, p = .000]. In particular, side-lying hip abduction (p = .000) and side-lying abduction with external rotation (p = .000) produced significantly greater TFL muscle activation compared to clamshell. The results demonstrated no significant differences for the interaction between gender and exercise [$F_{(2,56)}$= 1.427, p = .249].

Table 4-5 Normalized Descriptive Statistics for TFL across Three Exercises

Exercise	N	Mean	SD
Side-lying Abduction			
Male	15	0.2837	0.1945
Female	15	0.5356	0.3952
Clamshell			
Male	15	0.1574	0.0620
Female	15	0.3103	0.3498
Side-lying Abduction ER			
Male	15	0.3653	0.1541
Female	15	0.5548	0.3705

Note: Mean = average muscle activation level based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Muscle Activation for Lateral Hamstring

A 2 gender X 3 exercise (side-lying abduction, clamshell, side-lying abduction with external rotation) repeated measures ANOVA was conducted to determine the amount of lateral hamstring muscle activation during the three exercises (see Table 4-6). Results revealed no significant differences within-participants for exercise [$F_{(2,56)}$= .107, p = .899]. Also, there were no significant differences for the interaction between gender and exercise [$F_{(2,56)}$= 2.759, p = .072].

Table 4-6 Normalized Descriptive Statistics for Lateral Hamstring across Three Exercises

Exercise	N	Mean	SD
Side-lying Abduction			
Male	15	0.1169	0.1666
Female	15	0.0530	0.0374
Clamshell			
Male	15	0.0726	0.0438
Female	15	0.0834	0.0625
Side-lying Abduction ER			
Male	15	0.0947	0.0904
Female	15	0.0640	0.0683

Note: Mean = average muscle activation level based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Muscle Activation during Side-lying Hip Abduction

A 2 gender by 4 muscles (gluteus maximus, gluteus medius, TFL, lateral hamstring) repeated measures ANOVA was conducted to determine the amount of muscle activation across the four muscles during the side-lying hip abduction exercise (see Table 4-7). Results indicated significant differences within-participants for muscle [$F_{(3,84)}$= 7.890, p = .000]. Specifically, gluteus medius produced significantly greater muscle activation than gluteus maximus (p = .008) and lateral hamstring (p = .006). Also, TFL produced significantly greater muscle activation than gluteus maximus (p = .000) and lateral hamstring (p = .000). There were no significant differences in muscle activation between gluteus medius and TFL. Results revealed a significant difference for the interaction between gender and muscle [$F_{(3,84)}$= 2.931, p = .038]. Further analysis using independent t-tests with Bonferroni Corrections revealed that TFL activation was significantly greater in females than in males [t = -2.215, p = .009] (see Table 4-8).

Table 4-7 Normalized Descriptive Statistics for Side-lying Hip Abduction across Four Muscles

Muscle	N	Mean	SD
Gluteus Maximus			
Male	15	0.0657	0.0402
Female	15	0.1683	0.1850
Gluteus Medius			
Male	15	0.6890	1.0642
Female	15	0.3364	0.0886
TFL			
Male	15	0.2837	0.1945
Female	15	0.5356	0.3952
Lateral Hamstring			
Male	15	0.1169	0.1666
Female	15	0.0530	0.3736

Note: Mean = average muscle activation level based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table 4-8 Independent T-tests with Bonferroni Correction for Side-lying Hip Abduction across Four Muscles for Gender

Muscles	F	p	t	df	95% CI
Gluteus Maximus	6.595	.016	-2.098	28	-.203 to -.002
Gluteus Medius	3.412	.075	1.279	28	-.212 to .917
TFL	7.986	.009*	-2.215	28	-.485 to -.019
Lateral Hamstring	5.457	.027	1.449	28	-.026 to .154

*(significant at the p ≥ .0125 level)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Muscle Activation during Clamshell

A 2 gender by 4 muscles (gluteus maximus, gluteus medius, TFL, lateral hamstring) repeated measures ANOVA was conducted to determine the amount of muscle activation across the four muscles during the clamshell exercise (see Table 4-9). Results indicated significant differences within-participants for muscle [$F_{(3,84)}$= 11.247, p = .000]. Particularly, gluteus medius produced significantly greater muscle activation than gluteus maximus (p=.010) and lateral hamstring (p = .000). Also, lateral hamstring produced significantly less muscle activation than gluteus maximus (p = .000) and TFL (p = .001). There were no significant differences in muscle activation between gluteus medius and TFL. Results revealed significant differences for the interaction between gender and muscle [$F_{(3,84)}$= 5.788, p = .001]. Further analysis using independent t-tests with Bonferroni Correction revealed the TFL activation was significantly greater in females than in males [t = -1.668, p = .007] (see Table 4-10).

Table 4-9: Normalized Descriptive Statistics for Clamshell across Four Muscles

Muscle	N	Mean	SD
Gluteus Maximus			
Male	15	0.1177	0.0575
Female	15	0.2577	0.1815
Gluteus Medius			
Male	15	0.3796	0.2205
Female	15	0.2362	0.1795
TFL			
Male	15	0.1574	0.0620
Female	15	0.3103	0.3498
Lateral Hamstring			
Male	15	0.0726	0.0438
Female	15	0.0834	0.0625

Note: Mean = average muscle activation level based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table 4-10 Independent T-tests with Bonferroni Correction for Clamshell across Four Muscles for Gender

Muscles	F	p	t	df	95% CI
Gluteus Maximus	6.461	.017	-2.850	28	-.241 to -.039
Gluteus Medius	.141	.710	1.953	28	-.007 to .294
TFL	8.563	.007*	-1.668	28	-.341 to .035
Lateral Hamstring	1.427	.242	-.552	28	-.051 to .029

*(significant at the p = .0125 level)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Muscle Activation during Side-lying Hip Abduction with External Rotation

A 2 gender by 4 muscle (gluteus maximus, gluteus medius, TFL, lateral hamstring) repeated measures ANOVA was conducted to determine the amount of muscle activation across the four muscles during the side-lying abduction with external rotation exercise (see Table 4-11). Results indicated significant differences within-participants for muscle [$F_{(3,84)}$= 47.396, p = .000]. Specifically, TFL produced significantly greater muscle activation than gluteus maximus (p = .000), gluteus medius (p = .025) and lateral hamstring (p = .000). Also, gluteus medius produced significantly greater muscle activation than gluteus maximus (p = .000) and lateral hamstring (p = .000). Gluteus maximus also produced significantly more muscle activation than lateral hamstring (p = .029). Results demonstrated significant differences for the interaction between gender and muscle [$F_{(3,84)}$= 5.992, p = .001]. Further analysis using independent t-tests with Bonferroni Correction revealed the TFL activation was significantly greater in females than in males [t = -1.828, p = .013] (see Table 4-12).

Table 4-11 Normalized Descriptive Statistics for Side-lying Hip Abduction with External Rotation across Four Muscles

Muscle	N	Mean	SD
Gluteus Maximus			
Male	15	0.0897	0.0602
Female	15	0.2146	0.2439
Gluteus Medius			
Male	15	0.4176	0.1098
Female	15	0.3342	0.1711
TFL			
Male	15	0.3653	0.1541
Female	15	0.5548	0.3705
Lateral Hamstring			
Male	15	0.0947	0.0904
Female	15	0.0640	0.0683

Note: Mean = average muscle activation level based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table 4-12: Independent T-tests with Bonferroni Correction for Side-lying Hip abduction with External Rotation across Four Muscles for Gender

Muscles	F	p	t	df	95% CI
Gluteus Maximus	5.582	.025	-1.924	28	-.258 to .008
Gluteus Medius	1.016	.322	1.588	28	-.024 to .191
TFL	7.041	.013*	-1.828	28	-.402 to .023
Lateral Hamstring	.488	.490	1.048	28	-.029 to .091

*(significant at the p = .0125 level)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Chapter 5

DISCUSSION

The purpose of this study was twofold. First, to determine the muscle activation levels of four selected gluteus and hip muscles during three non-weight-bearing exercises. The second was to determine if differences existed between males and females in muscle activation levels during non-weight-bearing exercises. This was the first study to compare these three exercises and examine differences between males and females in muscle activation levels.

Results revealed several significant findings. The gluteus medius and TFL demonstrated the greatest muscle activation for all three exercises. The TFL revealed significantly greater activation than the other muscles during the side-lying hip abduction with external rotation exercise. During all three exercises, the gluteus maximus and the lateral hamstring displayed the lowest activation levels. Also, females demonstrated significantly greater TFL activation than males across all three exercises.

Analysis of the Muscle Activation during Non-Weight-Bearing Exercises

During all three exercises, the TFL and the gluteus medius demonstrated the greatest levels of muscle activation. The lateral hamstring and the gluteus maximus demonstrated the lowest muscle activation across all three exercises. Specifically, the TFL displayed the greatest activation levels during the clamshell and side-lying abduction with external rotation, while the gluteus medius was the most highly activated during the side-lying hip abduction exercise. The activation of the TFL was only significantly greater than the gluteus medius during the side-lying abduction with external rotation exercise. Although Bolgla and Uhl (2005) did not examine the same three exercises, they did find that the side-lying hip abduction exercise elicited the greatest amount of gluteus medius muscle activation during non-weight-bearing exercises. The TFL was not measured by Bolgla and Uhl (2005).

An isometric exercise similar to the clamshell exercise utilized in the current study revealed comparable muscle activation levels (Nyland et al., 2004). Nyland et al. (2004) found that across all subjects the TFL demonstrated the greatest activation level. They also concluded that those individuals with greater femoral anteversion had significantly less gluteus medius activation then subjects with less femoral anteversion. Although the current study did not examine femoral anteversion, it may provide insight into why the TFL was the dominant muscle during the clamshell and side-lying abduction with external rotation exercises. The gluteus medius was dominant in the side-lying abduction exercise; which was the only exercise that did not involve a rotational component. Perhaps the need to stabilize the hip in a multi-plane exercise with hip abduction causes individuals to rely more on other hip abductors than the gluteus medius.

Previous research demonstrated an increase in gluteus medius activation when a rotational component was added to a weight-bearing hip abduction exercise (Earl, 2004). Results from the current study revealed no significant difference in gluteus medius activation in which a rotational component was introduced during the side-lying abduction with external rotation or the clamshell exercise. Due to the clinical implications for the clamshell as a strengthening exercise for the gluteus medius, one would assume that the gluteus medius would have had the greatest activation levels; this was not supported by the results of this study.

The increased use of the TFL compared to the gluteus medius during the clamshell and side-lying abduction with external rotation exercises may be attributed to several factors. First, the participants may have been compensating for the inability to utilize the gluteus medius by activating the TFL since both muscles are strong hip abductors. Cynn et al. (2006) found that providing lumbar stabilization significantly increased the gluteus medius activation level in participants performing the side-lying hip abduction exercise. Perhaps, participants in the current study did not stabilize their lumbar spine during the exercises that involved rotation of the hip, and therefore where unable to effectively activate the gluteus medius. As stated by Bewyer and Bewyer (2003) another reason for increased use of the TFL may be due to motor pattern error that causes the participants to preferentially use the TFL for hip abduction. When the gluteus medius is weakened the TFL becomes shorter and stronger. This error may result from micro trauma to the gluteus medius over an extended time period, or macro trauma over a short time period.

Although the gluteus medius has been the focus of a wide array of research studies, the current study indicates that the TFL was activated equally, or to a greater degree than the gluteus medius during non-weight-bearing exercises. It appears that exercises that activated the gluteus medius also activated the TFL. Perhaps, it is not specifically gluteus medius weakness that is related to lower extremity injuries, but rather weakness in the hip abductors in general. More research is needed to support or refute these speculations.

The results of this study demonstrated a lack of muscle activation in the gluteus maximus and lateral hamstring throughout the exercises. Researchers are aware that the actions in the exercises examined in this study are not primary actions for the lateral hamstring or the gluteus maximus. These muscles were included in the study to determine if the primary muscles were indeed activated more than the secondary muscles. Unlike Nyland et al. (2004) results from the current study did not indicate that the gluteus maximus was the second most activated muscle during the clamshell exercise. This dissimilarity may be due to differences in methodology. Nyland et al. (2004) examined an isometric exercise with only female participants while the current study utilized an isotonic exercise with male and female participants.

Analysis of Differences between Males and Females in Muscle Activation

During reference contractions, males produced a greater activation of the gluteus maximus and TFL while females demonstrated greater activation of the lateral hamstrings and gluteus medius. Results indicated only one significant difference in muscle activation between males and females during the non-weight-bearing exercises. Females demonstrated significantly greater TFL activation for each exercise. A possible explanation may be that females demonstrated greater TFL activation than males due to anatomical structural differences such as wider hips. Differences in hip width could affect the angle of attachments of the muscles, and therefore affect the activation of the muscles during certain activities. Females may have a more difficult time recruiting the gluteus medius and therefore compensate by increasing the activation of the TFL compared to males. Further research is necessary to examine these speculations.

Results revealed that no other significant differences existed between males and females during the non-weight bearing exercises. Similarly, Zeller et al. (2003) found no significant differences in muscle activation between males and females during a single-leg squat exercise when muscles were analyzed individually. Previous research has also demonstrated no significant difference in gluteus medius activation between males and females during a single-leg drop exercise (Russell et al., 2006; Zazulak et al., 2005). Furthermore, Worrell, Crisp, and LaRosa (1998) demonstrated no significant difference in hamstring and gluteus maximus activation between males and females for a lateral step-up exercise. Zazulak et al. (2005) did demonstrate significantly lower gluteus maximus activation for females compared to males during the postcontact phase of landing. One explanation for this discrepancy may be that the dynamic activity of a single-leg drop produces different hip and gluteus muscle activation than a slow, controlled squat or non-weight-bearing exercises.

The conflicting results and ambiguity of previous research reflect the inconsistency of methodology, specifically the exercises and muscles tested in each study. It is difficult to compare the current study to previous research due to the lack of research pertaining to differences between males and females during the non-weight-bearing exercises of the current study.

Utilization and Clinical Interpretation of results

Research has demonstrated the significant impact that gluteus medius weakness may have on lower extremity injuries, and has examined rehabilitation exercises and protocols for strengthening the gluteus medius and hip abductors in general. Until now some of the exercises, such as the clamshell, had never been tested to determine the muscle activation levels during this exercise. This study provides a basis for the use of the side-lying abduction, side-lying abduction with external rotation, and clamshell exercises in lower extremity rehabilitation where the goal is increasing activation of the TFL and gluteus medius muscles. Although the majority of rehabilitation protocols may also include weight-bearing and functional exercises, the results of this study confirmed that non-weight bearing exercises can be utilized to successfully activate the gluteus medius and TFL. The results revealed that use of these non-weight-bearing exercises could potentially decrease lower extremity pathologies by strengthening the hip abductors. Strengthening the hip abductors can aid in stabilizing the pelvis and decreasing malalignment and stress of the lower extremity.

It is recommended that the side-lying abduction with external rotation exercise be utilized for the greatest activation of the TFL muscle in both males and females. Furthermore, the side-lying hip abduction exercise may be the most beneficial when attempting to strengthen the gluteus medius. The non-weight bearing exercises in the current study provide a good starting point for rehabilitation or strengthening protocols for injuries related to TFL and gluteus medius weakness.

Limitations

One limitation to the current study was the sample population. Only recreational athletes from one Division I-A Institution participated in this study. Recruiting recreational athletes from various institutions and from multiple regions of the country would aid in providing a more diverse sample.

Another limitation was participants did not report the specific type of activities that they engage in on a regular basis. Certain activities may lead to increased strength and/or endurance in certain muscles that were tested. Every participant was a recreational athlete and therefore was doing some sort of physical activity for at least 20 minutes three times per week. Also, participants were allowed to rest between exercises in an effort to minimize fatigue.

Pelvic stability and movement were not controlled in this study. Individuals may have allowed the pelvis to rotate during the exercises, particularly the clamshell and side-lying abduction with external rotation which both involved rotation of the hip. Despite this limitation, participants were given verbal cues if the researcher observed the pelvic rotation.

A final limitation to this study was that body composition was not determined. Body composition may affect the accuracy of the surface EMG readings. Increased adipose tissue may make it more difficult to obtain an adequate reading via surface EMG. However, all participants answered "no" to the question "are you excessively overweight" on the health history questionnaire. These limitations should be addressed and controlled in future studies that examine the muscle activation levels of selected gluteus and hip muscles during non-weight-bearing exercises.

Future Research Implications

Future research should continue to examine the muscle activation of the gluteus and hip musculature during various types of exercises. These exercises may include adding weights to the non-weight-bearing exercises in the current study, examining the side-lying abduction exercise with an internal rotation component, or changing the angles of the knees and hips during the clamshell exercise. Future researchers may also compare the exercises in the current study with other weight-bearing and functional exercises. Examining other exercises may assist clinicians in developing exercise progressions and rehabilitation protocols.

Additionally, the effects of TFL weakness on lower extremity pathologies should be examined. Although the gluteus medius has been studied extensively, very little research has focused on the TFL and its role as a hip abductor. Research in this area may lead researchers to understand why females exhibited greater activation of the TFL than males in the current study.

Other future research may also focus on controlling body composition levels of participants during surface EMG readings. It is known that increased adipose tissue may make the EMG readings less accurate because it is harder to detect muscle activation through adipose tissue. Body composition may be measured and recorded to limit possible effects on surface EMG readings.

The effects of lumbar stabilization should be further investigated. Lumbar stabilization during the non-weight-bearing exercises in the current study may eliminate any pelvic rotation that may occur, particularly during the exercises that contain a rotational component. Pelvic rotation may affect the muscles that are activated or the activation levels. Understanding these areas may provide more accurate results about muscle activation levels.

It is also important for future research to expand on the current study to include a more diverse population, making the results more applicable to a larger clinical population. Samples may include collegiate or professional athletes, recreational athletes of a larger age range, or injured athletes. The current study may also be expanded by comparing the muscle activation levels across various sports.

Conclusion

This study examined the muscle activation during three different exercises across four different hip and gluteus muscles in an attempt to assist clinicians in developing the most effective exercises for activating and strengthening selected hip and gluteus muscles. More specifically this study observed differences in muscle activation levels of the gluteus maximus, gluteus medius, TFL and lateral hamstring comparing three different non-weight-bearing exercises. This study also observed differences between males and females in muscle activation levels during non-weight-bearing exercises. This was the first study to demonstrate the effects of these non-weight-bearing exercises on selected hip and gluteus muscle activation levels and compare the activation levels between males and females.

At the present time the TFL revealed the greatest muscle activation during the side-lying hip abduction with external rotation and clamshell exercises while the gluteus medius demonstrated the greatest activation during the side-lying hip abduction exercise. Furthermore, females demonstrated significantly greater TFL activation levels than males across all exercises. Further studies should continue to examine the muscle activation of the gluteus and hip muscles during various exercises, as well as attempt to gain better understanding of differences between males and females that may exist in muscle activation levels.

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APPENDIX A

Human Subjects Consent Form

Electromyography Measures of Gluteus and Hip Muscles of Recreational Athletes during Non-weight-Bearing Exercises

Informed Consent

For questions regarding this study,
Please contact:
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Phone: (507) 360-1426
Work: (517) 353-1655

For questions regarding your rights as a research participant, please contact:
Peter Vasilenko, Ph.D.
Biomedical Institutional Review Board
Michigan State University
202 Olds Hall
East Lansing, MI 48824
irb@msu.edu
Phone: (517) 355-2180
Fax: (517) 432-4503

The purpose of this research study is to observe the activation of the hip and gluteus muscles using surface electromyography while performing three different exercises. This study will also determine the difference in motor unit recruitment between male and female recreational athletes. The study will use surface EMG as an assessment tool of motor unit recruitment.

Your participation in this research study will consist of one 60 minute session. You will not be compensated for your participation in this study. During the 60 minute session the exercises will be demonstrated for you and you will have a chance to practice these exercises. An athletic trainer will then prepare the skin and place 8 surface electrodes (2 on each muscle) on the gluteus medius, gluteus maximus, tensor fascia latae, and biceps femoris muscles. An athletic trainer of the same sex as you will be available to apply the electrodes. You will then be asked to complete 10 repetitions of each of the three exercises.

It is impossible to completely eliminate the risk of injury during physical activity. However due to the nature of the study the risks are minimal. There is potential for the development of a rash due to the adhesive on the electrodes. There is also a possibility that you may experience minimal muscular soreness during or after the study as a result of completing the exercises. A certified athletic trainer will be present during all sessions. There will be a phone easily accessible during the study to contact emergency medical services if the need arises. This study will contribute to understanding the benefits of various exercises for the gluteus and hip muscles.

Your identity and recorded information will remain confidential. Confidentiality will be protected by; (a) results will be presented in aggregate form in any presentations and publications; and (b) all data will be stored in a computer that has a password necessary to see confidential data. Only authorized researchers will have access to the data. Your privacy will be protected to the maximum extent allowable by law.

Participation in this research study is completely voluntary. In order to participate in this study, we need your written consent in the spaces provided below. You may also discontinue participation at any time without penalty. Your participation in this research project will not involve any additional costs to you or your health care insurer.

If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or are in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Dr. Tracey Covassin (517) 353-2010 with any questions or to report an injury.

Any questions concerning participation in this research study should be directed to Kimberly S. Sieve (507) 360-1426 or Dr. Tracey Covassin (517) 353-2010. If you have any additional questions concerning your rights as a volunteer or are dissatisfied at any time with any aspect of this research study you may contact -- anonymously, if you wish -- Peter Vasilenko, PhD, Michigan State University's Chair of the Biomedical, Health Sciences Institutional Review Board by phone: (517) 355-2180, fax: (517) 432-4503, e-mail: irb@msu.edu, or regular mail: 202 Olds Hall, East Lansing, MI 48824.

INFORMED CONSENT

Your signature below indicates your voluntary agreement to participate in this research study.

I, ______________________________ have read and agree to participate in this research
(Please Print Your Name)

study as described above.

____
(Please Print Your Name)

______________________________ ______/______/______
(Please Sign Your Name) *(Date)*

APPENDIX B
Health History Questionnaire

Electromyography Measures of Gluteus and Hip Muscles of Recreational Athletes during Non-Weight-Bearing Exercises

MICHGAN STATE UNIVERSITY
38 IM SPORTS CIRCLE
HEALTH HISTORY QUESTIONNAIRE

Every participant must fill out this questionnaire and sign a release before he/she will be allowed to participate in an exercise program or EMG measures of muscular activity.

Name______________________________ Phone________________ Date__________

Address____________________________ Date of Birth__________ Age__________

Email______________________________ Ht___________ Wt___________

1. Has your doctor ever said you have heart trouble? Yes No

2. Have you ever had chest pain or heavy pressure in your chest as a result of exercise, walking, or other physical activity, such as climbing a flight of stairs? (Note: This does not include the normal out-of-breath feeling that results from vigorous exercise) Yes No

3. Do you often feel faint or experience severe dizziness? Yes No

4. Has a doctor ever told you that you have high blood pressure or diabetes? Yes No

5. Have you ever had a real or suspected heart attack or stroke? Yes No

6. Do you have any physical condition, impairment or disability, including any joint or muscle problem that should be considered before you undertake an exercise program? Yes No

7. Have you ever taken medication to reduce your blood pressure or cholesterol levels? Yes No

8. Are you excessively overweight? Yes No

9. Is there any good physical reason not mentioned here why you should not follow an exercise program even if you wanted to? Yes No

10. Are you over age 40, or not accustomed to vigorous exercise? Yes No

If you answered YES to one or more questions, and if you have not recently done so, consult with your physician BEFORE entering an exercise program or participating in an exercise test. After medical evaluation or consultation, have your physician sign this form indicating your suitability for the following activity:

____
____
____

______________________________ ___________ ________________
Signature of Physician Date Phone

Exclusion Criteria Questionnaire

Please answer the following questions regarding your health history.

Have you: (circle your response)

Had a lower extremity injury in the last six months? Y N

Had a hip or pelvis injury in the last six months? Y N

Ever had a hip surgery? Y N

Had an adhesive allergy? Y N

Is there any reason that you can identify that you would not be able to complete the exercises related to this study? Y N

Thank you for your participation. Answers to this questionnaire will remain confidential. If you are not selected for this study, or choose not to participate, your questionnaire will be shredded.

Signature: ____________________________ Date: ________________

APPENDIX C

Pairwise Comparisons and ANOVAs for Muscle Activation Levels

Table A-1 Repeated Measures ANOVA Comparing Gluteus Maximus for Exercise and Exercise * Gender

Techniques	SS	df	MS	F	P
Exercise	.075	2	.037	7.600	.001*
Exercise X Gender	.005	2	.003	.540	.586

*(significant at p = .05)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-2 Pairwise Comparison for Gluteus Maximus Activation across Three Exercises

Exercises	Mean Diff	Standard Error	p	95% CI
ABD to Clam	-.071	.020	.001*	-.112 to -.030
ABD to ABDER	-.035	.010	.001*	-.055 to -.015
Clam to ABD	.071	.020	.001*	.030 to .112
Clam to ABDER	.036	.022	.118	-.010 to .081
ABDER to ABD	.035	.010	.001*	-.015 to .055
ABDER to Clam	-.036	.022	.118	-.081 to .010

*(significant at the p = .05 level)
ABD = side-lying hip abduction, Clam = clamshell, ABDER = side-lying hip abduction with external rotation
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-3 Repeated Measures ANOVA Comparing Gluteus Medius for Exercise and Exercise * Gender

Techniques	SS	df	MS	F	P
Exercise	.653	2	.326	1.620	.207
Exercise X Gender	.300	2	.150	.744	.480

*(significant at p = .05)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-4 Pairwise Comparison for Gluteus Medius Activation across Three Exercises

Exercises	Mean Diff	Standard Error	p	95% CI
ABD to Clam	.205	.144	.165	-.089 to .499
ABD to ABDER	.137	.136	.324	-.142 to .416
Clam to ABD	-.205	.144	.165	-.499 to .089
Clam to ABDER	-.068	.034	.056	-.138 to .002
ABDER to ABD	-.137	.136	.324	-.416 to .142
ABDER to Clam	.068	.034	.056	-.002 to .138

*(significant at the p = .05 level)
ABD = side-lying hip abduction, Clam = clamshell, ABDER = side-lying hip abduction with external rotation
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-5: Repeated Measures ANOVA Comparing TFL for Exercise and Exercise * Gender

Techniques	SS	df	MS	F	P
Exercise	.846	2	.423	32.184	.000*
Exercise X Gender	.038	2	.019	1.427	.249

*(significant at p = .05)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-6 Pairwise Comparison for TFL Activation across Three Exercises

Exercises	Mean Diff	Standard Error	p	95% CI
ABD to Clam	.176	.036	.000*	.102 to .250
ABD to ABDER	-.050	.025	.058	-.102 to .002
Clam to ABD	-.176	.036	.000*	-.250 to -.102
Clam to ABDER	-.226	.026	.000*	-.279 to -.173
ABDER to ABD	.050	.025	.058	-.002 to .102
ABDER to Clam	.226	.026	.000*	.173 to .279

*(significant at the p = .05 level)
ABD = side-lying hip abduction, Clam = clamshell, ABDER = side-lying hip abduction with external rotation
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-7 Repeated Measures ANOVA Comparing Lateral Hamstring for Exercise and Exercise * Gender

Techniques	SS	df	MS	F	P
Exercise	.001	2	.000	.107	.899
Exercise X Gender	.021	2	.011	2.759	.072

*(significant at p = .05)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-8 Pairwise Comparison for Lateral Hamstring Activation across Three Exercises

Exercises	Mean Diff	Standard Error	p	95% CI
ABD to Clam	.007	.020	.729	-.034 to .048
ABD to ABDER	.006	.016	.724	-.027 to .038
Clam to ABD	-.007	.020	.729	-.048 to .034
Clam to ABDER	-.001	.011	.905	-.024 to .021
ABDER to ABD	-.006	.016	.724	-.038 to .027
ABDER to Clam	.001	.011	.905	-.021 to .024

*(significant at the p = .05 level)
ABD = side-lying hip abduction, Clam = clamshell, ABDER = side-lying hip abduction with external rotation
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-9 Repeated Measures ANOVA Comparing Side-lying Abduction for Muscle and Muscle * Gender

Techniques	SS	df	MS	F	P
Muscle	4.067	3	1.356	7.890	.000*
Muscle X Gender	1.511	3	.504	2.931	.038*

*(significant at p = .05)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-10 Pairwise Comparison for Side-lying Abduction across Four Muscles

Exercises	Mean Diff	Standard Error	p	95% CI
GMax to GMed	-.396	.140	.008*	-.682 to -.110
GMax to TFL	-.293	.053	.000*	-.401 to -.184
GMax to LHam	.032	.033	.335	-.035 to .099
GMed to GMax	.396	.140	.008*	.110 to .682
GMed to TFL	.103	.145	.483	-.194 to .400
GMed to LHam	.428	.143	.006*	.136 to .720
TFL to GMax	.293	.053	.000*	.184 to .401
TFL to GMed	-.103	.145	.483	-.400 to .194
TFL to LHam	.325	.064	.000*	.194 to .455
LHam to GMax	-.032	.033	.335	-.099 to .035
LHam to GMed	-.428	.143	.006*	-.720 to -.136
LHam to TFL	-.325	.064	.000*	-.455 to -.194

*(significant at the p = .05 level)
ABD = side-lying hip abduction, Clam = clamshell, ABDER = side-lying hip abduction with external rotation
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-11 Repeated Measures ANOVA Comparing Clamshell for Muscle and Muscle * Gender

Techniques	SS	df	MS	F	P
Muscle	.834	3	.278	11.247	.000*
Muscle X Gender	.429	3	.143	5.788	.001*

*(significant at p = .05)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-12 Pairwise Comparison for Clamshell across Four Muscles

Exercises	Mean Diff	Standard Error	p	95% CI
GMax to GMed	-.120	.044	.010*	-.210 to -.031
GMax to TFL	-.046	.030	.133	-.107 to .015
GMax to LHam	.110	.021	.000*	.067 to .152
GMed to GMax	.120	.044	.010*	.031 to .210
GMed to TFL	.074	.059	.220	-.047 to .195
GMed to LHam	.230	.040	.000*	.149 to .311
TFL to GMax	.046	.030	.133	-.015 to .107
TFL to GMed	-.074	.059	.220	-.195 to .047
TFL to LHam	.156	.040	.001*	.074 to .238
LHam to GMax	-.110	.021	.000*	-.152 to -.067
LHam to GMed	-.230	.040	.000*	-.311 to -.149
LHam to TFL	-.156	.040	.001*	-.238 to -.074

*(significant at the p = .05 level)
ABD = side-lying hip abduction, Clam = clamshell, ABDER = side-lying hip abduction with external rotation
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-13 Repeated Measures ANOVA Comparing Side-lying Abduction with External Rotation for Muscle and Muscle * Gender

Techniques	SS	df	MS	F	P
Muscle	2.926	3	.975	47.396	.000*
Muscle X Gender	.370	3	.123	5.992	.001*

*(significant at p = .05)
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction

Table A-14 Pairwise Comparison for Side-lying Abduction with External Rotation across Four Muscles

Exercises	Mean Diff	Standard Error	p	95% CI
GMax to GMed	-.224	.025	.000*	-.276 to -.172
GMax to TFL	-.308	.045	.000*	-.401 to -.215
GMax to LHam	.073	.032	.029*	.008 to .137
GMed to GMax	.224	.025	.000*	.172 to .276
GMed to TFL	-.084	.036	.025*	-.157 to -.011
GMed to LHam	.297	.028	.000*	.240 to .353
TFL to GMax	.308	.045	.000*	.215 to .401
TFL to GMed	.084	.036	.025*	.011 to .157
TFL to LHam	.381	.050	.000*	.278 to .484
LHam to GMax	-.073	.032	.029*	-.137 to -.008
LHam to GMed	-.297	.028	.000*	-.353 to -.240
LHam to TFL	-.381	.050	.000*	-.484 to -.278

*(significant at the p = .05 level)
ABD = side-lying hip abduction, Clam = clamshell, ABDER = side-lying hip abduction with external rotation
Note: Values based on normalized data. Normalized data = average muscle activation level divided by the reference contraction