THE EFFECTS OF INITIAL HIP ABDUCTION AND EXTERNAL ROTATION STRENGTH AND NEUROMUSCULAR FATIGUE OF THE GLUTEUS MEDIUS ON THE STAR EXCURSION BALANCE TEST IN MALE AND FEMALE HEALTHY SUBJECTS

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THE EFFECTS OF INITIAL HIP ABDUCTION AND EXTERNAL ROTATION STRENGTH AND NEUROMUSCULAR FATIGUE OF THE GLUTEUS MEDIOUS ON THE STAR EXCURSION BALANCE TEST IN MALE AND FEMALE HEALTHY SUBJECTS (58 pp.)

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The gluteus medius muscle is an essential hip stabilizer during unilateral stance. A weakened or fatigued gluteus medius may be associated with decreases in postural control during dynamic balance. The objective of this study was to determine if initial hip muscular strength and gender affect neuromuscular performance on the Star Excursion Balance Test (SEBT) following fatigue of the hip musculature. In a randomized control trial, set in a laboratory, 20 male and 20 female recreationally active subjects with no history of lower extremity injury were recruited to participate in this study. Subjects were randomized into control and experimental groups. Experimental subjects were placed through separate hip abduction and external rotation fatiguing exercises, followed by the SEBT. Control subjects were not placed through a fatiguing protocol before the SEBT. Fatigue was assessed with a handheld dynamometer compared to a 43% decrease in peak force compared to baseline measurements. The SEBT was used to determine normalized reach distances during all three sessions. No significant difference between reach distances was noted between fatigue and non-fatigue groups. A main effect of time for all subjects was observed (p=0.042). Gender was significant for all subjects, regardless of group (p = 0.001). Performance on the SEBT is...
not affected by initial strength and fatigue of the hip abductors and external rotators between genders.
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CHAPTER I

INTRODUCTION

Measurement of postural control is an important tool in the assessment of athletic populations for establishing levels of neuromuscular function for the purposes of athletic performance, injury prevention, and rehabilitation (Gribble & Hertel, 2003). Proper function and coordination of all muscles that provide stability to the lumbar spine, hips, and pelvis (i.e., the core) are important in providing optimal production, transfer, and control of forces and movement that occur throughout the body (McMullen, Cosby, Hertel, Ingersoll, & Hart, 2011). The gluteus medius (GMed) is an important muscle in maintaining normal movement patterns of the pelvic hip complex. It plays a major role in stabilizing the hip during unilateral stance to prevent the pelvis from dropping on the unsupported side and is critical to controlling internal rotation of the femur during closed kinetic chain activities (French, Dunleavy, & Cusak, 2010; O’Dwyer, Sainsbury, & O’Sullivan, 2011). Gluteus medius dysfunction is a common cause of insufficient hip abduction and external rotation strength that is often associated with decreases in postural control (Cichanowski, Schmitt, Johnson, & Niemuth, 2007; DiMattia, Livengood, Uhl, Mattacola, & Malone, 2005; McMullen et al., 2011).

Postural control may be classified as either static, which involves attempting to maintain a base of support with minimal movement, or dynamic, which is defined as attempting to maintain a stable base of support while completing a prescribed movement (Gribble, Hertel, Denegar, & Buckley, 2004). Dynamic balance is needed to maintain center of mass within the base of support with movements that require muscle control in
response to some type of disturbance (Borchers, Bruey, Crotts, & Pauly, 2010). Balance has been assessed using the Balance Error Scoring System (BESS), but the most valid, reliable, and widely used assessment tool of dynamic balance by contemporary researchers is the Star Excursion Balance Test (Bressel, Yonker, Kras, & Heath, 2007; Earl & Hertel, 2001; Gribble & Hertel, 2003; Leavey, Sandrey, & Dahmer, 2010; Norris & Trudelle-Jackson, 2011; Robinson & Gribble, 2008). It is a functional balance test that uses a unilateral stance on the center of an asterisk (star) taped on the floor and a maximal reach along each of the asterisk’s eight lines (Leavey et al., 2010).

Neuromuscular control during the SEBT is reflected by the distance reached in each direction, with an increased reach distance reflecting greater neuromuscular control (Norris & Trudelle-Jackson, 2011).

Although many factors decrease neuromuscular control, one critical factor is fatigue. One explanation for this relationship between fatigue and altered neuromuscular control is that slowed conduction of afferent signals from the fatigue altered state of the muscle will lead to slowed propagation of efferent signals, thereby affecting the ability to create compensatory movement effectively (Rozzi, Yuktanandana, Pincivero, & Lephart, 2000). Men and women exhibit many physiological differences along with different kinematic movement patterns (Jacobs, Uhl, Mattacola, Shapiro, & Ravens, 2007; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Zeller, McCrory, Kibler, & Uhl, 2003) during sport specific activity, which combined with fatigue could result in certain predispositions for injury. It also is well documented that men and women fatigue differently (Gribble, Robinson, Hertel, & Denegar, 2009; McMullen et al., 2011; Patrek,
Thomas, Willson, Wright, & Doberstein, 2011; Springer & Pincivero, 2009). During sustained and intermittent isometric contractions, women are less fatigable than men because of differences in their neuromuscular systems that allow physiologic adjustments during a sustained fatiguing task (Hunter, 2009). The magnitude of sex differences in fatigability is specific to the task performed, the age of the person performing the task, and the muscle group involved during the fatiguing exercise (McMullen et al., 2011). Fatigue and deficits in postural control may precipitate musculoskeletal injury (Gribble & Hertel, 2004).

**Statement of Problem**

Most athletic injuries occur in the lower extremities (Hrysomallis, 2011). Anecdotally, most of these injuries occur at the end of an activity, when the participant is fatigued (Yaggie & Armstrong, 2004). Muscle fatigue of at least 50% of peak torque or 43% of peak force compared to baseline measurements may increase the risk of injury because of decreased balancing ability (Gribble et al., 2004; Patrek et al., 2011). It is evident that the gluteus medius muscle might play a large role in lower extremity injury and should therefore be included in the rehabilitation program, but it has often been overlooked (Earl, 2004).

Fatigue of the gluteus medius muscle may elicit a decrease in postural control as reflected in dynamic balance assessments such as the Star Excursion Balance Test (SEBT). This decrease in postural control during the SEBT after fatigue of the gluteus medius may be indicative of fatigue leading to decreases in postural control during athletic performance. Decreases in dynamic balance due to fatigue and weakness of
muscles involved in postural stability can unequivocally lead to injuries, such as patellofemoral pain syndrome, iliotibial band syndrome, ankle sprains, and ACL tears (Niemuth, 2007). This study examines the effects fatigue of the gluteus medius has when assessing postural control during the Star Excursion Balance Test in healthy male and female subjects.

**Purpose**

The purpose of this research is to determine if initial hip muscular strength and gender affect neuromuscular performance on the Star Excursion Balance Test (SEBT) following fatigue of the hip musculature. The gluteus medius, although very involved in postural control, is often overlooked during strengthening and rehabilitation of injuries. Initial strength of the hip abductor and hip external rotator muscle groups were examined according to how these muscles are affected during fatigue and subsequent performance of the SEBT. This research determines whether there is a significant difference between initial hip ER strength and SEBT performance, as well as initial hip ABD strength and SEBT performance. Significant differences between genders were examined between hip ER strength and hip ABD strength and performance on the SEBT. Gender differences and SEBT performance following fatigue were also examined. It is predicted that women will show a difference in fatigability compared to men, as reported in previous research (Gribble & Hertel, 2004; Hunter, 2009; McMullen et al., 2011).

**Research Questions**

1. Does initial hip ER and ABD muscle strength affect neuromuscular performance on the SEBT following a fatigue protocol?
Hypotheses:

- There will be a significant difference between initial strength of the hip ER and SEBT performance.
- There will be a significant difference between initial strength of the hip ABD and SEBT performance.
- There will be a gender difference between initial strength of the hip ER and SEBT performance.
- There will be a gender difference between initial strength of the hip ABD and SEBT performance.

2. Does gender effect neuromuscular performance on the SEBT following a fatigue protocol of the hip musculature?

Hypothesis:

- There will be a significant difference between males and females and SEBT performance following fatigue.

Assumptions

The researcher assumes that all participants agree voluntarily to the terms and conditions of the study and will have signed a waiver. It is assumed that the participants will put forth their maximal efforts when performing the exercise program in order for the researcher to gain the best and most accurate information. It is assumed that the variables in the study have been clearly defined by previous research and are measurable. The researcher assumes that all instruments used in the study are valid and reliable.
measures for each variable being studied. It is assumed that all methodology relates to the purpose of the study and the statement of problem.

**Delimitations**

This research was delimited to college aged males and females, ranging from 18–26 years of age, who have not suffered a lower extremity injury in the past 6 months. The subjects are delimited to be recreationally active, participating in aerobic or athletic activity at least 2–3 times per week. The study is delimited to the examination of initial hip ABD and ER strength and performance of the SEBT after fatigue in healthy male and female subjects.

**Operational Terms**

*Balance:* The process of maintaining the position of the body’s center of gravity vertically over the base of support while relying on rapid, continuous feedback from visual, vestibular and somatosensory structures and then executing smooth and coordinated neuromuscular actions (Hrysomallis, 2011).

*Dynamic Postural control:* A process that involves completion of a functional task without compromising one’s base of support (Gribble & Hertel, 2003).

*Fatigue:* A reduction in force generating capacity of the total neuromuscular system, resulting in a 43% decrease in peak force in relation to baseline measurements (Paterek et al., 2011; Springer & Pincivero, 2009).

*Gluteus Medius:* A muscle located in the hip, which is broken into anterior, middle, and posterior subdivisions. Its primary functions are hip abduction and internal rotation (O’Dwyer et al., 2011).
Star Excursion Balance Test: A functional balance test that uses a unilateral stance on the center of an asterisk (star) taped on the floor and a maximal reach along each of the asterisk’s eight lines (Leavey et al., 2010).

Summary

The goal of this study is to determine the importance of the gluteus medius muscle in relation to initial strengthening and its importance in preventing weakness, fatigue, and injury. It has already been shown that fatigue has a negative effect on neuromuscular control of the body and can consequently lead to injury (Gribble & Hertel, 2004). Previous studies have failed to identify if initial strength of the hip ER and ABD muscle groups has an effect on dynamic balance performance on the SEBT. Previous studies have also neglected to investigate if males and females exhibit differences in performance on the SEBT following a fatigue protocol of the hip musculature. The aim of this research is to demonstrate that initial hip strength and gender will affect neuromuscular performance on the SEBT after fatigue of the gluteus medius.
CHAPTER II
REVIEW OF LITERATURE

Injuries occur frequently throughout sporting events, whether due to an external force or as a result of poorly trained and weakened muscles. Weakened or fatigued muscles that play a role in stabilization of joints offer a further risk of injury not only to the structures they directly support, but also all other structures within that area of the body (Niemuth, 2007). Reduction in force production, either from weak or fatigued muscles, limits the body’s ability to attenuate the high forces associated with dynamic movements (Jacobs et al., 2007). The gluteus medius is one such muscle that plays a crucial role in static and dynamic hip stabilization and compromise of this structure can lead to injury not only in the hip, but also throughout the knee and ankle (Niemuth, 2007).

The gluteus medius is involved heavily in dynamic postural control, particularly during unilateral movements of the leg, such as mini squats or stances. Athletes are encouraged to strengthen musculature involved with stabilization and dynamic postural control in order to prevent injury. A valid and reliable measure of dynamic postural control is the Star Excursion Balance Test (Bressel et al., 2007). In order to properly assess the integrity of the gluteus medius during postural control, it is necessary to mimic actual athletic participation in which the muscle would be fatigued. Fatigue is an essential factor that could potentially lead to injury if the musculature is not trained and conditioned properly.
Fatigue and Athletic Performance

The phenomenon of fatigue is complex and can be described as an exercise-induced impairment of performance and reduction in force generating capacity of the neuromuscular system during athletic activity (Knicker, Renshaw, Oldham, & Cairns, 2011; Patrek et al., 2011). The underlying process of fatigue develops as exercise proceeds, which ultimately manifests as a decline of performance. The sensation of fatigue includes the conscious perception of increasing effort needed to sustain a submaximal task (i.e., the exercise feels harder), together with muscle weakness and feelings that persist after the completion of the exercise. The number and extent of the fatigue symptoms, and the fatigue factors involved, depend on the characteristics of the sporting task, the individual and the environment (Knicker et al., 2011).

The main factors causing fatigue symptoms include (a) diminished carbohydrate availability, increased brain serotonin and dehydration during prolonged sports; (b) hyperkalaemia, systemic acidosis, and hypoxia during high-intensity sports; and (c) hyperthermia, dehydration, and hypoxia during sport events in hostile environmental conditions. Manifestations of central and peripheral fatigue, impaired technique and fatigue sensations often occur simultaneously, and psychological aspects may modify these symptoms (Knicker et al., 2011).

Prolonged exertion causes changes in neuromuscular control regarding both central and peripheral fatigue. Peripheral fatigue refers to a decrease in the ability of a muscle to produce force because of changes that occur at or distal to the neuromuscular junction, whereas central fatigue refers to an exercise induced reduction in voluntary
activation of a muscle because of changes that occur in a motor unit proximal to the neuromuscular junction (Patrek et al., 2011).

Fatigue increases the threshold of muscle spindle discharge, which disrupts afferent feedback, subsequently altering joint awareness (Gribble et al., 2004). In a fatigued state, the conduction of the afferent signal is impaired, which might lead to slower propagation of efferent signals necessary to maintain posture. Whole body fatiguing exercises have been compared to isolated muscle fatiguing exercises, revealing that both are equally detrimental to maintaining posture during single leg standing in healthy males and females (Springer & Pincivero, 2009). The magnitude of sex differences in fatigability is specific to the task performed, the age of the person performing the task, and the muscle group involved during the fatiguing exercise (McMullen et al., 2011).

**Gender Differences and Fatigue**

**Differences in Hip Strength**

Gender differences are present amongst several aspects of structure and physiological function. Alterations in lower extremity mechanics, differences in quadriceps angle (Q angle) of the hip, and muscle fiber cross sectional area and recruitment all play a diverse role physiologically between genders (Hunter, 2009; Patrek et al., 2011). It is often stated and assumed that males are stronger than females and have higher levels of muscular recruitment during exercise; however, women have been observed as having higher activation levels of the rectus femoris and gluteus maximus compared with men when performing closed kinetic chain exercises during a
rehabilitation program (Dwyer, Boudreau, Mattacola, Uhl, & Lattermann, 2010). Although strength differences and muscle activation are noted between men and women, it is not uncommon for strength differences to be present even when compared bilaterally in an athlete.

Limb dominance has also been defined as one limb demonstrating increased dynamic control as a result of an imbalance in muscular strength and recruitment patterns. Both limbs can be negatively affected by this asymmetry. Dependence on the dominant limb can increase stress on the joints of that extremity. Overreliance on the dominant limb can also result in weakness in the contralateral limb, which can decrease the nondominant extremity’s ability to absorb large forces associated with athletic activities. Gluteus medius muscle activation levels have been seen to be equal to or less than 30% of a maximum voluntary isometric contraction (MVIC) in the dominant limb of both men and women during single leg squat, lunge, and step up and over exercises. Implementation of the same three exercises on the non-dominant limb of the same subjects showed activation levels of less than 20% of a MVIC (Dwyer et al., 2010).

Not only do strength imbalances exist, but they may also result in increased injury rates for athletes with side-to-side strength differentials greater than 10% (Knapik, Bauman, Jones, Harris, & Vaughan, 1991). Sex differences have been observed in frontal plane and transverse plane hip motion during a single leg squat task, particularly with women demonstrating much greater hip adduction and external rotation when compared with men (Dwyer et al., 2010; Zeller et al., 2003). A previous study demonstrated that males are able to perform the Star Excursion Balance Test better,
demonstrating larger reach distances than females. However, when the reach distances were normalized to the leg length of the stance limb, no significant gender differences were observed (Gribble & Hertel, 2003).

There are neuromuscular and biomechanical differences between genders at the knee during functional tasks such as landing and cutting, with males demonstrating a larger amount of knee flexion than females. However, in tasks, such as the Star Excursion Balance Test, which measures maximum reach distance while maintaining dynamic balance, females have exhibited a greater degree of knee and hip flexion. This finding was reported with the subjects in a fatigued state and suggests that females may be more likely to maintain better control of these structures during dynamic tasks (Gribble et al., 2009). There is a negative correlation between contraction intensity of sustained contractions and the sex difference in muscle fatigue, which could be related to the absolute strength of men and women when exerting the same contraction intensity. One possibility for this difference is that men involve greater intramuscular pressures and occlusion of blood flow during static contractions than women, which involves a more rapid accumulation of metabolites, impairment of oxygen delivery to the muscle, and a more rapid rate of muscle fatigue (Hicks, Kent-Braun, & Ditor, 2001; Hunter, 2009).

**Comparison of Gender Kinematics and Lower Extremity Injury**

Gender related knee kinematic findings have been reported for various activities such as landing, cutting, and performing a single leg squat. Proximal hip musculature has been seen to influence kinematics at the tibiofemoral joint during landing, which could ultimately result in injury (Carcia, Eggen, & Shultz, 2005). Female athletes exhibit knee
motion patterns in many athletic tasks, such as landing and cutting, that frequently mimic or come close to positions in which non-contact ACL injuries may occur (Malinzak et al., 2001). These biomechanical and gender differences are a significant risk factor for an ACL injury, which could be attributed to a lack of strength in the proximal hip stabilizers. The relationship between hip abductor strength and chronic knee injury during prolonged activities suggests that the endurance of this muscle group also may play a crucial role in kinematics and neuromuscular control of the knee (Jacobs et al., 2007).

Insufficient proximal hip strength has been associated with altered lower extremity alignment including excessive femoral adduction, femoral internal rotation, and increased lateral patellar pressure in female athletes (Fulkerson, 2002; Heinert, Kernozek, Greany, & Fater, 2008). Lack of hip strength in female athletes may also contribute to greater non-sagittal hip and pelvis motion during walking and running across a range of speeds and inclines on a treadmill (Chumanov, Wall-Scheffler, & Heiderscheit, 2008).

In their kinematic and EMG study of males and females completing a single leg squat, Zeller et al. (2003) reported that the mean maximum EMG activation for the gluteus medius was 77.3% of maximum voluntary contraction for males and 41.0% for females. These differences can be attributed to a difference in strength of the gluteus medius, as well as a potential lack focus placed on this muscle during strength training. The gluteus medius plays a significant role in hip stabilization and is a muscle that continues to be overlooked from a strength training and rehabilitation standpoint.
The Gluteus Medius and Athletic Performance

Importance of the Gluteus Medius on Athletic Performance

Proper function and coordination of muscles that provide stability to the lumbar spine, hips, and pelvis (i.e., the core) are important for providing optimal production, transfer, and control of forces and movement that occur throughout the body (McMullen et al., 2011). The gluteus medius plays an important role in maintaining normal movement patterns of the pelvis and lower limb and is considered one of the primary stabilizers in the pelvic region (O’Dwyer et al., 2011). Gluteus medius is an important muscle in controlling frontal plane motion of the pelvic hip complex. It also plays a major role in stabilizing the hip during unilateral stance to prevent the pelvis dropping on the unsupported side and is critical to controlling internal rotation of the femur during closed kinetic chain activities (French et al., 2010). Contraction of the gluteus medius during single-leg stance prevents the contralateral pelvis from “dropping” and therefore provides proximal stability for lower extremity motion. The gluteus medius muscle is a primary abductor and internal rotator of the hip and is important to pelvic stabilization during walking and other functional activities (Earl, 2004).

During gait, the gluteus medius provides the majority of support in midstance, along with gluteus minimus. It also works synergistically with gluteus maximus to stabilize the pelvis in the frontal plane. Consequently, the gluteus medius has an important role in daily activities such as standing, walking, stair climbing and running (French et al., 2010). The gluteus medius is used to correct posture and keep an individual balanced and erect. Very infrequently does an individual train to strengthen
the gluteus medius muscle when attempting to increase dynamic postural control either before or after an injury such as a lateral ankle sprain (Leavey et al., 2010).

The gluteus medius muscle is located on the lateral portion of the hip, with the origin at the iliac crest and the insertion at the greater trochanter of the femur (Saladin, 2012). The gluteus medius consists of three different sections of fibers that make up the entirety of the muscle. The posterior fibers are arranged such that contraction causes the femoral head to be drawn into the acetabulum, thereby stabilizing the hip joint. Activity in this portion continues throughout the stance phase. The middle fibers run more vertically and parallel with the long axis of the femur, and although they initiate abduction of the hip during stance, they are secondary to the tensor fascia latae (TFL) as the primary abductor of the hip joint. The anterior portion of the gluteus medius is oriented such that it causes abduction and internal rotation of the hip joint. During gait, gluteus medius activation begins at the end of terminal swing, peaks during midstance, and ends at toe-off. The posterior portion is active first, followed by the middle and anterior portions (Earl, 2004). Identifying each portion of the muscle’s fibers is important in the evaluation of a hip injury, as well as when testing the strength of the gluteus medius.

**Injuries With a Fatigued or Weakened Gluteus Medius**

Historically, examination findings and treatments by sports medicine practitioners have focused directly on or distal to the site of pain, with no investigation into proximal findings. Sports medicine practitioners have begun looking more at the proximal portion of the lower extremity when evaluating injuries, such as ankle sprains and knee
pathologies, and have found that there was a significant weakness in hip abductor strength (Niemuth, 2007). As previously stated, proximal hip musculature influences kinematics at the tibiofemoral joint, which could lead to injury during athletic activity if the structures are weak (Carcia et al., 2005). Muscles in the proximal portion of the lower extremity have been noted as being active in the swing and stance phases of running. The gluteus medius and tensor fascia lata are active in the late swing phase and early to middle stance phase. Their role is to provide abductor stability preventing adduction of the hip joint just prior to and after foot contact with the ground (Niemuth, 2007).

Muscles performing in the frontal plane, such as the tibialis posterior and gluteus medius, accounted for 18.9% of concentric and eccentric muscle activity (Niemuth, 2007). This is accounted for in activities, such as running and other movements involving single leg control. Dynamic malalignment is described as contralateral pelvic drop, femoral adduction and internal rotation, knee valgus, tibial internal rotation, and hyperpronation that occur when the gluteus medius does not stabilize the pelvis during single-leg stance (Earl, 2004). Altered activation levels of the gluteus medius muscle have been purported to result in increased frontal-plane motion at the hip joint during weight bearing, producing greater degrees of knee valgus angle (Dwyer et al., 2010).

In a study done by Leetun, Ireland, and Wilson (2004), 139 intercollegiate basketball and track athletes had initial strength tests done during pre-season in order for researchers to monitor their injury patterns throughout the season. Of the 139 athletes, 41 sustained an injury to their lower extremity, with 65% to the foot and ankle, 23% to the
knee, and 13% to the hip. These injuries were strongly correlated with weakness in the hip abductor and external rotator muscle groups (Niemuth, 2007). Males and females who have sustained injuries during their respective sport seasons reported with significantly weaker hip abductor and external rotator strength compared with uninjured athletes (Cichanowski et al., 2007). There have been links between weakened gluteus medius muscles and musculo-skeletal disorders such as hip osteoarthritis (OA), iliotibial band syndrome (ITBS) and patello-femoral pain syndrome (PFPS; French et al., 2010). Females tend to exhibit an increase in non-sagittal plane motion, which can likely contribute to various injuries while running, such as patellofemoral pain and ITBS (Fredericson, Cookingham, & Chaudhari, 2000; Niemuth, 2007).

Cross sectional area samples obtained during replacement surgery found muscle atrophy correlated with radiographic signs of OA, both at the operated hip and contralateral hip. Therefore, abductor weakness may be of aetiological importance for the development of OA and that maintenance of the gluteus medius structure and function in both hips was essential. Although the relationship between muscle dysfunction and OA severity is not well established, significant dysfunction of these muscles has been demonstrated in patients undergoing joint replacement. OA is primarily a joint disorder, however muscles around the affected joint may become atrophied as a result of reduced joint use and loss of joint motion, thereby further compromising joint support. Strengthening of the gluteus medius muscle is essential, along with emphasis on the other gluteal muscles (gluteus maximus and gluteus minimus).
is commonly recommended in exercise therapy for hip OA (French, Gilsenan & Cusak, 2008).

The hip-abductor muscles have been theorized to eccentrically control hip adduction and, thus, knee genu valgum angle during the stance phase of running. A greater genu valgum angle (or increase in the dynamic Q-angle) has been purported to increase patellofemoral contact pressure and to lead to PFPS. Patients with PFPS exhibited greater hip adduction during single-leg squats, running, and repetitive single-leg jumps, and they attributed the atypical frontal-plane mechanics to weakness of the hip-abductor musculature (Ferber, Kendall & Farr, 2011).

Iliotibial band (ITB) syndrome is another condition that is associated with weakness of hip abductor musculature, particularly the gluteus medius. This weakness has been known to create further problems, such as over firing and tightness of the surrounding hip musculature and structures, including but not limited to the tensor fascia lata muscle and iliotibial band. Rehabilitation exercises involving hip abduction movements done to target the gluteus medius have reported decreases in pain in runners who previously presented with ITB syndrome (Fredericson et al., 2000).

Persistent pain at any point throughout the kinetic chain should lead to examination of the structures of the hip. Young girls who experienced patellofemoral pain had their hip abduction and external rotation strength tested by a group of researchers (Ireland, Wilson, & Ballantyne, 2003). Compared to healthy subjects of the same age, the girls experiencing the patellofemoral pain displayed an average hip abductor strength that was 26% less than the control group, and an external rotation
strength that was 36% weaker (Niemuth, 2007). Patients who initially presented with PFPS had a 28.71% reduction in maximal isometric hip-abductor muscle strength at baseline compared to a control group. With three weeks of rehabilitation focusing on the hip abductor muscle group, those same patients exhibited a 40% decrease in levels of pain and an average of 32.69% improvement in strength compared to their baseline measurements (Ferber et al., 2011). With the hip muscles, particularly the hip abductors and external rotators, contributing to pelvic stability and femoral movements, strengthening these muscles along with other traditional treatments of patellofemoral pain may lead to better femoral control and decreased potential for patellofemoral pain (Cichanowski et al., 2007).

Strength deficits of the hip abductors have been observed in patients not only with patellofemoral pain syndrome, but also iliotibial band syndrome, and chronic ankle sprains (Niemuth, 2007). Subjects who experienced chronic ankle sprains (Beckman & Buchanan, 1995) were more likely to have a weaker recruitment pattern of their gluteus medius muscle if they also presented with hypermobility of their ankles. All studies that implemented an abductor-strengthening program resulted in increased strength and a decrease in symptoms (Niemuth, 2007).

**Gluteus Medius Strengthening Program for Rehabilitation of Injuries**

After injury, the neuromuscular system provides compensation for the loss of mechanical stability by improving functional stability (Earl & Hertel, 2001). Neural adaptation is equally as important as improving strength of an injured structure in order to further adapt to changes in neuromuscular activation and decrease any dysfunction that
has occurred (Ferber et al., 2011). For muscle-strength adaptations to occur, it is suggested that neuromuscular activation be in the range of 40-60% of maximal effort (Andersen et al., 2006). Addressing dysfunction of hip muscles such as the gluteus medius can significantly improve functional lower limb kinematics, assist in injury prevention, improve athletic performance and result in decreased pain. Weight-bearing strengthening exercises have been shown to produce significantly higher gluteus medius activity in comparison to non-weight-bearing exercises (French et al., 2010; O’Sullivan, Smith & Sainsbury, 2010). Three optimal, functional exercises recommended for closed kinetic chain rehabilitation programs are single leg squats, lunges, and step up and over exercises. These exercises, used in conjunction with further strengthening programs, are beneficial after a lower extremity injury in subjects who need to activate hip musculature during functional exercises (Dwyer et al., 2010). Open kinetic chain exercises may be used, but should be limited to side lying hip abduction exercises. This specific exercise produces the greatest activation of the gluteus medius, with the clamshell exercise offering slightly less activation (McBeth, Earl-Boehm, Cobb, & Huddleston, 2012).

If the goal of the therapeutic intervention is muscle strengthening, the medial direction may most effectively target the gluteus medius. Conversely, if the goal of the therapeutic exercise is muscle endurance or to enhance the stabilization function of a muscle, clinicians may consider using the anterior or posteromedial direction for the gluteus medius (Norris & Trudelle-Jackson, 2011).

One functional approach for healthy subjects to strengthen the gluteus medius is by carrying a dumbbell in the contralateral hand. The subjects used a dumbbell in the
range of 5% to 15% of their body weight by walking while carrying the weight. The study determined through side-lying manual muscle testing, as well as a standing Trendelenburg sign, that this effectively strengthened the gluteus medius (Leavey et al., 2010). “Arc walking” is another strengthening method used to increase strength in the gluteus medius musculature (Wilson, 2005). In arc walking, the individual walks while attached to a secure structure by a resistance band. The individual walks in an arc pattern around the origin of the resistance band while keeping his or her toes pointed at the band. The lateral sidestepping against resistance was shown to strengthen the gluteus medius also, using the side-lying manual muscle test and Trendelenburg sign. Strengthening of the gluteus medius was also the result of a six week proprioceptive training, strength training, or a combination program, in which subjects also increased their reach distances on the Star Excursion Balance test, indicating an increase in dynamic postural control (Leavey et al., 2010).

**The Star Excursion Balance Test**

Squatting exercises are commonly included in lower-extremity rehabilitation programs in an effort to improve strength, balance, and neuromuscular control. The Star Excursion Balance Test (SEBT) is a clinical test of dynamic postural control that involves unilateral stances while attempting maximal reach with the opposite leg in 8 different directions: 3 anterior, 2 lateral, and 3 posterior. These minisquats are a way of testing neuromuscular control of several muscles, including the gluteus medius (Earl & Hertel, 2001; Robinson & Gribble, 2008).
The SEBT has become the gold standard of dynamic balance assessment, dating back to 1998 when it was first deemed a reliable and valid test for these purposes (Kinzey & Armstrong, 1998). Since this original study, further studies have confirmed the SEBT as a valid and reliable test (Hertel, Miller & Denegar, 2000). Whereas the SEBT originally was designed to be used as a rehabilitative tool for lower extremity pathologic conditions, researchers and clinicians have adopted it as a diagnostic tool to differentiate the presence of pathologic conditions, the success of interventions, and the predictive value in detecting risk of injury. With appropriate instruction and practice by the participant and normalization of the reaching distances, the SEBT can provide objective measure to differentiate deficits and improvements in dynamic postural control related to lower extremity injury, and induced fatigue, and its potential to predict injury to the lower extremity (Gribble, Hertel & Plisky, 2012).

The SEBT has also been previously used as a screening tool for lower extremity injury. Plisky, Rauh, Kaminski, and Underwood (2006) tested high school male and female basketball athletes to determine the gender discrepancies in risk of injury and found that females with a lower composite SEBT score than their male cohorts were six times more likely to sustain a lower extremity injury during the season. Whereas findings of that nature could be very beneficial to the athletic population, the SEBT is most commonly used to assess dynamic balance and strength.

**Neuromuscular Control/Postural Control and Athletic Performance**

Balance is the process of maintaining the position of the body’s center of gravity vertically over the base of support and relies on rapid, continuous feedback from visual,
vestibular and somatosensory structures, and then executing smooth and coordinated
neuromuscular actions (Hrysomallis, 2011). Balance can also be defined as the position
of the body relative to the arrangement of the limbs and segments, for a specific activity,
or the characteristic that one bears the weight of one’s body (Yaggie & Armstrong, 2004).
Improvements in balance are reflected during tasks involving neuromuscular control.
Maintaining body positioning during sport specific activities and decreasing the amount
of accessory/compensatory movements allow for optimal neuromuscular control, which
can likely improve performance and physical outcome measures. Balance training may
lead to task-specific neural adaptations at the spinal and supraspinal levels. It may
suppress spinal reflex excitability such as the muscle stretch reflex during postural tasks,
which leads to less destabilizing movements and improved balance as required in sports.
The inhibition of muscle stretch reflexes may enhance agonist-antagonist muscle co-
contraction, which increases joint stiffness, stabilizing the joints against perturbations and
therefore may improve balance and postural control (Hrysomallis, 2011).

Postural control is often described as being either static, maintaining a stable
position with minimal movement, or dynamic, maintaining a stable base of support while
completing a prescribed movement. Static postural control tasks require the individual to
establish a stable base of support and maintain this position while minimizing segment
and body movement during the assessment. Dynamic postural control often involves
some level of expected movement around a base of support to complete a functional task
without compromising that base of support (Gribble & Hertel, 2003; Gribble et al., 2012).
The advantage of assessing dynamic postural control is that additional demands of proprioception, range of motion (ROM), and strength are required along with the ability to remain upright and steady (Gribble & Hertel, 2003). Dynamic postural control has been acknowledged as essential for return to function and sport after lower extremity injury. Unilateral weight-bearing exercises are often used to train and assess dynamic postural control. During the performance of unilateral weight-bearing exercises, proximal stability is required at the trunk and pelvis while movement is coordinated between multiple joints of the lower extremity (Norris & Trudelle-Jackson, 2011).

Within the field of athletic training, neuromuscular training programs that include balance exercises are often implemented with the aim of optimizing performance, preventing injury, providing rehabilitation, and reducing sport-related injury risk as well as in enhancing functional performance after sport injury (Zech et al., 2010). The SEBT can serve as a valuable tool for screening of injuries, as well as a source for evaluation and rehabilitation of dynamic postural control and injuries. While standing on the injured or affected limb to maintain stability, a deficit is produced in the reaching distances, indicating a deficiency in dynamic postural control that might be associated with the pathologic condition in the stance limb (Gribble et al., 2012). The SEBT requires neuromuscular control through proper joint positioning as well as strength in surrounding musculature to create and maintain the necessary positions throughout the test (Gribble & Hertel, 2003).
**Fatigue and Performance of the Star Excursion Balance Test**

It is not uncommon to see a number of sports injuries resulting from fatigue of a group of muscles or whole body fatigue (Knicker et al., 2011; Springer & Pincivero, 2009). Fatigue to proximal musculature groups, such as the hip and the knee, have produced greater deficits in postural control, compared to fatigue of distal structures, such as ankle musculature. This is due to a greater increase in center of pressure velocity scores at the hip after fatigue, compared with the ankle (Gribble et al., 2004).

Fatigue changes the efficiency of contraction capability in the extrafusal muscle fibers and challenges the efficiency of the afferent information from muscle spindles, which ultimately alters neuromuscular control (Gribble et al., 2012). Fatigue and deficits in postural control may be predispositions to musculoskeletal injury (Gribble & Hertel, 2004). The effect of fatigue on postural control and neuromuscular control during functional activities can be tested and mimicked using the Star Excursion Balance Test. Neuromuscular control during the SEBT is reflected by the distance reached in each direction, with an increase in reach distance reflecting greater neuromuscular control. Decreased SEBT reach distances and corresponding decreases in sagittal-plane knee and hip flexion have been noted when the SEBT was performed after fatiguing tasks (Norris & Trudelle-Jackson, 2011). Knee flexion and reach differences on the SEBT coincide with each other after a fatigue protocol has been implemented. Reach distances and knee flexion both decreased amongst genders, with males showing a greater decrease (Gribble et al., 2009). This further represents a sagittal plane knee movement during functional tasks in males and should be noted when rehabbing and overcoming the differences after
fatigue. Fatigue of the proximal hip structures, especially the gluteus medius, create undesired accessory motions of femoral internal rotation and adduction during the SEBT that could translate over to a potential cause of injury in functional, single leg activities (McMullen et al., 2011).

**Conclusion**

Fatigue is a natural process that the body undergoes during any type of athletic performance or exercise. It has the tendency to negatively affect athletic performance, especially in subjects who have previously weakened structures that fatigue more rapidly (Knicker et al., 2011). One such structure that is commonly weak in athletic individuals is the gluteus medius muscle. Its ability to stabilize the pelvis during functional activity becomes diminished when fatigued. Fatigability amongst genders is also often present and can alter the way males and females perform. Gender differences and fatigue associated with the gluteus medius have been observed with kinematics, muscle weakness, and lower extremity injury, but have not been observed during performance of the Star Excursion Balance Test. Overcoming fatigue and implementing more strengthening exercises in athletes with weak proximal hip musculature can help aid in better postural control and further reduce the risk for injuries, such as patellofemoral pain syndrome, hip osteoarthritis, and ACL injuries.
CHAPTER III

METHODOLOGY

Gluteus medius dysfunction is a common cause of insufficient hip abduction and external rotation strength that is often associated with decreases in postural control (Cichanowski et al., 2007; DiMattia et al., 2005; McMullen et al., 2011). In the absence of sufficient hip strength, particularly in the hip abductors and external rotators, there may be excessive femoral internal rotation, hip adduction movements, and subsequent increased knee valgus motion with weight bearing activities (Cichanowski et al., 2007). Excessive motions in these regions have been known to cause musculo-skeletal disorders such as hip osteoarthritis (OA), iliotibial band syndrome (ITBS) and patello-femoral pain syndrome (PFPS; French et al., 2010).

Subjects

Forty college-aged recreational athletes (20 males and 20 females) volunteered to participate in this study. Subjects recruited were between the ages of 18–26 (Table 2 in Chapter 4). For purposes of this study, a recreational athlete is defined as anyone participating in an aerobic or athletic activity at least three times per week (Heinert et al., 2008). Subjects were given a questionnaire to determine if the criterion for a recreational athlete was met. Subjects with any lower extremity injury within the past six months were excluded from the study. The Kent State University Institutional Review Board approved this study and participants provided written informed consent prior to commencing.
Instrumentation

The Biodex System 3 Pro #835-000 & #835-002 (Biodex Medical Systems, Inc., Shirley, NY) was utilized to elicit fatigue of the hip abductors. A Surface Electromyography (EMG) machine (Biopac Systems Inc., MP150, Aero Camino Goleta, CA; Noraxon USA, Inc., Scottsdale, AZ) was used during hip abduction and external rotation fatigue protocols to detect gluteus medius muscle activity to confirm activation of the respective muscle groups. A handheld dynamometer (Lafayette Manual Muscle Test System, Model #01163, Lafayette Instrument Company) was used to test the strength of the hip abductors and hip external rotators, as well as serve as a predictor of fatigue according to a prescribed decrease in peak force of each muscle group. The Star Excursion Balance Test (SEBT) was used to assess dynamic balance in all subjects during all three testing sessions. The SEBT was used according to the normalizations and guidelines established for standardization of testing (Gribble & Hertel, 2003).

Procedures

After consent was obtained, participants filled out a questionnaire that asked them to describe their weekly workout schedule and injury history within the past six months. Individuals who did not meet the minimum exercise requirements and/or had a previous history of lower extremity injury were not considered eligible for the study. Subjects entered the lab for Session 1 of testing and were instructed to pick a tongue depressor from a cup for randomization. If the subjects picked a tongue depressor with the number “1” on it, they were placed in the control group, whereas if subjects picked a tongue depressor with the number “2” on it, they were placed in the experimental group.
Randomization occurred for males and females to ensure equitable distribution of males and females among both the control and experimental conditions. This process yielded 10 males and 10 females in the control group, and 10 males and 10 females in the experimental group. Testing was divided into three sessions for all subjects (see Figure 1).

For baseline measurements, height, weight, and limb length of the dominant leg were acquired during the first session of testing. Height was measured using a standard height measurement at the flat surface on the top of the head, as the athlete stood with their heels against the back of the scale against a standard height ruler attached to a Detecto® balance scale. Weight was assessed on a Detecto® balance scale to the nearest ¼ pound. Leg length was measured in centimeters on each limb with participants lying supine. A retractable tape measure was used to quantify the distance from the anterior superior iliac spine to the center of the ipsilateral medial malleolus. The measurements of leg length were later used to normalize excursion data of the SEBT by dividing reach distances by leg length and multiplying by 100 to calculate a variable that represents reach distance as a percentage of leg length (MAXD; Gribble & Hertel, 2003; Gribble et al., 2004).

Each participant then performed a baseline Star Excursion Balance Test, as well as separate baseline measurements of hip abductor and external rotator strength using the hand held dynamometer. For the Star Excursion Balance Test, subjects were instructed to stand on their dominant leg and reach as far as possible in all 8 directions: anterior (Ant), anterolateral (AntLat), anteromedial (AntMed), lateral (Lat), medial (Med),
Figure 1. Research Timeline (5-7 days between each session)
posterolateral (PostLat), posteromedial (PostMed), posterior (Post), and touch the floor lightly with the distal most part of the opposite foot. Upon touching the foot lightly on the ground, the subjects were instructed to return the leg back to the center while maintaining a single leg stance with the other leg in the center of the grid. All lines extended out from the center at 45 degrees from each other. Subjects performed 6 practice trials in each direction, with a rest period of one minute before testing begins. Three consecutive trials were performed in each direction. Participants began by reaching in the anterior direction and rotating in a clockwise direction around the grid. The excursion distance was marked on the floor with tape during the 3 trials. These 3 trials were then averaged together for statistical analysis of the mean score. Reach distances were measured from the center of the star to each marked distance. If at any point the investigator felt that the participant used the reaching leg for support, removed his or her foot from the center of the grid, or was unable to maintain balance, the trial was discarded and repeated (Earl & Hertel, 2001; Gribble & Hertel, 2003).

Hip abduction strength was measured in a side lying position, with the subject abducting their dominant leg to 20 degrees. The dynamometer was placed just superior to the lateral femoral condyle (Heinert et al., 2008). Hip external rotation strength was tested with the subject sitting with their legs hanging off the edge of the table. The dynamometer was placed 5 cm proximal to the lateral malleolus (Thorborg, Petersen, Magnusson, & Holmich, 2010). Both measurements were done with the subject isometrically contracting against the dynamometer for 5 seconds (Heinert et al., 2008; Thorborg et al., 2010).
Hip abduction and hip external rotator baseline strength were assessed using a handheld dynamometer. Strength for both muscle groups was recorded and average from three trials of maximal voluntary isometric contractions lasting 5 seconds. Each participant was given 2–3 practice repetitions of each motion to familiarize the movements before the trials were performed. Strength was normalized to body weight during analysis for each subject. Once baseline measurements were recorded, subjects reported back within 5–7 days to begin Session 2.

Control group subjects reported back to the lab on two separate occasions, one week apart. During Session 2 of testing, control subjects came into the lab and immediately sat and rested for five minutes. Following the 5-minute rest, the subjects were asked to perform the SEBT according to the procedure done in Session 1 of baseline testing. Subjects were then required to report back within one week to conduct Session 3 of testing. Session 3 of testing for control subjects mimicked that of Session 2.

Subjects in the experimental group were also required to come to the lab on two separate occasions, one week apart. Sessions 2 and 3 of testing began with one of the two fatigue protocols of the gluteus medius muscle. Hip abduction and hip external rotation fatigue were counterbalanced between sessions 2 and 3 (Table 1). Electromyography (EMG) electrodes were placed parallel to the muscle fiber orientation, approximately 2 cm apart, between the iliac crest and greater trochanter on an area superficial to the gluteus medius muscle, which was verified with isolated hip abduction and internal rotation (McMullen et al., 2011). Once activation of the gluteus medius was established, subjects were then given instructions according to the fatigue protocol they
Table 1

*Fatigue Counterbalance Spreadsheet*

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Hip ABD fatigue</th>
<th>Hip ER fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
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<tr>
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</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

*2= Session 2 of testing; 3= Session 3 of testing*
were assigned that session. Subjects who underwent the hip abduction fatigue protocol were put in a standing position with their dominant leg strapped into the Biodex. Hip abduction was performed repeatedly during a minimum of 5 sets of 15 repetitions, concentric/concentric protocol at functional, controlled speeds of 90, 75, 60, 45, and 30 degrees per second. Subjects who underwent the hip external rotator fatigue were placed in a clamshell position and instructed to repeat an external hip rotation motion repeatedly with added resistance coming from a small circular resistance band. Resistance bands provided a varied amount of resistance depending on the band that was selected. Participants had the choice of resistance bands, ranging resistances from extra light, light, medium, heavy, extra heavy. Bands were selected based on the subject’s ability to perform maximum repetitions. Resistance level (i.e., band color) was increased when participants could perform three sets of 12 repetitions maximum with correct technique through the full range of motion (Kraemer et al., 2002; O’Shea, Taylor, & Paratz, 2007).

Fatigue was indicated once a subject has reached a 43% reduction in peak hip abductor or hip external rotator force compared to baseline measurements, detected by using the hand held dynamometer (Patrek et al., 2011). Subjects also reported ratings of perceived exertion using the Borg RPE Scale to determine fatigue (Patrek et al., 2011). An RPE of 19/20 was the value met by all subjects to indicate fatigue. Once fatigue was reached, the participants performed a post-test, Star Excursion Balance Test. Testing was done in the exact manner as done during the baseline SEBT test, while the researcher recorded the reach distances to the nearest tenth of a centimeter. Electromyographic (EMG) activity was monitored throughout both fatigue protocols to ensure constant
activation of the gluteus medius muscle. EMG recordings were not analyzed simply used to confirm gluteus medius activation.

**Statistical Analysis**

In this study, several independent and dependent variables were being measured. The independent variables consist of fatigue, initial hip abduction strength, initial hip external rotation strength, and gender. Our outcome measure or dependent variable is performance on the Star Excursion Balance Test.

Statistical analysis of these variables included both between and within subject comparisons. I performed a two group by two gender repeated measures ANOVA to compare between subjects variables of group, gender, and group X gender. A repeated measures ANOVA was done to compare within subjects variables of time, time X group, time X gender, and time X group X gender. Post hoc LSD analyses were done for variables that had significance, such as the time and gender. We also used a correlation analysis to determine the significance between ABD and ER strength. An Independent Samples T-test was then used to determine significant differences between gender and ABD and ER strength. The level of significance was set at $p < 0.05$ a priori. All statistical calculations were performed with SPSS version 17.0 (SPSS, Inc., Chicago, IL).
CHAPTER IV

RESULTS

Subject baseline demographic information was recorded during baseline testing sessions and can be found in Table 2. For the within subjects measures, no significant differences were noted for time by group, time by sex, and time by group by sex (Table 3). A significant main effect of time was noted (Figure 2). An LSD post hoc analysis was run to determine significance of time. A significant main effect of time was found in the anterior reach direction from baseline to Session 2/ABD ($p = 0.039$), and from baseline to Session 3/ER ($p = 0.033$), as indicated by Figure 3. A significant main effect of time was found in the anterior reach direction from baseline to Session 2/ABD compared to baseline ($p = 0.010$) and from Session 3/ER compared baseline ($p = 0.044$). Figure 4 reflects these analyses. A significant main effect of time was found in the posterior lateral reach direction from Session 2/ABD compared to baseline ($p = 0.004$) and from Session 3/ER compared to baseline ($p = 0.001$), as indicated by Figure 5.

A repeated measures ANOVA also revealed no significant differences between groups and between groups by sex (Table 4). A significant interaction was found between sex. A post hoc analysis found that males had further reach differences overall compared to females in the posterior lateral direction ($p = 0.000$), posterior direction ($p = 0.000$), posterior medial direction ($p = 0.000$), and the medial direction ($p = 0.027$). (See Figure 6.)
## Table 2

**Subject Baseline Demographics**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Leg Length</th>
<th>Hip ABD strength</th>
<th>Hip ER strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>20</td>
<td>21.50 ±2.31</td>
<td>179.90±6.50</td>
<td>78.55±15.24</td>
<td>92.40±4.80</td>
<td>17.31±6.10</td>
<td>12.20±3.90</td>
</tr>
<tr>
<td>Females</td>
<td>20</td>
<td>21.15 ±2.58</td>
<td>166.20±7.90</td>
<td>65.70±12.29</td>
<td>86.33±4.94</td>
<td>14.60±4.84</td>
<td>9.38±2.17</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>21.33 ±2.42</td>
<td>173.05±9.94</td>
<td>72.12±15.14</td>
<td>89.35±5.69</td>
<td>15.94±5.60</td>
<td>10.77±3.40</td>
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</table>

## Table 3

**Within Subjects Comparisons**

<table>
<thead>
<tr>
<th></th>
<th>P-value</th>
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</thead>
<tbody>
<tr>
<td>Time</td>
<td>p = 0.042</td>
<td>2.241</td>
</tr>
<tr>
<td>Time x Group</td>
<td>p = 0.592</td>
<td>0.886</td>
</tr>
<tr>
<td>Time x Gender</td>
<td>p = 0.818</td>
<td>0.639</td>
</tr>
<tr>
<td>Time x Group x Gender</td>
<td>p = 0.063</td>
<td>2.040</td>
</tr>
</tbody>
</table>

## Table 4

**Between Subjects Comparisons**

<table>
<thead>
<tr>
<th></th>
<th>P-value</th>
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<tbody>
<tr>
<td>Group</td>
<td>p = 0.217</td>
<td>1.455</td>
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<tr>
<td>Gender</td>
<td>p = 0.001</td>
<td>4.427</td>
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<tr>
<td>Group x Gender</td>
<td>p = 0.476</td>
<td>0.973</td>
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</table>
A correlation analysis revealed no significant differences between groups and between sex. When collapsing across groups, abduction strength is significantly greater than external rotation strength ($p = 0.000$). Figure 7 reflects these measures. An Independent Samples T-test was done to examine the relationship between sex and abduction and external rotation strength. Abduction strength was not significantly different between males and females ($p = 0.121$), whereas men showed significantly more external rotation strength than females ($p = 0.008$), as reflected in Figure 8.

![Time: SEBT Reach Distance Means Across Three Sessions](image)

*Figure 2. Time; SEBT Reach Distance Means Across Three Sessions*

Mean reach distances during all three sessions were compared. Significance was found between each session, regardless of gender or group ($p = 0.042$).
Figure 3. Time; SEBT Anterior Reach Distance Means Across Three Sessions
Anterior reach direction was significant between all three sessions, regardless of gender and group. Baseline reach distances were better than Session 2/ABD ($p = 0.039$) and Session 3/ER ($p = 0.033$).

Figure 4. Time; SEBT Lateral Reach Distance Means Across Three Sessions
Lateral reach direction was significant between all three sessions, regardless of gender and group. Baseline reach distances were less than Session 2/ABD ($p = 0.010$) and Session 3/ER ($p = 0.044$).
Figure 5. Time; SEBT Posterior Lateral Reach Distance Means Across Three Sessions

Posterior lateral reach direction was significant between all three sessions, regardless of gender and group. Baseline reach distances were less than Session 2/ABD ($p = 0.004$) and Session 3/ER ($p = 0.001$).
Gender differences were significant overall, regardless of group. Males reached significantly farther compared to females in the Posterior Lateral ($p = 0.000$), Posterior ($p = 0.000$), Posterior Medial ($p = 0.000$) and Medial ($p = 0.027$) reach directions.
Overall initial abduction strength was significantly greater than external rotation strength ($p = 0.000$), regardless of gender.

Without normalizing strength to body weight, males had significantly stronger hip external rotators than females ($p = 0.008$).
Table 5

*Normalized Strength Means and P-Values Between Genders*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Norm ER</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>15.7451±4.90</td>
<td>0.108</td>
</tr>
<tr>
<td>Females</td>
<td>14.4367±2.97</td>
<td></td>
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<tr>
<td><strong>Norm ABD</strong></td>
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<tr>
<td>Males</td>
<td>22.6104±9.03</td>
<td>0.487</td>
</tr>
<tr>
<td>Females</td>
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</table>
CHAPTER V

DISCUSSION

The aim of this study was to determine if initial hip strength and fatigue affected neuromuscular performance on the Star Excursion Balance Test in male and female healthy subjects. Previous studies have evaluated performance on the SEBT following a fatiguing protocol of hip abductors alone and ankle plantar flexors/dorsiflexors, knee flexors/extensors, and hip flexors/extensors and have reported decreased reach distances (Borchers et al., 2010; Gribble et al., 2009; McMullen et al., 2011). Following separate fatigue protocols of the gluteus medius through both hip abduction and hip external rotation exercises, participants in this study did not demonstrate significant decreases in reach distances compared to the control group. These findings are consistent with both males and females.

Our results demonstrate that fatigue of these specific muscle groups, hip abductors and external rotators, does not have a significant impact on reach distances during the SEBT compared with non-fatigued participants’ reach distances although evidenced in earlier studies fatiguing other muscle groups (Borchers et al., 2010; Gribble et al., 2009; McMullen et al., 2011). These results indicate that more localized hip muscle fatigue may not have as much of an influence on dynamic balance during the SEBT as anticipated. Past studies that have found a significant difference in reach distance following fatigue utilized different fatiguing protocols. McMullen et al. (2011) focused on fatigue of the hip abductors, eccentrically in a side lying position and found that both men and women equally decreased reach distances on the SEBT. Other muscle
groups that have been previously fatigued to a decrease in 50% of peak torque, such as ankle plantarflexors/dorsiflexors, knee extensors/flexors, hip flexors/extensors, and hip abductors/extensors have resulted in decreased reach distances among subjects (Borchers et al., 2010; Gribble et al., 2009). While most studies looked to measure fatigue by a decrease of 50% of peak torque, we observed fatigue at a 43% decrease in peak force (Patrek et al., 2011). Decreases in force and torque, which indicate fatigue, could lead athletes to altered biomechanics, compensatory movement patterns, and a potential risk for injury. Anecdotally, subjects all reached the 43% decreased level and subjectively reported feeling fatigued during the fatiguing protocol and SEBT following the fatigue protocol. Our study was the first study to implement fatigue in a functional standing position, therefore this fatiguing protocol and level of decreased peak force, indicating fatigue may need to be further examined.

Previous research has demonstrated that females were more resistant to fatigue than males, as shown by decreased sway during a single leg stance (Springer & Pincivero, 2009) and further reach distances (Gribble et al., 2009) following a fatigue protocol. These findings were not consistent with the results found in this study. Our hypothesis was not supported because males and females did not show differences between groups in regards to reach distances. Our results are similar to those found by McMullen et al. (2011), which observed no significant differences between males and females, however both groups demonstrated decreases in reach distances on the SEBT after eccentric hip abduction fatigue.
Males in this present study did however reach further than females when all male subjects were compared to all female subjects, regardless of if they were fatigued or not fatigued. Leg length was normalized to reach distances; therefore indicating that males further reach distances was not the result of longer limbs. Previous research that has looked at SEBT performance between males and females in non-fatigued states found no differences when normalized to leg length (Gribble & Hertel, 2003; Kahle & Gribble, 2009). Sabin, Ebersole, Martindale, Price, and Broglio (2010) found that in a non-fatigued state, males reached 5% further than females in the posterior direction only.

Reach distances were different between the three sessions, regardless of the fatigue protocol or gender differences. In the anterior direction, subjects in the current study had further reach distances during their baseline session as compared to the second and third testing sessions. Previous research has reported that subjects felt a limited amount of ankle motion, resulting in a substantial decrease in reach distances in the anterior reach direction. These results have also been reported in relation to subjects with a gluteus medius deficit (McMullen et al., 2011; Gribble & Hertel, 2003). With this reach direction, an ankle strategy for maintaining balance is used. More distal ankle musculature is activated primarily, with eventual activation of proximal musculature. This strategy is utilized during more stable, limited movement activities where center of pressure is maintained in the foot during balance (Runge, Shupert, Horak, & Zajac, 1999). A learning effect of the SEBT may also be a factor. Subjects who had decreased reach distances in the second and third sessions may have reached a comfort level, which
led them to reach to a certain point where they felt comfortable, which may not have been their maximal distance, despite instruction to prompt them to reach their maximal reach.

In the lateral and posterior lateral directions, subjects had further reach distances during the second and third testing sessions compared to baseline. These differences may also be explained by the learning effect with the actual SEBT. Each subject completed the SEBT for a total of 3 sessions and 3 trials a session, excluding practice trials completed at the beginning of each testing session. Subjects who improved their reach distances in the second and third sessions may have utilized that comfort level to their advantage. These reach directions are not often used during activities of daily living and athletic activities and were very unfamiliar for subjects in this study. Given the unique nature of the lateral and posterior lateral reach directions, their original familiarity with the test during the baseline session may have allowed them to reach further in the latter sessions. Both directions also use more of a hip strategy for balance because of the large scale of movement at the hip and the greater activation of proximal musculature (Runge et al., 1999).

We would expect to see different reach distances between each eight directions of the SEBT because of activation of different muscles. Gluteus medius muscle activation has been reported to be most significant in the anterior and medial reach directions (Norris & Trudelle-Jackson, 2011). The anterior reach direction most replicates a single leg squat exercise, in which the gluteus medius acts as a primary hip stabilizer. The medial direction utilizes the gluteus medius as and abductor. Other muscles, such as the hamstrings, anterior tibialis, and quadriceps, that were utilized throughout all eight reach
directions could have influenced reach distances in both fatigued and non-fatigued conditions.

Strength of the abductors and external rotators was another variable that had no impact on SEBT performance, contrary to the initial hypothesis. Previous studies have reported the importance of strength of the hip musculature in regards to injury and mean force production. In the current study, which included only healthy subjects, strength when normalized to body weight did not significantly determine a subject’s reach distance during the SEBT. Subjects with an initially weak gluteus medius as characterized by gluteus medius dysfunction may have shown more decreases in reach distance after a fatiguing protocol.

**Limitations**

The current study used two separate fatigue protocols, standing hip abduction and side-lying clamshell exercises. Only the standing hip abduction position replicated a more functional type of fatigue, as opposed to the side lying position. Another limitation of this study was not initially setting a standard for hip strength to classify the subjects as having a weak or strong gluteus medius. The number of SEBT trials performed may have also created a learning outcome for subjects to familiarize themselves with the test, which is a limitation in this study. Reach distances were recorded by placing tape along the SEBT where the subjects touched down with their big toe. More accurate measurements could have been recorded using the Y-Balance Test/SEBT kit.
Recommendations for Future Research

Future studies may want to alter the amount and type of fatigue. Fatiguing the hip abductors and hip external rotators separately did not have a significant impact on SEBT performance, therefore future researchers may want to combine abduction and external rotation fatigue or use a more functional, sport specific fatiguing protocol for the whole lower extremity. This type of fatigue may mimic that of actual fatigue experienced during athletic performance. When evaluating strength measures, future researchers should have a threshold strength value normalized for body weight, which splits their subjects into strong and weak categories. Individuals who have already been identified as having gluteus medius dysfunction may want to be studied to determine the impact of fatigue on performance of the SEBT compared to healthy individuals. Flexibility and balance ability should also be compared when using the SEBT. Flexibility and strength may want to be compared to determine which has more of an impact on reach distances during the SEBT. Future research may also want to compare dominant and non-dominant limbs after fatigue, using the SEBT.

Conclusion

Gluteus medius dysfunction involves the weakness of both the hip abductor and external rotator muscle groups. Dynamic postural control on the Star Excursion Balance Test is not significantly reduced by separate fatigue of the hip abductor and hip external rotator muscle groups in both male and female recreationally active subjects. Initial strength of these muscle groups does not influence the reach distances on the SEBT following fatigue.
REFERENCES


