

THE RELATIONSHIP OF HIP MUSCLE ACTIVATION AND THE INCIDENCE OF SHOULDER INJURY
IN COLLEGIATE WOMEN'S VOLLEYBALL ATHLETES: A PILOT STUDY

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Dakota State University's regulations and meets the accepted standards for the
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ABSTRACT

Previous studies have indicated weak hip muscle activation in baseball pitchers leads to an increased incidence of shoulder injuries. This relationship, however, has not been explored in other overhead athletes, such as volleyball players. Surface electromyography (EMG) was used to evaluate each participant's muscle activation during five dynamic activities. Dynamic activity was normalized according to MMTs for the rectus femoris, biceps femoris, gluteus maximus, and gluteus medius. The GMed during the eccentric box jump was statistically significant for position where setters showed the greatest activation and defensive players the least. The GMax during the single-leg deadlift was statistically significant for position where setters showed the greatest activation and defensive players the least. The hamstring showed statistically significant activation during the eccentric box jump where defensive players showed the highest activation and setters the least. The results should serve as a pilot study for future research due to the limited population.

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I would like to thank my family for their continued support, no matter where my journey has taken me. My mom taught me to be hard-working and relentless in the pursuit of my goals from a very early age. She has been my side-kick in life and has always helped me find my motivation when I wasn't sure of myself. I would not be where I am today without my mom, as well as my grandparents. My family has backed my every goal and loved me through every adventure I've embarked on.

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LIST OF ABBREVIATIONS

MMT	Manual Muscle Test
EMG	Electromyography
NCAA	National Collegiate Athletic Association
ROM	Range of Motion
IR.....	Internal Rotation
ER	External Rotation
EXT	Extension
SST	Simple Shoulder Test
RF.....	Rectus Femoris
BF.....	Biceps Femoris
VMO	Vastus Medialis Oblique
VL.....	Vastus Lateralis

CHAPTER 1: INTRODUCTION

1.1. Overview of the Problem

Shoulder pain and dysfunction are the third most common overuse pathologies among competitive volleyball players and result from repeated overhead contact.¹⁻³ One study investigating the epidemiology and risk factors for shoulder injuries in volleyball reports that 57% of male and 60% of female athletes experienced a shoulder injury during his or her volleyball career.¹ Literature supports that poor lower body muscle activation along the kinetic chain in baseball pitchers leads to compensations in the upper body, thus predisposing athletes to shoulder injury. However, little is known about this correlation in other overhead sports, such as volleyball. There is evidence that female volleyball players have weaker hip muscles, higher quadriceps activity, and reduced hamstring activity during athletic movements, in addition to faster fatigue in the associated muscles.⁴ The lack of research and subsequent absence of evidence-based prevention and rehabilitation protocols for athletes competing in volleyball potentially predisposes them to injury.

1.2. Statement of Purpose

The purpose of this research was to investigate the relationship of hip muscle activation to previous or current shoulder injuries in collegiate volleyball players. Hip muscle activation, specifically the gluteus maximus, gluteus medius, rectus femoris, and biceps femoris, was determined through surface electromyography (EMG) during the following five activities: concentric box jump, eccentric box jump, volleyball hit approach, single-leg squat, and single-leg deadlift. Differences in hip muscle activation were compared between National Collegiate Athletic Association (NCAA) Divisions I, II, and III as well as identified volleyball position. A quasi-experimental study was conducted using a within-subjects and between-subjects repeated measures design.

1.3. Research Questions

Q1: What is the relationship between the athletes' retrospective reporting of shoulder injury and hip muscle activation?

Q2: What are the differences in muscle activation of static and dynamic movements for the gluteus maximus, gluteus medius, rectus femoris, and biceps femoris in volleyball players when compared across NCAA Divisions I, II, and III as well as compared between positions on the court?

1.4. Limitations

The limitations of this research study may have affected the outcomes. First, EMG has been shown to produce variable data that may cause chance results. EMG has been shown to be a reliable and valid instrument for evaluating muscle activation; however, there are differences in muscular anatomy between each subject.⁵⁻⁸ Without access or feasibility of taking radiographic imaging, slight differences in muscle activation may have occurred based on electrode placement.⁷ Although the use of maximal voluntary isometric contractions (MVIC) to normalize EMG has been supported by previous research^{5,7,9-11}, there has not been an agreement on the most accurate normalization method for dynamic assessments. MVIC requires participants to reach their full muscle contraction potential which may not have actually occurred. In short, surface EMG is a reliable and valid tool to record muscle activation and in consideration of the limitations, researchers took precautions to avoid alterations in application that could have damaged results.

Additionally, this study relied on self-reported history of shoulder injuries throughout a participant's volleyball career rather than clinical diagnoses. Although the demographics and health history questionnaire that were used in this study specified that injuries must have been diagnosed by a healthcare professional, some responses may not have accurately reflected pathologies. With this in mind, there might have been slight variability in reports of volleyball related shoulder injury.

Finally, only three teams were included in this study. There was a decreased number of members on the active roster during the spring season which further limited the amount of overall participants in the study. Unfortunately, the small sample size gave only a snapshot of volleyball related shoulder injuries and hip muscle activation. Due to these limitations, clinician discretion should be used when making recommendations based off the evidence produced in this research. These limitations should be considered before conducting future research regarding hip muscle activation and volleyball related shoulder injuries.

1.5. Delimitations

Muscle activation during box jumping activities, volleyball hit approach, and the two single-leg exercises were based solely on data collected through surface EMG. Biomechanics of jumping and exercise have been previously analyzed more thoroughly as a predictive factor to sport-related injuries

and were not taken into consideration in this study. Certainly, each participant may have used different muscle activation patterns to perform the tasks during data collection which could have affected results. For the purpose of this research, minimal verbal cues related to biomechanics of exercise performance were given in order to collect data on a participant's natural technique and muscle activation patterns.

1.6. Assumptions

Assumptions were made throughout this research as a result of volleyball athletes continuing with their typical daily routines rather than altering their training patterns prior to the study. It was assumed that the participants were able to accurately report their shoulder injury history. The team's Certified Athletic Trainer (ATC) was present in order to assist the participant in the case that she was unsure of her injury history.

Surface EMG methodology was duplicated from previous studies to ensure the most reliable procedures were used in the application of EMG electrodes. In spite of this, muscular anatomy between individuals differs and may have caused minor incongruity between subjects in the exact muscles targeted during EMG evaluation. Maximal voluntary isometric contractions achieved through manual muscle testing were used to normalize EMG data. This method assumed that the individuals were giving a maximal effort contraction on a voluntary basis. Instructions were given to assist the participant in achieving a maximal contraction. Granted these assumptions of surface EMG, the instrument is still considered a reliable way to measure muscle activation.

1.7. Variables

For research question one, the independent variables in the current study were dynamic hip muscle activation of the gluteus medius, gluteus maximus, biceps femoris, and rectus femoris during box jumping, volleyball approaches, and two single-leg exercises. The dependent variable in the current study was the number of shoulder injuries sustained over the course of the athlete's competitive volleyball career.

For research question two, the independent variables in the current study were NCAA division and identified position (libero, setter, hitter, etc.). The dependent variables were the hip muscle activation of the gluteus medius, gluteus maximus, biceps femoris, and rectus femoris.

1.8. Significance of the Current Study

As previously stated, shoulder injuries are one of the most common pathologies effecting volleyball athletes. The athletic movements required during volleyball activities leave clinicians wondering if a lack of activation in the hip musculature could lead to compensations predisposing an athlete to upper extremity injury, as this relationship has been found in baseball pitchers. Evidence of a correlation between hip muscle activation and volleyball related shoulder injuries would allow clinicians to provide evidence-based recommendations for injury prevention programs specific to volleyball athletes rather than relying on research for baseball athletes. In addition, clinicians could apply appropriate recommendations regarding hip activation to each position rather than absolute treatments for all volleyball athletes.

1.9. Definitions

Definitions of volleyball-related shoulder injuries vary greatly among current research studies which makes comparison of results challenging. The following definitions were used in order to provide consistency among terminology.

Shoulder injury: Any dysfunction in the bones, muscles, ligaments, or joint surrounding the shoulder requiring at least one day of missed play, or which prevented the athlete from completing the day's required work load.¹²

Electromyography (EMG): A diagnostic tool used to measure the electrical activity of muscle fibers by attaching electrodes to the surface of the skin overlying superficial muscle.^{7,8}

Collegiate volleyball player: An athlete who is a member of the active roster of a National Collegiate Athletic Association Division I, II, or III volleyball team.

Manual muscle test: A test of strength of a specific muscle which requires manual resistance to be applied by a clinician at a specific joint angle.¹³

Hip muscle activation: For the purpose of this study, hip muscle activation will be defined as the average muscle activation, measured by electromyography, during the testing protocol.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

The activation of the hip musculature as it relates to shoulder injuries has been studied extensively in baseball pitchers, specifically how the kinetic chain transfers energy from the lower body to the arm. There is evidence supporting that poor lower body muscle activation along the kinetic chain leads to compensations in the upper body, and thus predisposes pitchers to shoulder injuries.^{2,12,14-18} However, there is a lack of research directly exploring the relationship of hip muscle activation to shoulder injuries in other overhead athletes such as volleyball players.

Shoulder pain and dysfunction are the third most common overuse pathologies among competitive volleyball players and can result from repeated overhead contact.¹⁻³ There is also evidence that female volleyball players have weaker hip muscles, higher quadriceps activity, and reduced hamstring activity during athletic movements in addition to faster fatigue in the associated muscles.⁴ With reliable equipment such as surface electromyography, researchers have a pathway of exploring the activation patterns in the hip musculature. The lack of research and subsequent absence of evidence-based prevention and rehabilitation protocols for athletes competing in volleyball potentially predisposes them to injury.

2.2. Baseball and the Relationship of Hip Muscle Activation to Shoulder Injuries

Research supports the relationship between hip muscle activation and incidence of shoulder injuries in baseball athletes.^{12,14-17} The phases of a baseball pitch are intricately linked resulting in efficient generation and transfer of energy from the body to the ball.¹⁶ The lower extremity and core musculature are intertwined to reduce kinetic contributions from the shoulder thus making the pitching motion, not an upper extremity activity, but rather a complex movement of the entire body. Repetitive, improper muscle activation in the lower body and energy transfer can result in shoulder injury, reducing the health and durability of the pitcher.^{14,16,17}

2.2.1. Ground Reaction Forces in Pitching

The pitching kinetic chain, a sport-specific movement involving the coordination of all body segments, begins on the pitching rubber. Here, the forces created by the upper and lower extremities of the pitcher interact with the environmental characteristics of the pitching mound to affect the velocity and

accuracy of the pitch. The characteristics of these ground reaction forces were explored in seven right-handed pitchers.¹⁴ Each pitcher was fitted with reflective markers for evaluation using a five-camera video analysis system. Ground reaction forces were collected through the use of two multicomponent force plates attached to a steel-framed pitching mound built with the major league regulation size and slope. One force plate was set below the rubber to record push off forces and a second force plate was positioned lower on the slope to record landing forces. These plates were adjusted for individual pitcher's stride length. Data were recorded during five maximal effort pitches that crossed through the strike zone.

General movement of the body was defined as anterior-posterior shear and was recorded in terms of body weight (BW). These reaction forces for the push-off limb demonstrated a negative direction at -0.35 BW, thereby propelling the body forward. BW began to shift to the landing leg once the forefoot contacted the pitching mound and the arm moved forward. There was a decrease in anterior-posterior shear on the push-off limb and an increase in anterior-posterior shear of the landing leg, measuring at a maximum of 0.72 BW, just before the ball was released. A consistently positive direction of the BW force suggests that the lead foot anchored the body to balance the forces generated in the upper extremities during the pitching motion. In other words, the lead foot is the contact point from which the body pushes off, resisting the negative motion, and moving the body forward during a pitch.

In contrast, medial-lateral shear is directed towards first base. More specifically, it is oriented medially for the push-off force and laterally for the landing force. The landing forces reflect the rotational motion of the trunk. All forces collected for medial-lateral shear was less than ten percent of all resultant forces. After foot contact, the small but significant medial force in the trunk halts and changes to a lateral direction as the BW is fully transferred to the lead leg. This change in direction is due to the muscular activation of the pitching motion and causes the energy to transfer through the body and generates the forward motion in the arm.¹⁴

The resultant forces from the combination of the anterior-posterior shear and the medial-lateral shear forces were directed in the plane of the pitch for both push-off and landing. Push-off resultant forces were consistently 1.0 BW before foot contact. Landing resultant forces increased from foot contact to prior to ball release at a maximum of 1.75 BW.¹⁴ An increase between the two measurements suggests an increase in energy as the arm begins the forward motion. As these forces work together and against

each other during the pitching movement, they create a rapid kinetic chain that flows through the pitcher's body and affects both the pitcher's extremities and the resultant pitch. The pitching motion relies heavily on ground reaction forces and the kinetic chain to produce an accurate, high velocity ball release.

The scapula and shoulder joint are key factors in facilitating energy transfer from the lower body to the hand for the release of the ball.¹⁶ Kibler and Chandler¹⁸ calculated that a 20% decrease in kinetic energy deriving from the hips and trunk requires a 34% increase in the rotational velocity of the shoulder in order to produce the same amount of force to the wrist and hand. With this evidence, researchers sought to examine the theory that, from lower on the kinetic chain, a forceful leg drive also correlates with the velocity of the ball.¹⁴ Wrist linear velocity was analyzed against ground reaction force. Wrist velocity was shown to have a high correlation with ball velocity measured with the motion analysis system. Wrist velocity at ball release correlated with push-off anterior-posterior shear force ($r^2 = 0.82$), landing anterior-posterior shear force ($r^2 = 0.86$), and also landing resultant forces at ball release ($r^2 = 0.88$). The pitching motion requires contributions from the lower extremities to produce forward movement. Researchers found evidence which supported that if there is a greater push-off anterior-posterior shear force, there will be a greater magnitude of kinetic energy in the direction of the pitch.¹⁴

2.2.2. Range of Motion Requirements for Sport-specific Skills

Range of motion (ROM) is essential to proper energy transfer to consecutive body segments, and any deficits predispose an athlete to injury. A study conducted by Tippett et al.¹⁵ examined 16 NCAA Division I college baseball pitchers' lower extremity strength and active range of motion between the stance leg and kick leg. In the case of a right handed pitcher, the kick leg is the left (non-dominant) leg and the stance leg is the right (dominant) leg. To start the pitching motion, both legs are aligned facing the catcher. The stance leg supports the weight of the body as the hip of the kick leg flexes. Once the pitcher begins forward motion, the stance leg begins hip internal rotation, hip extension, and ankle plantarflexion to push off the rubber. When weight is transferred to the kick leg, the arm internally rotates and releases the ball, and then begins to decelerate. The closed kinetic chain of the stance leg contacting the mound allows the trunk to coil and load before the transfer of energy from the leg to the hip, to the torso, and finally the arm. In this study, each pitcher was evaluated for active ROM using a goniometer to measure supine hip flexion, prone hip extension, sitting hip internal and external rotation, supine hip

abduction, supine knee extension with the hip flexed to 90 degrees, and long sitting ankle plantarflexion and dorsiflexion. Each pitcher performed three repetitions of active ROM for data collection. Following ROM evaluation, concentric strength was evaluated using a Cybex II (Biodex). Each pitcher performed five slow repetitions and 15 fast repetitions with a 30-second rest between testing speeds and a two-minute rest before testing the contralateral side. Three maximal torque peaks were averaged to find peak torque of each motion.

Range of motion was found to be specific to pitchers as a result of the mechanics of the pitching motion. ROM measurements were consistent with the demands of the pitching motion and revealed significantly greater hip flexion on the non-dominant leg than the dominant leg ($P < 0.05$). Internal rotation, ankle plantarflexion, and hip extension were significantly greater on the dominant leg than the non-dominant leg ($P < 0.01$). Poor lower extremity range of motion prevents optimal energy transfer to the upper extremities, which may predispose a pitcher for shoulder injury. For example, decreased hip internal rotation on the stance leg would require the shoulder to increase external rotation due to poor lower extremity ROM and subsequently increase stress to the glenohumeral joint capsule and surrounding tendons.¹⁶ Repeated stress on the shoulder in pitchers can ultimately lead to impingement or rotator cuff injury.^{1,12,16} Because of the interconnectedness of the structures of the body, ROM throughout the lower extremities is vital to the health of a pitcher.

The energy in the pitching motion summates in a high velocity pitch. However, because the energy begins in the lower extremities and transfers to the upper extremity, the effects on the upper extremity ROM need to be explored. A study by Scher et al.¹⁷ examined the association between hip and shoulder range of motion as they relate to shoulder injury in 29 professional baseball pitchers and 28 professional positional players. The authors hypothesized that poor extension of the dominant hip, or stance leg, during the maximal acceleration phase of the pitching motion could cause the pitcher to increase the amount of shoulder external rotation in attempt to achieve the desired throwing motion; this concept is referred to as “flying open” in baseball. The pitching motion was compared against data from a regular throwing motion with the positional players. The authors further hypothesized that flying open would place more stress on the anterior structures of the shoulder, thereby increasing the risk of shoulder injury. Limited internal rotation of the non-dominant hip during the follow through of a pitch could limit the

lower extremity's ability to absorb energy generated during the acceleration phase. The results of this study confirmed the previously described research by Tippet et al corroborating the conclusion that less internal rotation on the non-dominant leg can lead to upper extremity pathomechanics.

Scher et al.¹⁷ connected a lack of ROM to an increased stress on the rotator cuff and posterior shoulder dysfunction during deceleration of the arm. Using a goniometer, passive ROM measurements for hip internal rotation, external rotation, extension, and shoulder external rotation and internal rotation for both dominant and non-dominant arms were recorded. Athletes were asked to document any hip, shoulder, or elbow injuries within the past year that required more than two days of missed play via an injury participation questionnaire. Data from pitchers and positional players were analyzed separately because the physical demands differ significantly between groups.

Figure 1 illustrates dominant shoulder ROM in professional baseball pitchers and positional players. No differences were found between pitchers with or without a history of shoulder injury for either dominant shoulder IR or ER ($P > 0.71$). In contrast, positional players with a history of shoulder injury were found to have increased dominant shoulder external rotation ($P = 0.08$) and decreased dominant shoulder internal rotation ($P = 0.03$) when compared to positional players without a history of shoulder injury. Eleven pitchers reported a history of injury and were found to have $10.1^\circ \pm 9.0^\circ$ difference in shoulder internal rotation which was calculated as ROM in the dominant shoulder subtracted from the non-dominant shoulder. Internal rotation deficits could be due to length of career of the pitcher, history of injury, and ROM differences.¹⁷

Figure 2 illustrates hip IR in pitchers and positional players with and without a history of injury. No significant differences in dominant hip EXT were found between pitchers with or without a history of injury ($P = 0.61$), non-dominant hip EXT ($P = 0.74$), dominant hip IR ($P = 0.30$), or non-dominant hip IR ($P = 0.20$). Similarly, no significant differences in dominant hip EXT ($P = 0.81$), non-dominant hip EXT ($P = 0.71$), or dominant hip IR ($P = 0.23$) were found in positional players with or without a history of shoulder injury. However, a significant difference was revealed in non-dominant hip IR ($P = 0.05$). This information suggests restricted hip internal rotation is a contributor to shoulder injury reported in baseball pitchers and non-pitchers.

To explore the possible connection between the hip and shoulder, the study by Scher et al.¹⁷ also reported a difference in dominant hip EXT and dominant shoulder IR in both pitchers and positional players. Non-dominant hip IR plays a role in decelerating the body after the ball is released. Interestingly, there were approximately five degrees less in players with a history of shoulder injury. With five less degrees IR, the energy of deceleration of the hips is not optimally transferred through the trunk and increases force at the shoulder. This relationship could predispose an athlete to injury. The results of this study support the role of the kinetic chain in the complex relationship between hip and shoulder ROM in the overhand throwing motion and how a restriction in the lower extremity affects the upper extremity.

2.2.3. Hip Muscle Activation and Injury

Evidence supports that there is a relationship between muscle activation dysfunction of the hip and shoulder ROM with an increased risk of injury.^{1,2,16,17} A study by Chaudhari et al.¹² examined lumbopelvic control and the amount of days missed because of injury in professional baseball pitchers. A total of 347 major league baseball pitchers participated, which required them to perform a standing single leg raise test while keeping the hips level. Measurements were taken using a tilt sensor placed on the anterior and posterior superior iliac spines and were collected during the final two weeks of spring training. Throughout the course of the season, each team's medical staff recorded days missed; at the end of the season all data was compiled for all participants. Days missed were defined as "any day that a subject was unable to complete his scheduled work because of a musculoskeletal injury suffered during baseball-related activity".¹² Results showed that participants with poor lumbopelvic control were three times more likely to miss at least 30 days than those with moderate or good lumbopelvic control. The season for the rookie league is around 90 days and major league is around 180 days. This means that 30 days of restricted or non-play is equal to 17% or 33% of the season, respectively. These results suggest that attention should be focused on improving hip muscle control and activation to potentially decrease the rate of injury among pitchers.

Several studies have shown relationships between pitching velocity and ground reaction forces, which suggest that pitch velocity depends on the generation and transfer of energy through the body, crossing the lumbopelvic region.^{12,14-17} Evidence has shown relationships between lumbopelvic control, the kinetic chain, and muscle activation.^{1,12,14-17} A lack of proper muscle activation and energy transfer

during the pitching motion increases the contribution from the shoulder, causing decreased health and durability of the athlete.¹⁶

Research and understanding of shoulder overuse pathologies has grown significantly in the past decade. Although many of the publications have focused on baseball, few have focused on other overhead sports such as volleyball. There are sufficient similarities between the biomechanical aspects of the various overhead sports, and researchers have come to appreciate the consistencies of the role of the kinetic chain and transfer of energy from the lower body, through the torso, funneling into the arm.² For the purpose of this literature review, data were focused on expanding the understanding of shoulder injuries caused by volleyball-specific movements.

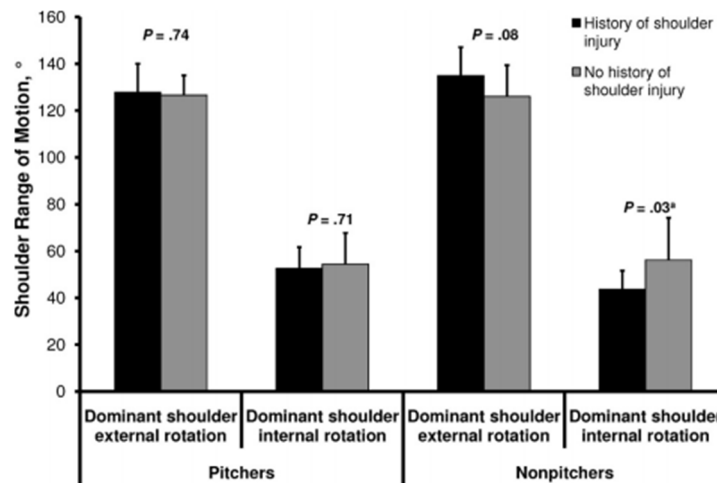


Figure 1. Dominant shoulder ROM in professional baseball pitchers and positional players.

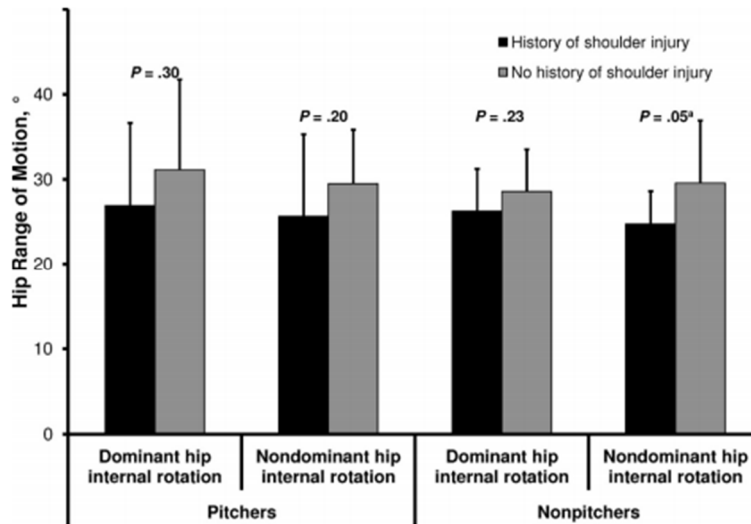


Figure 2. Hip internal rotation in pitchers and positional players with and without a history of injury

2.3. Volleyball

Volleyball is the second most popular sport in the world. Volleyball can be played indoors, outdoors, court, or on sand. Shoulder pain and dysfunction are common among competitive volleyball players and can result from repeated overhead contact with the ball.^{1,2} One study estimated that an elite volleyball athlete in the attacker position performs as many as 40,000 spikes in a season³, and shoulder injuries account for the longest time loss from injury.¹⁹ With the frequency of injuries in the sport, it is important to understand the injury pattern characteristics in order to implement effective injury prevention programs.

2.3.1. Injury Epidemiology

Epidemiological research has revealed that volleyball athletes are generally at greatest risk of acute ankle injuries and overuse conditions of the knee and shoulder.^{1,2,19} Despite the widespread nature of the problem, relatively little is known about the epidemiology of shoulder pain among volleyball players. Although relatively outdated data, the 1986 NCAA injury surveillance system reports that shoulder injuries are the third most common injury in volleyball, consisting of predominantly impingement and functional instability.² To further explore these statistics, 422 athletes from the 2006 club volleyball nationals were asked to complete a survey adapted from a survey for elite Gaelic football players and modified by the researchers. The volleyball players were asked to recall injuries over the preceding one year period to help identify the nature and common causes of injury in volleyball players. Of the participants, 276 also

underwent a physical examination.¹ The Simple Shoulder Test (SST) and a visual analog scale allowed each subject to quantify the extent of a perceived functional limitation. 57% of the 286 male respondents reported having experienced a shoulder injury, 44% within the current season. 60% of the 136 female respondents reported having experienced a shoulder injury, 42% during the current season. The right shoulder, or the dominant shoulder, was symptomatic in 92% of those who have experienced a shoulder injury. The survey relied on a self-report to determine volleyball-related exposures and this subjective data limited the researchers in way of association rather than finding a true cause-and-effect relationship.

To enhance the data collected from the subjective surveys, researchers used a physical examination to gain objective results. The physical examination of 186 males and 90 females assessed scapular positioning, glenohumeral range of motion, shoulder girdle strength, and core stability. Half of the cohort demonstrated forward head posture and 47% demonstrated rounded shoulders (51% of men, 38% of females). 36% of males and 19% of females had a unilaterally dropped scapula, predisposing him or her for impingement or other functional deficits. Periscapular atrophy, or weakening of the muscles surrounding the scapula, was observed in 14% of the subjects. Although most overhead sports share common risk factors, the study suggests that there are additional volleyball-specific risk factors which reflect biomechanical and muscle activation demands of the sport.^{1,2}

The findings in Reeser et al.¹ provided statistics of injury data collected in a physical examination, while a study by Jadhav et al.²⁰ surveyed the nature, location, causes, and outcomes of injuries. Participants were 18-25 years old and competed at a collegiate level varsity volleyball tournament. One hundred and forty four volleyball players completed the survey and 121 reported injury within the preceding year. There were a total of 178 injuries; 36% of which were recurrent. The ankle accounted for the highest percentage of injury (23.03%), followed by the knee (21.921%), and finally the shoulder (11.79%). 11.79% is equal to roughly 21 shoulder injuries reported in this population. The highest percentage of circumstance giving rise to upper and lower extremity injury was the spiking motion (33.70%), followed by blocking (24.15%).²⁰ The spiking motion is an overhead arm swing that requires a summation of kinetic energy in order to forcefully hit the ball; a shoulder motion similar to the baseball pitch. In the study by Reeser et al.¹, injury prevalence across position assignments was also investigated. 64% of attackers reported shoulder pain during the current season as compared to 49% of setters and

liberos who perform different sport-specific skills. 67% of jump servers reported shoulder injury, while 57% of float servers reported injury.¹ Attackers and jump servers forcefully hit the ball overhead similar to the spiking motion as discussed previously. Evidence from both studies by Reeser et al.^{1,2} exhibit an increased risk for upper extremity injuries which parallels statistical data collection that has been done by the National Collegiate Athletic Association injury surveillance program.²¹

2.3.2. Incidence of Shoulder Injury in Volleyball

Despite the non-contact nature of volleyball, the sport has a high incidence of injury. Studies have suggested that ankle injuries account for the highest incidence of acute injuries, however, less research has been done to explore overuse injuries in the sport as well as the impact an overuse injury makes on time lost from sport.¹⁹ Shoulder injuries in volleyball players have been reported usually as a result of repetitive motions.^{1,2,22,23} To quantify the overall incidence of overuse as well as acute injuries, one study examined 486 volleyball athletes throughout a season.¹⁹ Results depicted that shoulder injuries caused the longest absence from sport at an average of 7.9 weeks. Also, shoulder injuries accounted for 32% of all overuse injuries with injuries to the back (30%) and the knees (20%) following behind. This study suggests that shoulder injuries are more common in volleyball than previous research portrays, and prevention of the initial injury through proper training and rehabilitation may be necessary to reduce repetitive injury to the area.

Contrasting from the results from this study, Bahr et al.²⁴ found that shoulder injuries accounted for only 10% of overuse injuries. Researchers tracked injury incidence and patterns during a seven and a half week duration of a summer season of professional male and female beach volleyball players. Of the 178 athletes in this study, 67 of them reported a total of 79 overuse injuries that required medical intervention. This study agreed that the shoulder, back, and knees were most commonly involved; however, the back ranked first in incidence at 19% and the knee followed with 12%. Importantly, this study differs because researchers evaluated data from beach volleyball players who play on an uneven surface and are, therefore, at a greater risk for lower extremity injuries at the knee and ankle. Overall, 10% incidence of shoulder injury is still significant and warrants exploration into the understanding of the kinematics of volleyball athletes in order to improve prevention and rehabilitation programs.

2.3.3. Incidence of Poor Hip Muscle Activation in Volleyball

In overhead sports, such as volleyball, female athletes are more susceptible to injury due to their movement patterns and muscle activation.⁴ The body interacts with the playing environment and can be influenced by ground reaction forces, hip flexion angles, muscle strength, and flexibility. Deficits in any area can lead to injury. A group of researchers^{4,25,26} have explored the role of hip muscle activation in volleyball athletes, with one study²⁶ reporting that female volleyball athletes have decreased hamstring muscle activation and increased quadriceps activation.

A review by Barber-Westin et al.⁴ summarized current research knowledge of risk factors hypothesized to influence the increased predisposition female athletes have to anterior cruciate ligament injuries. Also included were the neuromuscular programs designed to correct the biomechanical problems found in these athletes. The review concluded that female volleyball players have weaker hip muscles, higher quadriceps activity and reduced hamstring activity during athletic movements, with faster fatigue times in these muscles.^{4,26-29} The review also goes on to discuss that successful neuromuscular programs have involved teaching the athlete control of not only the lower body, but also the upper body and trunk. The research shows importance in training the whole body in order to reduce injury. Weak activation of hip musculature and reduced hamstring activity creates deficits in energy generation and transfer along the kinetic chain in an athletic maneuver such as an overhead volleyball serve or spike.

Further, an analysis of response speed of musculature of the knee in professional volleyball players was completed by researchers to explore the muscular activation of the vastus medialis (VMO), rectus femoris (RF), vastus lateralis (VL), and biceps femoris (BF).²⁵ Eight teams, totaling 166 athletes, from each the Spanish Men's and Women's Superleagues participated. Tensiomyography was used to evaluate the four muscles based on the premise that these are the most significant in the actions involved in volleyball movements and jumping. A contraction was provoked with electrical current applied with two electrodes on the muscle belly. Normalized response speed (Vrn) was represented by the increase in muscle contraction time between the radial displacement of 10% and 90% of the muscle belly's maximum displacement. The researchers concluded that females are quadriceps dominant and males are hamstring dominant (BF Vrn: $P < 0.001$), although males have a greater balance in the activation of the hamstrings and quadriceps. Female volleyball players perform the jumping action mainly by calling on the

quadriceps (VMO Vrn: $P = 0.013$) and have an overall slower response speed as compared to males. The findings support the significance in muscle activation deficits and response speed in female volleyball athletes. With evidence showing decreased hamstring activation and overall slower response speeds in female volleyball athletes, as well as evidence stating shoulder injuries are accounting for 32% of all overuse injuries in the sport¹⁹, a relationship could exist between the muscle activation deficits and shoulder injuries.

A high incidence of shoulder injury displays a need by medical professionals and other individuals directly involved with a team to decrease the frequency of this debilitating injury. Reports suggest a shoulder overuse injury can result in, on average, slightly over seven weeks of lost competition or training time and account for 32% of all overuse injuries in the sport.¹⁹ Besides preventing the time lost, the health and well-being of an athlete is a primary concern. There is a substantial amount of research investigating the role of hip muscle activation relating to shoulder injuries in baseball pitchers; however, there are gaps in the literature investigating this relationship in other overhead sports. Volleyball is the second most common sport across the world and therefore displays a need to turn researchers' attention to the sport. A deeper understanding of the hip muscle activation in volleyball players along with an injury history survey could serve to improve injury prevention and rehabilitation programs for these athletes.

2.4. Surface Electromyography

Surface electromyography (EMG) is a diagnostic tool used to measure the electrical activity of muscle fibers by attaching electrodes to the surface of the skin overlying superficial muscle.^{7,8,11} The muscle activation information which can be obtained using EMG can be used to investigate motor coordination, treatment efficacy, muscle fatigue, and disuse.^{7,8} EMG has gained acceptance as a valuable evaluation procedure for most purposes, however, it can be of limited value in other evaluation procedures.

2.4.1. EMG Reliability and Normalization

The reliability of an instrument is imperative to ensure optimal statistical results. Reliability is the ability of an assessment tool to produce stable and consistent results.³⁰ Test-retest reliability is obtained by repetitions of the same test multiple times of a cohort while interrater reliability is the degree of which different raters are able to perform the same assessment and obtain consistent results.³⁰ A study

performed by Bolgla et al.⁵ explored the reliability of three normalization methods for analyzing hip abductor activation while subjects perform rehabilitation exercises. Surface EMG was conducted on the gluteus medius during 15 repetitions of the following exercises: standing hip abduction, standing hip abduction with a flexed hip, single leg stance with a contralateral load, side lying hip abduction, single leg stance with a contralateral load and a flexed hip, and pelvic drops.

Data were normalized using a maximum voluntary isometric contraction (MVIC) method with manual muscle testing subject positioning, mean dynamic activity (M-Dyn), and peak dynamic activity (P-Dyn). Intraclass coefficient correlation ranged from 0.93 to 0.96 for the MVIC method, 0.41 to 0.97 for the M-Dyn method, and 0.71 to 0.98 for the P-Dyn method. Inter-subject coefficient of variation (CV's) ranged from 55% to 77% using the MVIC method, 19% to 44% using the M-Dyn method, and 26% to 61% using the P-Dyn method. Intra-subject CVs ranged from 11% to 22% for all methods. The consistency of ICC, inter-subject CV, and intra-subject CV support that normalization using MVIC method can provide the highest reliability for determining differences in muscle activation.⁵ With this evidence, it is supported that clinicians can compile the most reliable data using a maximum voluntary isometric contraction for normalization before rehabilitation exercises.

2.4.2. EMG Electrode Placement and Patient Positioning

Several factors influence the statistical results and variable estimates depending on the placement of the electrode; therefore, it is important to standardize the positioning along the length of the muscle. The most advantageous location for electrode placement differs across muscles as well as patients. One study⁷ collected data from 10 subjects and began by finding myoelectric signals from 13 lower extremity muscles using a linear array of 8 or 16 electrodes. A linear array is a placement of electrodes in a number of points along a line where the EMG signals provide information on motor units such as the innervation zone (IZ) and tendons and fiber length.³¹ Initial positioning and orientation of the electrodes was dictated by manual muscle testing and outlining the muscle belly and length. Electrodes were then placed along the length of the muscle with the array oriented perpendicular to the muscle fibers with respect to the innervation zone, or where the nerve terminates and the muscle fibers connect.

Isometric contractions were performed against manual resistance and followed guidelines of a study previously performed by Kendall et al.¹³ Nine of the 13 muscles (Biceps Femoris, Semitendinosus,

Vastus Lateralis, Tensor Fascia Latae, Gastrocnemius medialis and lateralis, Gluteus Maximus, Vastus Medialis Obliquus, and Tibialis Anterior) tested provided feedback that classified as excellent or good. The study defined excellent as meaning the direction of the muscle fibers may be palpated and the array may be placed correctly, the IZ is identifiable, and the action potential is recognizable throughout the fiber length. The array positioning with respect to the IZs of the 13 muscles were studied and demonstrated that in eight of the 13 muscles (Biceps Femoris, Semitendinosus, Vastus Lateralis, Tensor Fascia Latae, Gastrocnemius Lateralis, Gluteus Maximus, Vastus Medialis Obliquus, and Tibialis Anterior), it is possible to obtain information based on bony landmarks for a standard EMG electrode placement between the IZ and the distal and proximal muscle tendon. This study supports the use of bony landmarks for placement of EMG electrodes to collect data using isometric contraction. Data from dynamic contractions rather than isometric contractions might be more clinically applicable because of the dynamic movements required to compete in sports.

Similar to the study by Rainoldi et al.⁷, Jeon et al.⁸ explored EMG amplitude for the Gluteus maximus (GM), Biceps femoris (BF), and Semitendinosus (ST) during three different prone hip extension exercises in healthy subjects. However, this study used dynamic contractions while Rainoldi et al.⁷ used isometric contractions. Each participant performed prone hip extension (PHE), prone table hip extension (PTHE), and prone table hip extension with knee flexion (PTHEK). A pressure bio-feedback unit at 70 mmHg was positioned under the abdomen to encourage an abdominal drawing-in maneuver as well as to evaluate pelvic anterior tilt and rotation. EMG amplitude showed the greatest amount of Gluteus Maximus activation during PTHEK (EMG amplitude = $55.11\% \pm 18.29$ MVIC, $P < 0.001$). Biceps femoris and Semitendinosus amplitudes were significantly greater in the PTHE (BF EMG amplitude = $69.37\% \pm 30.01$ MVIC, $p < 0.001$, ST EMG amplitude = $36.80\% \pm 13.84$ MVIC, $P < 0.001$) than PHE and PTHEK. These findings suggest knee flexion could inhibit the Biceps Femoris and the Semitendinosus to selectively record signals that are produced solely by the Gluteus Maximus. Secondly, because no significant difference was found in kinematic motion across all three exercises when using the pressure bio-feedback unit, it is suggested that lumbopelvic motion does not play a large role on EMG amplitude and that patient positioning during an exercise is the biggest influencer of results. This evidence demonstrates that clinicians should focus on patient positioning for more effective muscle activation.

2.5. Lower Extremity Muscle Activation

Muscles in the lower extremity play a variety of roles. A muscle can act as a stabilizer, as the gluteus medius does during a squat, or prime mover, as the gluteus maximus does during a wind-up for a kick. A muscle can cross only one joint or two, effecting the overall action produced and can determine the significance of the contraction. Dysfunction or poor activation of the lower extremity muscles lead to pathologies in the body.⁶ Clinicians and researchers alike have explored the effectiveness of the many different exercises in activating and strengthening these different types of muscles.^{6,9,10,32}

2.5.1. Muscle Activation during Common Therapeutic Exercises

Lower extremity rehabilitation programs employ common exercises varying in difficulty to target gluteal muscles. Muscle activity recordings during these functional exercises provide clinicians with information, which allows them to formulate the most effective rehabilitation and injury prevention programs. With a wide range of exercises available, one study⁹ aimed to quantify and compare EMG signal amplitude of the gluteus medius and gluteus maximus muscles during 12 common therapeutic exercises in order to determine which exercises best recruit these muscles. Twenty-one recreationally active participants were taught and practiced the 12 different exercises until he or she felt comfortable performing the task. Subjects completed eight repetitions of each exercise with two minutes of rest between sets while EMG data was collected. The exercises performed included hip clams with 30 and 60 degrees of hip flexion; side-lying hip abduction; single-limb squat and deadlift; lateral band walks; forward, sideways, and transverse lunges; and finally, forward, sideways, and transverse hops.

The reliability analysis for the gluteus medius resulted in 0.93 to 0.98 for ICC values, with the exception of hopping tasks which were less reliable (0.37 to 0.56). The gluteus maximus reliability analysis resulted in ICC values ranging from 0.85 to 0.98, with the exception of hopping tasks (0.21 to 0.42). This suggests high reliability, or the ability to reproduce the data collection and find the same results, for both the gluteus medius and gluteus maximus during all tasks besides the hopping tasks.

Tables 1 and 2 display the means, standard deviations, and confidence intervals of the signal amplitude (%MVIC) during the 12 exercises for the gluteus medius and gluteus maximus respectively. The side-lying hip abduction produced greater activation ($81\% \pm 42$) of the gluteus medius than either of the clam exercises (30 degrees hip flexion: $40\% \pm 38$, 60 degrees hip flexion: $38\% \pm 29$), lunges in all

directions (transverse: $48\% \pm 21$, forward: $42\% \pm 21$, sideways: $39\% \pm 19$) and the forward ($45\% \pm 21$) and transverse ($48\% \pm 25$) hop. The top five most effective exercises for the Gluteus Medius displayed only a 10% observed difference in mean EMG amplitude and also involved the primary action of the muscle (i.e. the Gluteus Medius isometrically stabilizes the hip, concentrically abducts the hip, and eccentrically controls hip internal rotation. The single-limb squat requires these actions to perform the exercise.). Overall, the side-lying hip abduction exercise was the best exercise to target the gluteus medius.

For the gluteus maximus (Table 2), there was significantly greater activation signals during the single-limb squat ($59\% \pm 27$) and deadlift ($59\% \pm 28$) exercises than the other exercises. The single-limb squat and deadlift exercises both demonstrated gluteus maximus activation levels higher than 50% MVIC. The single-limb squat and deadlift exercises were the most effective to target the gluteus maximus.⁹

Table 1. Gluteus Medius Mean Signal Amplitude (%MVIC)

Exercise	Mean \pm SD
Side-lying hip abduction	81 ± 42
Single-limb squat	64 ± 24
Lateral band walk	61 ± 34
Single-limb deadlift	58 ± 25
Sideways hop	57 ± 35
Transverse hop	48 ± 25
Transverse lunge	48 ± 21
Forward hop	45 ± 21
Forward lunge	42 ± 21
Clam with 30° hip flexion	40 ± 38
Sideways lunge	39 ± 19
Clam with 60° hip flexion	38 ± 29

Table 2. Gluteus Maximus Mean Signal Amplitude (%MVIC)

Exercise	Mean \pm SD
Single-limb squat	59 \pm 27
Single-limb deadlift	59 \pm 28
Transverse lunge	49 \pm 20
Forward lunge	44 \pm 23
Sideways lunge	41 \pm 20
Side-lying hip abduction	39 \pm 18
Sideways hop	30 \pm 19
Clam with 60° hip flexion	39 \pm 34
Transverse hop	35 \pm 16
Forward hop	35 \pm 22
Clam with 30° hip flexion	34 \pm 27
Lateral band walk	27 \pm 16

Two other frequently used therapeutic exercises are the lateral step-up and the stair-stepping machine, which both aim to exercise the legs. One study gathered EMG data of muscle activation and co-activation levels during these two exercises to determine if there are any significant differences in muscle activity levels in the RF, VMO, BF, ST, and gastrocnemius (G).¹⁰ Eighteen subjects performed two, 90-second trials of the stair-stepping machine and an eight-inch lateral step-up while EMG data was collected on the dominant leg.

Results demonstrated the RF (27.8%) and VMO (44.7%) had significantly higher levels of activation during the lateral step-up for mean EMG amplitude (%MVIC). Researchers attribute this to the subject's center of gravity being maintained at an almost constant height during the stair-stepping machine as compared to the lateral step-up where the subject must lift the entire body weight with the test leg. Similar to the results reported by Marchetti et al.³², the biceps femoris EMG recording suggested muscle activity throughout the entire exercise cycle, not a specific knee angle, lending to the muscle's role as a knee stabilizer. However, the mean EMG activity (%MVIC) of the BF during the lateral step-up was 4.6% MVIC which is higher than activity during the stair-stepping machine at 3.9%. Despite the consistent hamstring muscle activity levels reported over the total exercise cycle, the mean is higher for the lateral step-up than the stair-stepping machine. Paired with the increased mean quadriceps muscle activation, the lateral step-up was more effective at overall muscle activation.

Many researchers strive to explain the mechanical effect occurring second to weak musculature. Due to several exercises being frequently used across many settings to strengthen the musculature, researchers compared the most common exercises used during the previously discussed studies, as well

as several other commonly performed exercises to determine which exercises are most effective to recruit the gluteal muscles.⁶ In this study, 24 subjects had EMG data collected on the activation of the gluteus maximus and gluteus medius during 22 different exercises. Some exercises required advanced strength or stability, such as a single-limb bridge on an unstable surface and a side plank, which reduced the number of participants able to successfully complete an exercise to 20. Similar to the study by Distefano et al.⁹, subjects performed eight repetitions of each exercises and were given two minutes of rest between each set. Peak amplitudes expressed as %MVIC for gluteus medius and maximus were placed in rank order.

Table 3 and Table 4 show the top five exercises which most effectively recruited the gluteus medius and gluteus maximus, respectively. Table 5 displays the muscles that most effectively activated both muscles. Notably, two exercises produced results where %MVIC were higher than MVIC: the side plank abduction with the dominant leg down (103 %MVIC) for the gluteus medius and the front plank with hip extension (10 %MVIC) for the gluteus maximus. Authors discuss that this occurrence may be due to a lack of proper verbal cues in order to produce a true maximal contraction during MVIC testing. Researchers also discussed that these two exercises require co-contraction of the core muscles which could have led to higher values than what was obtained during MVIC testing as well. With all data in consideration, the authors concluded that a front plank with hip extension, a single-limb squat, and a side plank on either side are most effective at producing maximal activation of the gluteus medius and maximus.

Table 3. Top exercises for gluteus medius activation in rank order

Exercise	%MVIC
1. Side plank abduction with dominant leg down	103.11
2. Side plank abduction with dominant leg up	88.82
3. Single-limb squat	82.26
4. Clamshell 4	76.88
5. Front plank with hip extension	75.13

Table 4. Top exercises for gluteus maximus activation in rank order

Exercise	%MVIC
1. Front plank with hip extension	106.22
2. Gluteal squeeze	80.72
3. Side plank abduction with dominant leg up	72.87
4. Side plank abduction with dominant leg down	70.96
5. Single-limb squat	70.74

2.5.2. Muscle Activation during Isometric Contractions

Isometric contractions are used in a variety of applications in therapeutic rehabilitation. Although athletics involves dynamic movements with many different types of muscle contractions, isometric contractions allow clinicians to isolate a muscle in a controlled environment for safe rehabilitation at any stage. Marchetti et al.³² compared the muscle activation of lower limb muscles while performing maximal isometric exercise. In addition to the gluteus maximus (GM), this study also examined the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VMO), biceps femoris (BF), and semitendinosus (ST). The study used a maximal isometric back squat during three different positions to investigate the differences in muscle activation as the joint angles are manipulated. Fifteen resistance-trained males performed three trials of 10-second maximal isometric back squats against a locked smith machine at 20°, 90°, and 140° of knee flexion. Surface EMG was placed on the dominant limb and was normalized using the MVIC method prior to dynamic activity data collection.

Results showed a main effect from the different knee angles on the VL ($P < 0.001$), RF ($P = 0.018$), VMO ($P = 0.030$), and GM ($P < 0.001$) for muscle activity during the three different knee angle positions. VL activity was significantly less at 140° than 20° ($\Delta\% = 24.4$) and 90° ($\Delta\% = 37.5$). RF activity was significantly less at 20° than 90° ($\Delta\% = 36$). GM activity was also significantly less at 140° than 90° ($\Delta\% = 80.4$) and 20° ($\Delta\% = 80$). These results are illustrated in Figure 3. The study by Distefano et al.⁹ found the single-limb deadlift with 30° of hip and knee flexion to be one of the most effective exercises to activate the GM (mean 58%MVIC).

Distefano's findings are consistent with the findings by Marchetti et al.³² in the way that the back squat at 20° has minimal knee flexion similar to the single-limb deadlift. However, Distefano did not examine EMG activity of the hamstring muscles. Marchetti et al.³² reported that the activation of the BF

and ST did not significantly differ over the three positions. The squat exercise activates several biarticular muscles such as the BF, ST, and RF which have an agonist role at one joint and antagonist role at another. When the contraction is isometric, the biceps femoris and semitendinosus act as a joint stabilizer at the knee and a prime mover at the hip which could be illustrated in the results showing low activation at all positions for these two muscles. The knee is in a lesser degree of flexion, therefore, engaging the muscles more proximally.

Table 5. Top exercises for activation of both muscles

Exercise	%MVIC gluteus medius	%MVIC gluteus maximus
Front plank with hip extension	75.13	106.22
Side plank abduction with dominant leg up	88.82	72.87
Side plank abduction with dominant leg down	103.11	70.96
Single-limb squat	82.26	70.74

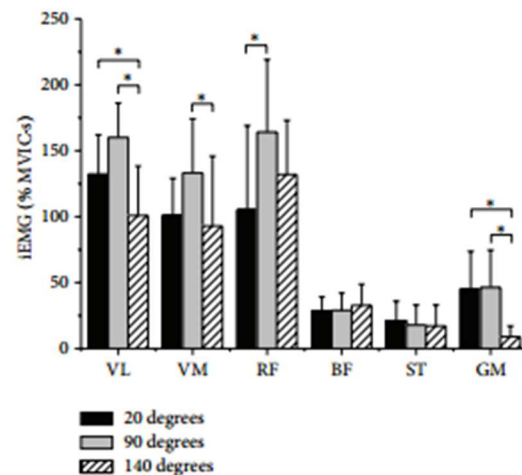


Figure 3. Mean and standard deviation of EMG in three different knee joint-angles positions.

2.6. Conclusion

In summary, future research is warranted to determine if a correlation exists between hip muscle activation and shoulder injury in collegiate volleyball players. The athletic movements calling on the gluteus medius, gluteus maximus, rectus femoris, and biceps femoris in volleyball leave clinicians wondering if a lack of activation could lead to shoulder injuries, as this relationship has been found in

baseball players.^{12,14-17} With extensive research into baseball, there is a need to expand this research into other overhead sports in order to provide the highest quality care for the athletes.

CHAPTER 3: METHODS

3.1. Purpose

The purpose of this research was to investigate the relationship of hip muscle activation to previous or current shoulder injuries in collegiate volleyball players. Differences in hip muscle activation were also compared between National Collegiate Athletic Association (NCAA) Divisions I, II, and III as well as identified volleyball position. Hip muscle activation was determined through surface electromyography (EMG) during the following five activities: concentric box jump, eccentric box jump, volleyball hit approach, single-leg squat, and single-leg deadlift. A quasi-experimental design will be conducted using a within-subjects and between-subjects repeated measures analysis. The goal of this study was to answer the following research questions:

Q₁: What is the relationship between the athletes' retrospective reporting of shoulder injury and hip muscle activation?

Q₂: What are the differences in muscle activation of static and dynamic movements for the gluteus maximus, gluteus medius, rectus femoris, and biceps femoris in volleyball players when compared across NCAA Divisions I, II, and III as well as compared between positions on the court?

3.2. Participants

The participants were recruited from three collegiate volleyball teams, each representing a different NCAA division. Subjects were recruited by word of mouth from the research team, team athletic trainer, and respective coach. Inclusion criteria for this study required the athlete to be a current member on the varsity roster of one of the NCAA Division I, II, or III volleyball teams and be within the ages of 18 to 25 years old. Exclusion criteria included rheumatoid arthritis in the lower extremities and nerve conduction health history including, but not limited to: Amyotrophic Lateral Sclerosis (ALS), Multiple Sclerosis (MS), or Parkinson's disease. Additional exclusion criteria included orthopedic injury which would inhibit the athlete from participating in any of the four movements as determined by the institution's certified athletic trainer. Once recruited, participants were asked to refrain from maximal weight lifting 48 hours prior to data collection. Athletes were also asked not to participate in any sport-related activities the day of data collection. By avoiding these activities, excessive fatigue was limited. Each participant

received ten dollars cash for compensation of her time and efforts, except for Division III athletes who were not compensated due to NCAA Division III rules and regulations.

This study was initially approved by the Institutional Review Board at North Dakota State University followed by Minnesota State University Moorhead and Concordia College (Appendix A). An informed consent (Appendix B) was read and signed by each participant prior to data collection. Next, each subject completed a brief demographic and injury history questionnaire (Appendix C). Data collection was conducted at each institution's available athletic facility.

3.3. Surface Electromyography

Data were obtained using electromyography analysis through Biopac Systems, Inc. (Version 4.1, Goleta, CA). Manual Muscle Tests (MMT) was initially conducted to determine optimal electrode placement for the four muscles before performing the exercises. Each contraction was five seconds in duration with at least three to five seconds of rest between contractions. MMTs were performed by placing the subject in a specific joint position in order to isolate the muscle. These results were used for normalization of EMG data collection during the exercises. This method was deemed a reliable normalization method through studies by Bolgla et al.⁵ and Rainoldi et al.⁷

The study by Rainoldi et al.⁷ explored placement of electrodes on 13 lower limb muscles, including the four target muscles in this study. Following EMG recordings, electrodes can be reliably placed in respect to distal and proximal muscle tendon and bony landmarks during a maximal MMT isometric contraction for the Biceps Femoris and Gluteus Maximus. The Biceps Femoris and the Gluteus Maximus were classified as fair for innervation zone uniformity, however, excellent in signal quality. The Gluteus Medius was categorized as fair for both innervation zone uniformity and signal quality. Rainoldi et al.⁷ did not include the Rectus Femoris in the study due to EMG data from this muscle not meeting the defined minimum criteria for a muscle to be included in the study. However, Nene et al.³³ was able to record accurate EMG data for the Rectus Femoris by placing electrodes half of the distance between the anterior superior iliac spine and the superior border of the patella. EMG data initially appeared similar to the Vastus Lateralis, raising concern for cross talk, but was ruled to be signals from solely the Rectus Femoris through manual muscle testing. Muscular and bony anatomy was palpated by the researcher

during data collection in order to allow the researcher to accurately place electrodes halfway between the muscles' distal and proximal tendon for each subject.

3.4. Participant Preparation

Surface electrode placement was found by determining the mid-way point between the distal and proximal muscle tendon of the biceps femoris, gluteus medius, gluteus maximus, and rectus femoris. The skin surface was cleaned with 70% isopropyl alcohol pads, skin abraded, excessive hair trimmed, and the skin surface cleaned again with 70% isopropyl alcohol pads. In order to conduct a bipolar recording, one electrode was placed on the anterior superior iliac spine as well as the posterior superior iliac spine, serving as dispersion electrodes to complete the circuit. The dispersion electrodes were not included in surface EMG analysis.³⁴ Two 40 millimeter, adhesive silver/silver-chloride bipolar surface electrodes were placed two centimeters apart. The portable transmitter wires were connected to the electrodes which then allowed assessors to ensure proper electrode placement with real-time visual inspection of the EMG signals during MMT.

Analog channels were established initially to collect static and dynamic variables at a continuous rate from a single source (Biopac Systems, Inc., Version 4.1; Goleta, CA). Raw signals were collected at a sample rate of 2,000 samples per second and a channel sampling rate was established at 2.000 kilohertz for each of the four muscles. The acquisition length was set at 1,800.00 seconds.

3.5. Manual Muscle Testing

Static muscle testing began with the subject's maximal voluntary isometric contraction through MMT to isolate the biceps femoris, gluteus medius, gluteus maximus, and rectus femoris, in the respective order. Raw data were collected using the surface EMG through Biopac Systems, Inc. (Version 4.1; Goleta CA) on the dominant leg as determined by the leg a participant would use to kick a ball. Each MMT was completed three times and held for five seconds, cycling through the same order to reduce fatigue.

The Biceps Femoris MMT was performed with the subject lying prone with the test leg knee flexed to 90 degrees and the hip slightly externally rotated with the tibia internally rotated. The assessor stabilized with one hand on the Gluteus Maximus and the other hand on the posterior lower leg in order to apply a force pushing the knee into extension.³⁵ The subject was asked to hold this position while the

resistance was applied for five seconds. The MMT for the Gluteus Medius began with the subject side-lying with the test leg stacked on top of the other leg. The subject slightly abducted, extended, and externally rotated the leg. The assessor applied a downward force on the proximal lower leg while stabilizing at the iliac crest to ensure the pelvis did not rotate and asked the subject to hold this position for five seconds.¹³ If the subject rotates the pelvis during this test, the specificity of the Gluteus Medius greatly diminishes as the Tensor Fascia Latae and Gluteus Minimus become active. The MMT for the Gluteus Maximus began with the subject lying prone, again with the knee flexed to 90 degrees. She then extended the hip, contracting the Gluteus Maximus. The assessor stabilized with one hand just superior to the Gluteus Maximus while applying a downward pressure with the other hand on the distal posterior thigh and asked the subject to hold the position for five seconds.³⁵ Last, the MMT for the Rectus Femoris began with the subject lying supine. Participants slightly flexed one hip while keeping the knee fully extended (similar to a straight leg raise) about 10 inches off of the testing surface. The assessor stabilized at the anterior superior iliac spine, applied a downward force at the proximal anterior lower leg, and asked the subject to hold the position for five seconds.¹³ Because the Rectus Femoris is a biarticular muscle crossing the hip and knee joints, it is best to have both joints extended as a preference of the researcher. Some clinicians prefer to test the Rectus Femoris in varying ways, however having both of the joints extended more effectively isolates the Rectus Femoris without allowing the other quadriceps muscles or the Iliopsoas to assist with the resistance. Small, self-adhesive stickers were placed to mark the placement of the electrodes in case they move during participation.

3.6. Therapeutic Exercise Performance

Following manual muscle testing, subjects performed dynamic exercises in order to collect EMG recordings of the target muscles similar to contractions during athletic movements. All exercises were performed in a randomized order in an effort to reduce fatigue and increase validity. In order to reduce risk for participants, each subject performed a brief warm-up before participation. The warm-up consisted of a three minute jog followed by 30 seconds of jumping jacks, high-knee running, and butt-kick running, and then 15 tuck jumps and 15 body weight squats. Subjects began by doing a maximum of two practice jumps before performing five more box jumps for data collection. The box was 18 inches high and was placed eight inches in front of the subject. Subjects performed the jumps with minimal verbal cues in

order to collect data on their natural contractions during movement. If a subject was unable to properly perform a jump at this height, she was disqualified from participation. The participant carefully stepped off the box each time, rather than jumping down. After completing the five jumps up to the box, the subjects performed five repetitions of jumping down using the same box, again with minimal verbal cues. Following, the participant performed five volleyball hit approach jumps with her natural technique, again with two practice jumps.

Next, the subjects performed two therapeutic exercises commonly used in a clinical rehabilitation setting.^{5,6,9} The single-leg squat was ranked third by Boren et al.⁶ in effectively activating the Gluteus Medius and ranked fifth in activating the Gluteus Maximus when compared to 21 other common exercises. Cook et al.¹⁰ found that the Rectus Femoris and Biceps Femoris had higher levels of activation when the subject's center of gravity moves up or down, such as what is required to perform this exercise. Distefano et al.⁹ ranked the single-leg squat second for Gluteus Medius mean EMG signal amplitude and first for the Gluteus Maximus mean EMG signal amplitude.

This study followed instructions set by Distefano et al.⁹ to perform the single-leg squat (Figure 1). Subjects started by balancing on their dominant leg with the knee and hip both flexed approximately 30 degrees with the ipsilateral hand on the hip. The subject slowly lowered herself to touch her foot with her contralateral hand, flexing at her ankle, knee, and hip joints. The subject could not reach forward with her shoulders and then returned to the starting position after completing the task. Distefano et al.⁹ used cues to keep the subject's knee over the toe to prevent knee valgus force, which will also be used in this study. The subject performed five repetitions with 10 seconds of rest between repetitions.

The final exercise was a single-leg deadlift (Figure 2). Distefano et al.⁹ ranked this exercise fourth in Gluteus Medius mean EMG signal amplitude and second in Gluteus Maximus mean EMG signal amplitude. This study followed the instructions set by Distefano et al.⁹ for the single-leg deadlift. The subject began by balancing on her dominant leg with the knee and hip flexed to approximately 30 degrees and hands on her hips. The subject then slowly flexed her hip and trunk and touch her foot with her contralateral hand before returning to the starting position. Each subject performed five repetitions with 10 seconds of rest between repetitions. Distefano et al.⁹ used verbal cues to keep the knee flexed 30 degrees while reaching down to focus on hip and trunk flexion, and to keep the knee over the toes. The

Gluteus Maximus and Biceps Femoris contract eccentrically and the Rectus Femoris contracts eccentrically during the downward reach. While returning to the starting position the Gluteus Maximus and Biceps Femoris then switch to a concentric contraction. Throughout the exercise, the Gluteus Medius works to stabilize the hip and to prevent the pelvis from dropping to the non-dominant side, commonly known as a Trendelenburg's Sign.



Figure 4. Single-limb Squat



Figure 5. Single-Limb Deadlift

3.7. Data and Statistical Analysis

Surface EMG was analyzed through ACQKnowledge (Biopac Systems, Goleta, CA.). The latest SPSS software available (Version 23) was used to complete statistical analysis. At no point in time did a coach have access to individual data results of athletes' participation. In order to make evidence-based conclusions, the following statistical methods were conducted based on the original research questions. Statistical analysis was completed using SPSS Software Version 23.0. A two-way, repeated measures

ANOVA was conducted in order to capture the within-subject data across time as well as a between-subject comparing differences in NCAA Division and position. The relationship between muscle activation and previous or current shoulder injuries was evaluated with a Pearson's product-moment correlation. The significance level was established at $P < .05$.

3.8. Conclusion

The purpose of this research was to investigate the relationship of hip muscle activation to previous or current shoulder injuries in collegiate volleyball players. Using surface EMG, hip muscle activation was determined during the following five activities: concentric box jump, eccentric box jump, volleyball hit approach, single-leg squat, and single-leg deadlift. The results strive to provide insight on collegiate volleyball players' ability to activate hip musculature as well as the history of shoulder pathologies across the three NCAA divisions.

CHAPTER 4: MANUSCRIPT

4.1. Abstract

Title: The Relationship of Hip Muscle Activation and the Incidence of Shoulder Injury in Collegiate Women's Volleyball Athletes: A Pilot Study

Authors: Jessica Kinder, ATC, Katie Lyman, PhD, ATC, NREMT, Bryan Christensen, PhD, CSCS, Ronda Peterson, MS, ATC, Thomas A. Hanson

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Objective: The primary purpose of this research was to investigate hip muscle activation of collegiate volleyball athletes during five dynamic movements. The secondary purpose was to compare hip muscle activation between college volleyball athletes who reported previous shoulder injury and those who have not experienced an injury.

Background: Previous studies have indicated that weak hip muscle activation in baseball pitchers leads to an increased incidence of shoulder injuries. This relationship, however, has not been explored in other overhead athletes, such as volleyball players. Research confirms that female athletes have decreased hamstring activation and faster fatigue times in the musculature surrounding the hips, yet there is a lack of knowledge of how these traits affect the upper extremities.

Design: A total of 20 ANOVA models were estimated to assess the significance of self-reported injury. The dependent variable was muscle activation, as measured by surface electromyography (EMG). Additional between-subject factors included NCAA Division and position. Within-subject observations were averaged and computed as a percentage of the Manual Muscle Tests (MMT). The relationship between muscle activation and previous or current shoulder injuries was further evaluated with Pearson's product-moment correlation. The significance level was set *a priori* at 5% with a Bonferroni adjustment for multiple comparisons.

Participants: 18 female NCAA Division I (n = 4), II (n = 9), or III (n = 5) volleyball athletes. The average age was 19.89 (± 1.32) years old.

Interventions: Participants completed a shoulder injury history and demographics questionnaire. Surface electromyography (EMG) was used to evaluate each participant's muscle activation while she performed five single limb squats, five single limb deadlifts, five volleyball jump approaches, five

concentric box jumps, and five eccentric box jumps. Dynamic activity was normalized according to MMTs for the rectus femoris, biceps femoris, gluteus maximus, and gluteus medius.

Main Outcome Measures: Surface EMG output of the Rectus Femoris, Gluteus Medius, Gluteus Maximus, and Biceps Femoris during dynamic muscle activation as well as demographics including a self-reported shoulder injury history.

Results: The gluteus medius during the eccentric box jump was statistically significant ($F[3, 6] = 163.42, p = .003$) for position where setters showed the greatest activation and defensive players the least. The gluteus maximus during the single-leg deadlift was statistically significant ($F[3, 6] = 8.68, p = .013$) for position where, again, setters showed the greatest activation and defensive players the least. Surprisingly, the hamstring showed statistically significant activation during the eccentric box jump where defensive players showed the highest activation and setters the least ($F[3, 6] = 6.66, p = .025$). For this sample size, 22.2% of participants reported having a history of shoulder injury over her volleyball career.

Conclusions: Based on a limited population as well as few self-reported shoulder injuries, this research reports few differences in muscle activation when compared across position. There were no differences in hip muscle activation when compared across NCAA Division. The results should serve as a pilot study for future research due to the limited population.

4.2. Introduction

Shoulder pain and dysfunction are the third most common overuse pathologies among competitive volleyball players and result from repeated overhead contact.¹⁻³ When investigating the epidemiology and risk factors for shoulder injuries in volleyball, it has been reported 57% of male participants and 60% of female participants experienced a shoulder injury during his or her volleyball career.¹ Literature supports poor lower body muscle activation along the kinetic chain in baseball pitchers leads to compensations in the upper body, thus predisposing athletes to shoulder injury. It has been calculated that as little as a 20% decrease in kinetic energy generation in the hip musculature requires a 34% increase in rotational velocity of the shoulder in order to produce the same amount of force behind a baseball pitch.¹⁸ This compensation overworks the shoulder joint and heightens the risk for undue injuries. Although literature exists which reports concrete evidence of a relationship between hip muscle activation and shoulder injuries in baseball pitchers,^{14,15,17,18} little is known about this correlation in other

overhead sports, such as volleyball which also requires frequent overhead, rotational movements as what is required to perform a spike or serve. Research indicates female athletes have weaker hip muscles, higher quadriceps activity, and reduced hamstring activity during athletic movements, in addition to faster fatigue in the associated muscles when compared to male counterparts.⁴ To the knowledge of the researchers of the current study, no previous studies exist which investigate whether weaker hip musculature is related to an increase in sustained shoulder injuries in collegiate volleyball athletes.

The lack of research and subsequent absence of evidence-based injury prevention and rehabilitation protocols for athletes competing in volleyball potentially increases their risk of injury. As a clinician, a requirement to properly treat and rehabilitate athletes is knowledge of which muscles are effectively strengthened by specific exercises. For example, previous studies have concluded significant, concurrent gluteus medius and gluteus maximus activation can be achieved with a single-limb squat or single-limb deadlift.⁹ Conversely, a clamshell exercise with 30 degrees of hip flexion poorly activates these two muscles.⁹ When creating a rehabilitation or injury prevention program with a goal of strengthening the gluteal muscles, the single-limb squat and single-limb deadlift would more effectively activate these muscles. Not only does lower extremity muscle weakness predispose an athlete to upper extremity injury as observed in baseball players,^{12,14,15,36} but lower extremity muscle weakness can also predispose an athlete to injuries such as ACL tears.^{4,28,37,38} With a lack of research surrounding the relationship of hip muscle activation and the incidence of shoulder injury in volleyball athletes, it is difficult to determine necessary aspects needed to formulate an effective injury prevention program.

The purpose of this study was to investigate the relationship of hip muscle activation to previous or current shoulder injuries in collegiate volleyball players. A secondary purpose of this study was to collect quantitative data about the activation of the gluteus maximus, gluteus medius, rectus femoris, and biceps femoris in relation to respective playing position and National Collegiate Athletic Association (NCAA) Division of the athlete. Hip muscle activation was determined through surface electromyography (EMG) during the following dynamic activities: five single limb squats, five single limb deadlifts, five volleyball jump approaches, five concentric box jumps, and five eccentric box jumps. Relevant injury history and demographics were collected via a self-reported questionnaire. Differences in hip muscle activation were compared between NCAA Divisions I, II, and III as well as identified volleyball position.

4.3. Methods

4.3.1. Participants

This study was initially approved by the Institutional Review Board at North Dakota State University followed by Minnesota State University Moorhead and Concordia College Institutional Review Boards (Appendix A). An informed consent (Appendix B) was read and signed by each participant prior to data collection. Each subject completed a brief demographic and injury history questionnaire (Appendix C). Data collection was conducted at the institution's available athletic facility.

Participants were recruited from three collegiate volleyball teams, each representing a different NCAA Division. Inclusion criteria for this study required the athlete to be a current member on the varsity roster of one of the NCAA Division I, II, or III volleyball teams and be within the ages of 18 to 25 years old. Exclusion criteria included rheumatoid arthritis in the lower extremities and nerve conduction health history including, but not limited to: Amyotrophic Lateral Sclerosis (ALS), Multiple Sclerosis (MS), or Parkinson's disease. Additional exclusion criteria included orthopedic injury which would inhibit the athlete from participating in any of the five movements as determined by the institution's certified athletic trainer. Once recruited, participants were asked to refrain from maximal weight lifting 48 hours prior to data collection. Athletes were also asked not to participate in any sport-related activities the day of data collection.

4.3.2. Participant Preparation

Placement of surface electrodes was found by determining the mid-way point between the distal and proximal muscle tendon of the biceps femoris, gluteus medius, gluteus maximus, and rectus femoris. The skin surface was cleaned with 70% isopropyl alcohol pads, abraded, and cleaned again with 70% isopropyl alcohol pads. In order to conduct a bipolar recording, one electrode was placed on the greater trochanter of the test leg as well as the posterior superior iliac spine, serving as dispersion electrodes to complete the circuit. The dispersion electrodes were not included in surface EMG analysis. Two, 40 millimeter, adhesive silver/silver-chloride bipolar surface electrodes were placed two centimeters apart. The portable transmitter wires were connected to the electrodes which then allowed assessors to ensure proper electrode placement with real-time visual inspection of the EMG signals during manual muscle testing (MMT).

Analog channels were established initially to collect static and dynamic variables at a continuous rate from a single source (Biopac Systems, Inc., Version 4.1; Goleta, CA). Raw signals were collected at a sample rate of 2,000 samples per second and a channel sampling rate was established at 2.000 kilohertz for each of the four muscles. The acquisition length was set at 1,800.00 seconds.

4.3.3. Manual Muscle Testing/ EMG Normalization

Static muscle testing began with the subject's maximal voluntary isometric contraction (MVIC) through MMT to isolate the biceps femoris, gluteus medius, gluteus maximus, and rectus femoris, in the respective order. Raw data were collected using the surface EMG through Biopac Systems, Inc. (Version 4.1; Goleta CA) on the dominant leg as determined by the leg a participant would use to kick a ball. Each MMT was completed two times and held for five seconds. The subject positioning for conducting the MMT mimicked methods as described by Kendall et al.¹³ for the gluteus medius and rectus femoris and Hislop et al.³⁵ for the gluteus maximus and biceps femoris.

4.3.4. Exercise Performance

Following manual muscle testing, subjects performed dynamic exercises to collect EMG recordings of the targeted muscles similar to contractions during volleyball-specific and athletic movements. All exercises were performed in a randomized order in an effort to reduce fatigue and increase validity. In order to reduce risk for participants, each subject performed a brief, standardized warm-up before participation and was given the chance to perform two practice box jumps.

Data collection consisted of the following exercises and their descriptions. Participants completed box jumps on an 18 inch box placed eight inches in front of the participant. Five repetitions of concentric jumps as well as five repetitions of eccentric jumps were completed with minimal verbal cues in order to collect data on their natural muscular contractions during the movement. Each participant also completed five volleyball hit approaches with her natural technique. Along with these three jumping tasks, two additional exercises were selected to mimic commonly used lower extremity rehabilitation exercises in a clinical setting: a single-leg squat and a single-leg deadlift.^{5,6,9} This study followed instructions set by Distefano et al.⁹ to perform the single-leg squat (Figure 6) which allowed the use of verbal cues to keep the subject's knee over the toe to prevent knee valgus force. During performance of the single-leg deadlift (Figure 7), verbal cues were used to keep the knee flexed 30 degrees while reaching down to focus on

hip and trunk flexion, and to keep the knee over the toes. Both of these exercises were performed in five repetitions with 10 seconds of rest between each repetition.



Figure 6. Single-limb Squat

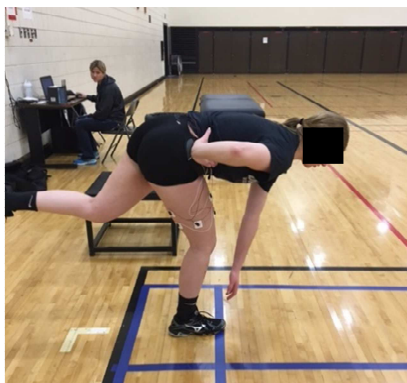


Figure 7. Single-Limb Deadlift

4.4. Statistical Analysis

A total of 20 three-way ANOVA models were estimated to assess the significance of self-reported injury with between-subject factors of NCAA Division, position, and injury status. The dependent variable was muscle activation, as measured by surface electromyography (EMG). Within subject observations were averaged and computed as a percentage of the Manual Muscle Tests (MMT). The significance level was set *a priori* at 5% with a Bonferroni adjustment for multiple comparisons.

4.5. Results

The small sample size should be taken into consideration when reviewing results of this study. With a total of 18 cases, four participants were Division I athletes, nine were Division II athletes, and five were Division III athletes. In this study, 22.2% of participants reported having a history of shoulder injury over her volleyball career, which differs greatly from a previous study that found 60% of female volleyball

athletes reported a shoulder injury.¹ Table 7 illustrates that the 14 non-injured cases demonstrated greater muscle activation except for mean activation for the gluteus maximus during the concentric box jump, the hamstring during the single-limb squat, and the gluteus medius during the concentric box jump as well as the volleyball approach.

As shown in Table 6, the gluteus maximus during the single-leg deadlift was statistically significant ($F[3, 11] = 6.86, p = .013$) for position. Further, descriptive statistics in Table 8 reveals setters showed the greatest activation and defensive players the least during this activity. The other statistically significant effect was for the gluteus maximus during the eccentric jump ($F[3, 11] = 5.855, p = .02$) for position.

Table 9 displays descriptive statistics specific to NCAA Division. Of the 18 participants in this study, four participants reported having shoulder injury. Two of the injuries were reported by Division I athletes and two were reported by Division II athletes. There were no reported shoulder injuries in Division III athletes. The Division III athletes had the greatest mean muscle activation in ten of the cases. Division II athletes had the greatest mean muscle activation in eight cases, and Division I in only two of the cases: gluteus medius activation during the concentric box jump and the volleyball approach.

Exploratory one-way ANOVA models were also estimated separately for each dimension to investigate if the data would suggest any future directions. Given the multiplicity of models, the Type I error is relatively high, so these results should be considered preliminary suggestions, rather than definitive conclusions. The gluteus medius during the eccentric box jump was statistically significant ($F[3, 6] = 163.42, p = .003$) for position where setters showed the greatest activation and defensive players the least. Conversely, the hamstring showed statistically significant activation during the eccentric box jump where defensive players showed the highest activation and setters the least ($F[3, 6] = 6.66, p = .025$).

Table 6. Results of all F-tests including division, position, and injury presence

Table 6		df=11	Division (df=2)		Position (df=3)		Injury (df=1)	
Muscle	Activity	n	F	p	F	p	F	p
Rectus	Up	18	0.694	0.520	1.796	0.206	0.166	0.691
	Squat	18	0.788	0.479	0.758	0.540	0.233	0.639
	Down	18	1.354	0.298	2.487	0.115	0.620	0.448
	Dead	18	0.381	0.692	0.589	0.635	0.094	0.765
	Approach	18	1.448	0.277	2.370	0.126	0.253	0.625
Max	Up	15	0.443	0.657	0.602	0.631	0.223	0.649
	Squat	15	0.502	0.623	0.440	0.731	0.068	0.800
	Down	15	1.499	0.280	5.855*	0.020	0.004	0.949
	Dead	15	2.672	0.129	6.860*	0.013	0.013	0.912
	Approach	15	1.357	0.311	1.542	0.277	0.006	0.939
Ham	Up	17	0.919	0.430	0.343	0.795	1.383	0.267
	Squat	17	0.239	0.792	0.580	0.642	0.054	0.821
	Down	17	1.472	0.275	1.680	0.234	1.016	0.337
	Dead	17	0.715	0.513	0.291	0.831	0.463	0.512
	Approach	17	2.145	0.168	1.715	0.227	1.132	0.312
Med	Up	14	0.674	0.540	0.178	0.908	0.319	0.590
	Squat	14	0.043	0.958	0.424	0.742	0.174	0.689
	Down	14	0.239	0.794	0.042	0.988	0.029	0.869
	Dead	14	1.418	0.304	0.670	0.597	0.002	0.964
	Approach	14	0.574	0.588	0.168	0.915	0.256	0.629

Table 7. Descriptive statistics of the mean EMG activity and standard deviation between non-injured and injured subjects (%MVIC)

Table 7		Noninjured (n=14)		Injured (n=4)	
Muscle	Activity	Mean	SD	Mean	SD
Rectus	Up	130.6	99.0	83.4	29.6
	Squat	115.6	74.6	73.2	25.4
	Down	120.4	85.3	62.4	22.1
	Dead	40.7	46.8	26.3	11.0
	Approach	211.8	204.0	95.0	30.8
Max	Up	92.3	68.0	101.7	81.8
	Squat	62.2	25.6	55.4	12.0
	Down	89.1	77.7	56.0	27.6
	Dead	56.3	35.0	38.5	16.9
	Approach	131.6	98.5	97.1	34.4
Ham	Up	66.7	53.2	47.8	20.1
	Squat	28.8	12.5	32.3	16.6
	Down	54.7	62.3	33.3	11.4
	Dead	33.7	27.4	28.6	12.5
	Approach	146.2	165.0	92.2	46.4
Med	Up	85.1	40.8	189.6	256.5
	Squat	83.0	27.1	98.4	35.5
	Down	61.5	34.8	68.0	49.2
	Dead	71.0	22.6	65.8	7.3
	Approach	116.0	53.5	211.8	237.3

Table 8. Descriptive statistics of mean EMG activity and standard deviation with subjects separated into groups dictated by her playing position (%MVIC)

Table 8		Defense (n=3)		Mid (n=5)		Right (n=8)		Setter (n=2)	
Muscle	Activity	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Rectus	Up	79.3	31.0	190.6	151.0	97.1	34.7	97.2	16.5
	Squat	83.9	17.8	139.4	113.4	96.0	53.1	97.0	11.7
	Down	65.4	8.2	168.7	127.1	90.6	45.4	85.1	5.4
	Dead	14.7	6.0	50.7	59.9	38.7	42.1	34.5	10.0
	Approach	97.6	10.3	324.3	313.6	146.3	88.4	130.4	12.4
Max	Up	62.8	18.6	78.8	43.5	98.7	80.5	145.3	115.8
	Squat	59.0	3.7	67.4	36.1	54.0	15.6	70.2	32.3
	Down	44.8	18.6	58.1	25.1	69.9	72.2	196.4	10.5
	Dead	27.7	23.5	52.3	18.3	42.8	18.6	104.4	56.2
	Approach	85.3	32.8	102.0	60.0	125.9	105.0	187.8	113.7
Ham	Up	39.7	24.6	61.2	36.2	79.1	68.4	49.4	7.3
	Squat	24.4	12.3	28.4	09.7	34.5	16.0	22.1	4.1
	Down	95.0	125.4	41.2	22.6	44.8	42.8	30.5	6.5
	Dead	28.4	12.3	41.4	46.3	32.8	8.3	18.2	4.3
	Approach	25.8	297.5	170.8	158.5	90.4	76.5	79.4	39.1
Med	Up	68.9	12.9	77.2	25.0	156.8	205.1	111.0	103.9
	Squat	79.2	17.0	86.6	33.6	96.9	26.8	68.9	49.2
	Down	43.4	17.8	63.0	41.4	66.7	38.9	73.8	64.7
	Dead	57.6	7.7	73.2	20.9	68.9	12.3	75.6	47.7
	Approach	95.1	5.8	114.0	68.2	182.9	189.2	133.5	100.1

Table 9. Descriptive statistics of mean EMG activity and standard deviation per division (%MVIC)

Table 9		Div 1 (n=4)		Div 2 (n=9)		Div 3 (n=5)	
Muscle	Activity	Mean	SD	Mean	SD	Mean	SD
Rectus	Up	76.2	24.6	127.5	96.9	142.0	111.2
	Squat	68.3	27.5	110.8	87.2	128.2	46.1
	Down	62.0	20.3	110.3	86.5	138.7	89.7
	Dead	19.7	5.4	42.4	44.5	43.1	54.5
	Approach	94.3	34.3	173.8	130.0	280.8	303.2
Max	Up	109.0	74.6	80.3	62.3	131.7	116.1
	Squat	49.3	14.4	64.9	26.8	62.3	8.4
	Down	88.5	79.0	65.8	51.5	129.0	137.7
	Dead	36.6	19.9	61.5	36.3	36.8	10.7
	Approach	95.4	36.4	115.1	69.4	209.0	207.8
Ham	Up	47.2	10.3	79.5	62.2	44.2	24.0
	Squat	24.6	4.4	29.7	9.6	31.9	20.8
	Down	32.9	4.7	71.3	73.2	25.1	15.2
	Dead	23.5	9.1	40.5	32.9	24.5	6.9
	Approach	99.0	46.3	197.8	188.4	49.2	13.2
Med	Up	194.1	254.4	85.9	41.5	59.8	NA*
	Squat	83.1	46.2	88.9	23.8	91.2	NA*
	Down	64.9	50.6	66.3	34.4	30.8	NA*
	Dead	56.1	11.1	76.1	20.3	63.1	NA*
	Approach	214.5	237.2	117.0	54.2	99.2	NA*

*Due to equipment malfunctions, this study was only able to obtain gluteus medius activation data for one participant from Division III athletes. Therefore, there is no standard deviation.

4.6. Discussion

Shoulder pain and dysfunction are the third most common overuse pathologies among competitive volleyball players and can result from repeated overhead contact.¹⁻³ There is also evidence female volleyball players have weaker hip muscles, higher quadriceps activity, and reduced hamstring activity during athletic movements.⁴ With reliable equipment such as surface EMG, researchers have a pathway of exploring the activation patterns in the hip musculature. This study used EMG to investigate hip muscle activation of collegiate women's volleyball athletes during five dynamic movements. The secondary purpose was to compare hip muscle activation between college volleyball athletes who reported previous shoulder injury and those who have not experienced an injury.

All four of the reported shoulder injuries in this study played the position of hitter. Three of the four reported shoulder injuries were from outside hitters and the other was a middle hitter. When investigating

hip muscle activation specific to position (Table 8), the middle hitters had the greatest mean rectus femoris activation for all five activities: eccentric and concentric box jumps, single-limb squats and deadlifts, and the volleyball approach. The right side hitters had comparable mean rectus femoris activation to the setters but greater than the defensive specialists. The defensive specialists had the greatest mean muscle activation in only one case, the right side hitters in five cases, and the middle hitters in seven cases. Although this study does not have a large enough sample size to directly correlate quadriceps-dominant muscle activation to shoulder injury, several previous studies have confirmed quadriceps-dominance in female athletes to an increased risk of anterior cruciate ligament (ACL) injury.^{4,37,38} As clinicians, it is important to recognize this relationship in order to implement appropriate rehabilitation and injury prevention programs to reduce the risk of injury.

Previous studies have compared various hip exercises in order to determine which are most effective for isolating specific muscles. The single-limb squat was ranked third by Boren et al.⁶ in effectively activating the Gluteus Medius and ranked fifth in activating the Gluteus Maximus when compared to 21 other common exercises. In the current study, results of non-injured athletes indicate the single-limb squat ranked higher than the single-limb deadlift for Gluteus Maximus and Gluteus Medius activation (refer to Table 7). Distefano et al.⁹ ranked the single-limb squat second for Gluteus Medius mean EMG signal amplitude and first for the Gluteus Maximus mean EMG signal amplitude. Despite using the exact same exercise performance and verbal cues as the study by Distefano et al,⁹ the non-injured athletes of the current study showed the single-leg squat ranked much lower for Gluteus Maximus activation.

When investigating professional baseball pitchers, where the relationship of hip muscle activation and the incidence of shoulder injury has been studied more extensively, greater gluteal activation and lumbopelvic control related to a consistently higher velocity pitch as well as a more successful pitching season.³⁶ An additional study on baseball pitchers concluded gluteus maximus activation is vital in eccentrically controlling deceleration of hip flexion and deceleration of the arm during the follow-through phase of the pitching motion.³⁹ Without the eccentric control in the hips, pitchers would have less stability and control when decelerating the arm. With an estimated 100 pitches per game and roughly 33 games per season as a starting pitcher, proper gluteal muscle activation during each phase of the pitch is

required to reduce shoulder and elbow injury over time.³⁹ Comparing these numbers to the sport of volleyball, where an elite athlete could perform an estimated 40,000 overhead hits per season,³ adequate gluteal activation could be even more influential in reducing shoulder injuries.

Previous researchers have attempted to connect hip muscle activation in female athletes to risk factors for ACL injury. A study by Zebis et al.³⁸ found female athletes had disproportionately greater EMG activation of the biceps femoris than males. This dominantly lateral muscle activation potentially opens the medial joint space during landing and lateral athletic movements.³⁸ In agreement with a study by Myer et al.,⁴⁰ the subsequent dynamic valgus increases the risk of ACL injury. Our study found defensive players had significant hamstring activation during the eccentric box jump where defensive players showed the highest activation and setters the least ($p = .025$). Due to demands of the position, defensive players do not perform as many jumping activities as players in the hitter or setter position.

Although research surrounding ACL injury is plentiful, many of the findings suggest different casual relationships of risk factors for ACL injury in female athletes. In contrast to the findings by Zebis et al.,³⁸ a study by Barber-Westin et al.⁴ concluded female athletes have quadriceps-dominant muscle activation in relation to the hamstrings. When considering the demands of the hitter position, the rectus femoris contraction delivers an anterior force at the tibial tuberosity. This force tightens and loads the ACL.³⁷ Therefore, an athlete with quadriceps-dominant muscle activation and lower hamstring activation during the box jumping and approach activities could be at a higher risk for ACL injury. In the current study, this observation was found in the middle and right side hitters, where these positions showed a significantly higher quadriceps activation than hamstring activation. Furthermore, a four year prospective study concluded neither hamstring nor quadriceps strength, including hamstring-to-quadriceps strength ratio, is predictive of ACL injury,²⁹ which conflicts with both previously discussed studies. Inconsistencies within the existing literature surrounding hamstring and quadriceps activation as ACL risk factors for female athletes provides an opportunity for future research investigating both hamstring and quadriceps activation during dynamic movement to assist ACL injury prevention and rehabilitation protocols.

Overall findings of this study conclude position is a statistically significant factor for the eccentric jump and the single-limb deadlift activities for the Gluteus Maximus. As illustrated in Table 8, defensive players had the greatest mean muscle activation in only one case, right side hitters in five, and setters

and middle hitters each in seven cases. When comparing our findings across NCAA Division, Division III athletes had the highest muscle activation. Division II athletes were highest in eight activities, and Division I in only two of the activities.

These findings stem from a pilot study that lays the foundation for further research. There are no previous studies investigating the relationship of hip muscle activation and the incidence of shoulder injury in volleyball athletes, as well as no previous studies investigating the differences in muscle activation across NCAA Division. These relationships are important in discovering the role of muscle activation and the kinetic chain during sport-specific activities of these athletes. The lack of research in this area leads to an absence of evidence-based injury prevention and rehabilitation protocols for volleyball athletes and potentially increases their risk for injury.

4.7. Limitations

The limitations of this research study may have affected the outcomes. First, surface EMG has been shown to produce variable data that may cause chance results. EMG has been shown to be a reliable and valid instrument for evaluating muscle activation; however, there are differences in muscular anatomy between each subject.⁵⁻⁸ Without access or feasibility of taking radiographic imaging, slight differences in muscle activation may have occurred based on electrode placement.⁷ Although the use of maximal voluntary isometric contractions (MVIC) to normalize EMG has been supported by previous research^{5,7,9-11}, there has not been an agreement on the most accurate normalization method for dynamic assessments. MVIC requires participants to reach their full muscle contraction potential which may not have actually occurred. In short, surface EMG is a reliable and valid tool to record muscle activation, and in consideration of the limitations, researchers took precautions to avoid alterations in electrode application that could have altered results.

Range of Motion (ROM) deficits have been shown to produce additional demands on the shoulder joint that lead to injury. Studies have previously investigated ROM in the hip and shoulder joints and have concluded deficits can lead to increased injury.¹⁵⁻¹⁷ One study found that the relationship between dominant hip extension and shoulder external rotation was significant both for baseball pitchers and nonpitchers, or positional players, with a history of shoulder injury.¹⁷ Due to previous confirmation

that ROM influences incidence of injury, this study did not collect any additional information on participants' hip or shoulder ROM.

Additionally, this study relied on self-reported history of shoulder injuries throughout a participant's volleyball career rather than clinical diagnoses. Although the demographics and health history questionnaire that were used in this study specified that injuries must have been diagnosed by a healthcare professional, some responses may not have accurately reflected pathologies. With this in mind, there might have been slight variability in reports of volleyball related shoulder injury.

Finally, only three teams were included in this study. There was a limited amount of active participants during the spring season which limited the amount of overall participants in the study. Unfortunately, the small sample size gave only a glimpse of volleyball related shoulder injuries and hip muscle activation. Due to these limitations, clinician discretion should be used when making recommendations based off the evidence produced in this research. These limitations should be considered before conducting future research regarding hip muscle activation and volleyball related shoulder injuries.

4.8. Conclusions

Based on a limited population as well as few self-reported should injuries, this research reports only a few differences in muscle activation when compared across playing position. There were no significant differences in mean hip muscle activation when compared across NCAA Division. The results should serve as a pilot study for future research specific to volleyball players in order to provide evidence-based recommendations regarding the relationship between lower extremity muscle weakness and incidence of shoulder injuries. Future studies stemming from this data would benefit from an increased sample size in order to observe a larger and more accurate picture of the collegiate women's volleyball athlete population.

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APPENDIX A: NDSU INSTITUTIONAL REVIEW BOARD APPROVAL



April 19, 2017

Dr. Katie Lyman
Health, Nutrition & Exercise Sciences

IRB Approval of Protocol #HE17214, "The Relationship of Hip Muscle Activation and the Incidence of Shoulder Injury in Collegiate Women's Volleyball Athletes"
Co-investigator(s) and research team: Jessica Kinder

Approval period: 4/19/2017 to 4/18/2018
Continuing Review Report Due: 3/1/2018

Research site(s): NDSU, MSUM, Concordia Funding Agency: n/a
Review Type: Expedited category # 4
IRB approval is based on the revised protocol submission (received 4/13/2017).

Additional approval from the IRB is required:

- o Prior to implementation of any changes to the protocol (Protocol Amendment Request Form).
- o For continuation of the project beyond the approval period (Continuing Review/Completion Report Form). A reminder is typically sent approximately 4 weeks prior to the expiration date; timely submission of the report the responsibility of the PI. To avoid a lapse in approval, suspension of recruitment, and/or data collection, a report must be received, and the protocol reviewed and approved prior to the expiration date.

Other institutional approvals:

- Research projects may be subject to further review and approval/disapproval.

A report is required for:

- o Any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence (Report of Unanticipated Problem or Serious Adverse Event Form).
- o Any significant new findings that may affect risks to participants.
- o Closure of the project (Continuing Review/Completion Report Form).

Research records are subject to random or directed audits at any time to verify compliance with human subjects protection regulations and NDSU policies.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

Sincerely,

Digitally signed by Kristy Shirley
DN: cn=Kristy Shirley, o=NDSU,
ou=Institutional Review Board,
email=kristy.shirley@ndsu.edu, c=US
Date: 2017.04.19 10:53:58 -05'00'

Kristy Shirley, CIP, Research Compliance Administrator

For more information regarding IRB Office submissions and guidelines, please consult www.ndsu.edu/irb. This Institution has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

INSTITUTIONAL REVIEW BOARD

NDSU Dept 4000 | PO Box 6050 | Fargo ND 58108-6050 | 701.231.8995 | Fax 701.231.8098 | ndsu.edu/irb

Shipping address: Research 1, 1735 NDSU Research Park Drive, Fargo ND 58102

NDSU is an EO/AA university.

APPENDIX B: MINNESOTA STATE UNIVERSITY MOORHEAD INSTITUTIONAL REVIEW BOARD

APPROVAL

Date:	April 19th, 2017
Principle Investigator:	Ronda Peterson
Co-Investigator(s):	Jessica Kinder
Title of Study:	The Relationship of Hip Muscle Activation and the Incidence of Shoulder Injuries in Collegiate Volleyball Athletes

Thank you for submitting your IRB Exempt Status Proposal. Your proposal has been reviewed and approved **per IRB Approval of Protocol #HE17214 at NDSU**. You may proceed with your study after April 19th, 2017.

The IRB will not conduct subsequent reviews of this protocol unless changes to the protocol occur. Any changes to the protocol will require a formal application to, and approval of, the IRB prior to implementation of the change. IRB applications are available on the Minnesota State University Moorhead IRB webpage: <https://www.mnstate.edu/irb/>

Best of Luck to you with your research!

Dr. Lisa I. Karch
PhD, LPC, NCC, NCSC
Director of Graduate Studies

218-477-2699
lisa.karch@mnstate.edu

APPENDIX C: CONCORDIA COLLEGE MOORHEAD INSTITUTIONAL REVIEW BOARD APPROVAL

Office Institutional Review Board

Approval of Protocol Number: 2017.0419

*Please refer to this assigned protocol identification number
in any further correspondence with the IRB regarding this project.*

Expiration Date: April 19, 2018

Dr. Katie Lyman
Jessica Kinder

April 19, 2017

Dear Katie and Jessica:

The Concordia College Institutional Review Board (IRB) recognizes the approval of the protocol application 2017.0419 for your study, "The Relationship of Hip Muscle Activation and the Incidence of Shoulder Injury in Collegiate Women's Volleyball Athletes". This approval remains in effect for one year from the date of the approval. If the study continues after the expiration date of the approval, you will need to reapply for Concordia IRB approval by submitting re-application materials. Standard IRB regulations must be followed regarding modifications to the study protocol and incidents of concern regarding study subjects. Please notify us of any changes in the status of the approval.

Best wishes for a successful study.

Sincerely,

Cindy Larson-Casselton
Chair, Institutional Review Board

APPENDIX D: INFORMED CONSENT

NDSU North Dakota State University

Health, Nutrition, and Exercise Sciences
PO Box 6050, Dept. 2620
Fargo, ND 58108-6050
(218)443-6446

Title of Research Study: The Relationship of Hip Muscle Activation and the Incidence of Shoulder Injury in Collegiate Women's Volleyball.

This study is being conducted by: Principal Investigator- Katie Lyman, HNES, Dept 2620; 231-8208, katie.lyman@ndsu.edu.

Why am I being asked to take part in this research study?

You are being asked to participate in this study because you are a collegiate volleyball player between 18 and 25 years of age.

You should not participate in this study if you have experienced any items listed below or reported them on your Demographics Questionnaire:

- Any current lower extremity injury (including the hip) that has been diagnosed within three months of the data collection period, which prevents you from playing volleyball.
- Any recent orthopedic surgical procedures within the past six months.
- Diagnosed Rheumatoid Arthritis and/or other nerve conduction health history including but not limited to: amyotrophic lateral sclerosis (ALS, Lou Gehrig's disease), Multiple Sclerosis (MS), or Parkinson's disease.

What is the reason for doing the study? The purpose of this study is to determine if there is a relationship between static and/or dynamic hip strength and shoulder injury in collegiate volleyball players. By determining if there is a relationship between these two variables, we can provide support for strengthening activities for collegiate volleyball players to perform in order to decrease the likelihood that they will sustain an injury.

What will I be asked to do? OR What information will be collected about me? You will be asked to visit your respective institution's athletic facility for one testing session that will take approximately one hour. You will be asked to complete a number of forms and provide a few pieces of demographic information.

Preparation for Testing:

After filling out all necessary forms, small electrodes (about the size of a quarter) will be placed in specific spots (upper legs/buttocks) to measure the activity of specific muscles. We may have to shave small portions of these areas to make sure the electrode sticks to your skin. Once the electrodes are in place, we will ask you to contract your muscles one by one to ensure the electrodes are on the correct muscles. Each contraction will last about 6 seconds with about a minute rest between each contraction. Self-adhesive stickers will be placed to mark the placement of the electrodes in case they move during participation.

Exercise Testing:

After we record data from each of the four muscles we will have you jog for three minutes at a pace which you feel comfortable for a warm-up. You will then do 30 seconds of jumping jacks, high-knee running, and butt-kick running, followed by 15 jumping jacks, 15 tuck jumps, and 15 body weight squats. After the warm-up we will have you perform a maximum of two practice box jumps on the 18 inch box. Following, you will perform five jumps up and five jumps down for data collection. You will carefully step off the box

and restart each time. You will have a two minute rest between jumping up and jumping down. Then, you will perform five volleyball hit approaches with your natural technique. Next, you will perform five single-leg squats with 10 seconds of rest in between. Lastly, you will perform five single-leg deadlifts with 10 seconds of rest in between. We will record muscle activity for short increments while you exercise with the technique you would use on a normal training day.

**Please note: If you are instructed by a health care provider to discontinue your participation, please do not continue in this study.*

Where is the study going to take place, and how long will it take? This study will occur in a one session event at your respective institution's athletic facility. It will take approximately one hour per participant.

What are the risks and discomforts?

It is not possible to identify all potential risks throughout research procedures, but the researchers of this study have taken reasonable safeguards to minimize any known risks to you.

Throughout the muscle contractions you may feel slight discomfort in your muscles however because of your background of collegiate athletics it is unlikely that these short contractions will cause discomfort.

The adhesive on the electrode pads used to collect muscle contraction information could cause slight skin irritation. The skin will be cleaned and prepared before application to reduce this risk.

You may stop activity or withdraw from this research study at any time throughout the data collection period.

What are the benefits to me? You are not expected to get any benefit from being in this research study.

What are the benefits to other people? Beyond the advancement of scientific knowledge, this research may provide data to support specific causes of volleyball related injury. Knowledge of these specific causes will assist collegiate volleyball players with a better idea of how to prevent injuries.

Do I have to take part in the study? Your participation in this research is your choice. If you decide to participate in the study, you may change your mind and stop participating at any time without penalty or loss of benefits to which you are already entitled.

What will it cost me to participate? Other than your personal time, there are no costs to participation.

What are the alternatives to being in this research study? Instead of being in this research study, you can choose not to participate.

Who will see the information that I give?

We will keep private all research records that identify you. Your information will be combined with information from other people taking part in the study. When we write about the study, we will write about the combined information that we have gathered. We may publish the results of the study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key.

At the end of this study, all data will be destroyed.

If you withdraw before the research is over, your information will be removed at your request, and we will not collect additional information about you.

Will I receive any compensation for taking part in this study?

NCAA rules and policies dictate the compensation we can give for athletes partaking in this study. NDSU and MSUM athletes will receive \$10 for their participation while Concordia athletes will receive no compensation.

What happens if I am injured because of this research?

If you receive an injury in the course of taking part in the research, you should contact Katie Lyman at the following phone number; 701-231-8208 or Jessica Kinder at 847-224-9562. In case of injury, you are encouraged to seek care from your medical professional. The co-investigators are not able to provide medical treatment; they are only able to answer questions regarding the components associated with research (i.e. definition of injury). Payment for this treatment must be provided by you and your third party payer (such as health insurance or Medicare). This does not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a result of your participation in this research.

What if I have questions?

Before you decide whether to accept this invitation to take part in the research study, please ask any questions that might come to mind now. Later, if you have any questions about the study, you can contact the researcher, Katie Lyman at 701-231-8208 or Katie.lyman@ndsu.edu.

What are my rights as a research participant?

You have rights as a participant in research. If you have questions about your rights, or complaints about this research, you may talk to the researcher or contact the NDSU Human Research Protection Program by:

- Telephone: 701.231.8995 or toll-free 1-855-800-6717
- Email: ndsu.irb@ndsu.edu
- Mail: NDSU HRPP Office, NDSU Dept. 4000, PO Box 6050, Fargo, ND 58108-6050.

The role of the Human Research Protection Program is to see that your rights are protected in this research; more information about your rights can be found at: www.ndsu.edu/irb

Documentation of Informed Consent:

You are freely making a decision whether to be in this research study. Signing this form means that

1. you have read and understood this consent form,
2. you have had your questions answered, and
3. you have decided to be in the study.

You will be given a copy of this consent form to keep.

Your signature

Date

Your printed name

Signature of researcher explaining study

Date

Printed name of researcher explaining study

APPENDIX E: HEALTH HISTORY AND DEMOGRAPHICS QUESTIONNAIRE

Demographics Questionnaire

Note: Identifying information will be kept private. No one will have access to your responses except for the researchers. Your answers will be destroyed after data collection is complete.

Name:

Age:

College:

1. What year in school are you?
 - a. Freshman
 - b. Sophomore
 - c. Junior
 - d. Senior
 - e. 5th year Senior

2. Are you right or left hand dominant?
 - a. Right
 - b. Left
 - c. Unsure

3. Are you currently cleared by a team physician and certified athletic trainer to fully participate in all team activities?
 - a. Yes
 - b. No

4. How long have you participated in competitive volleyball?
 - a. Less than a year
 - b. 1-3 years
 - c. 4-7 years
 - d. 8 or more

5. What position do you play?
 - a. Outside Hitter
 - b. Right side hitter
 - c. Middle hitter
 - d. Libero
 - e. Defensive specialist
 - f. Setter

6. Do you work with a certified strength and conditioning specialist or coach as part of your volleyball schedule?
 - a. Yes
 - b. No

7. Have you ever experienced a shoulder injury diagnosed by a health care professional?
 - a. Yes
 - b. No

If yes, please answer the following:

Have you ever been diagnosed by a health care professional with (please circle R/L):

Labral tear (R/L) date: _____

Impingement (R/L) date: _____

Fracture (R/L) date: _____

Biceps Tendonitis (R/L) date: _____

Rotator cuff tear (R/L) date: _____

AC Sprain/Separation (R/L) date: _____

Dislocation (R/L) date: _____ Anterior/Posterior/Inferior? (Circle One)

Subluxation (R/L) date: _____

Multi-Direction Instability (R/L) date: _____

8. Have you had any surgical procedures in the past six months?
- a. Yes
 - b. No

If yes, please list: _____

APPENDIX F: WORD OF MOUTH SCRIPT

NDSU North Dakota State University
Health, Nutrition, and Exercise Sciences
Department # 2620, PO Box 6050
Fargo, ND 58108-6050
218-443-6446

Word-of-Mouth Recruitment Script

My name is Jessica Kinder, and I am a Certified Athletic Trainer in the Master of Science Program in the Department of Health Nutrition, and Exercise Sciences at North Dakota State University. I would like to invite you to participate in my IRB-approved research study titled 'The Relationship of Hip Muscle Activation and Incidence of Shoulder Injury in Collegiate Volleyball Players'. Volleyball has become an increasingly popular collegiate sport around the world and as the number of athletes increase, the number of shoulder injuries reported has also increased. The numerous variables that effect volleyball related injury rates make it important to track athletes over time in order to investigate if hip muscle activation habits have a possible contribution in rates of shoulder injury.

If you choose to participate in this study, you will report to only one data collection session that should last approximately one hour. During that session, you will have electrodes placed on four muscles around your hip and you will be asked to contract those muscles to your full capability with specific instructions provided. You will also be asked to perform box jumps, volleyball hit approaches, a single-leg squat, and a single-leg deadlift following a brief warm-up. Although you may feel slight discomfort from the maximal muscle contraction, the discomfort should be minimal and you should be able to continue your regular training immediately following. We, as researchers, will be available to you anytime you may have questions or concerns throughout the process.

I am in need of approximately 30 individuals from NCAA Division I, II and III volleyball teams, between the ages of 18- and 25-years-old. In order to participate, you must be a current member on the roster and are able to participate in your sport activities as determined by a certified athletic trainer. You may not participate in the study if you have suffered from: (1) a current lower extremity injury (including the hip) or significant pain; (2) Any orthopedic surgery in the past 6 months; (3) Any diagnosed Neurological disease or impairment; (4) Reported allergies to electrode pads or adhesive tapes.

To compensate you for your time and participation in this study, you will receive \$10.00, regardless of your completion of the study.

If you have further questions or wish to participate in this study, please contact me at jessica.kinder@ndsu.edu or 847-224-9562