This is to certify that the
thesis entitled

Electromyographic Analysis of Shoulder Muscle Activity During
Two Volleyball Spike Mechanics

presented by

Katie J. Hanson

has been accepted towards fulfillment
of the requirements for the

Master of Science degree in Kinesiology

Tracey Covassin
Major Professor's Signature

April 20, 07
Date

ELECTROMYOGRAPHIC ANALYSIS OF SHOULDER MUSCLE ACTIVITY DURING TWO VOLLEYBALL SPIKE MECHANICS

By

Katie J. Hanson

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTERS OF SCIENCE

Department of Kinesiology

2007

Success

"To laugh often and much,
to win the respect of
intelligent people and the
affection of children,
To earn the
appreciation of honest
critics and endure the
betrayl of false friends
To appreciate beauty,
to find the best in
others!

To leave the world a bit
better, whether by a
healthy child, a garden
patch or a redeemed
social condition,
to know even one life has
breathed easier because
you have lived.
This is to have
succeeded."
-Ralph Waldo Emerson

ABSTRACT

ELECTROMYOGRAPHIC ANALYSIS OF SHOULDER MUSCLE ACTIVITY DURING TWO VOLLEYBALL SPIKE MECHANICS

By
Katie J. Hanson

To date, no researchers have compared shoulder muscle activation patterns in two separate volleyball attack methods. Therefore, the purpose of this study was to examine muscle activation patterns of the shoulder complex and gender differences in two separate volleyball attack methods. A total of 29 subjects (15 male, 14 female) volunteered for the study. The dependent variables were the infraspinatus, supraspinatus, teres minor, pectoralis major, anterior deltoid, and the biceps brachii. Subjects were randomized and performed five volleyball attacks for method 1 and five volleyball attacks for method 2. Results for the MANOVA revealed significant differences for both technique ($p = .005$) and gender ($p = .006$). The interaction between technique and gender was not significant ($p = .979$) nor was swing preference ($p = .152$). It is recommended that health care providers strengthen the musculature about the shoulder complex in order to potentially prevent injury.

ACKNOWLEDGEMENTS

The completion of this thesis would not have been possible without the help of so many people. Most important, I would like to thank my thesis committee for all of their help and ideas. This is a subject I am passionate about, and I appreciate the guidance you have given me throughout the year.

Tracey Covassin allowed me to graduate this year! With all of your other research and classes, you always found time to assist with data collection, proofread another chapter, and talk on the phone for hours about the statistics. Thank you for everything!

In order to attempt this thesis, I needed to have the expertise of a physician to guide me through the fine-wire needle EMG. Dr. Barinder Mahal went above and beyond the call of duty by spending over 35 hours helping me collect data. This thesis would not have been possible him.

Thank you to Dr. Powell for offering me a position and the opportunity to study at Michigan State University.

Thank you to Sue Brand who acted as my technology support! So many things would have taken so many more hours without your assistance. Thank you for always understanding what I am trying to accomplish!

Kim Sieve and I went through the entire thesis process together! Thank you for always understanding!

Tom Hanson and Jeff Child out of North Dakota State University acted as after hour statistics consultants. Thank you for taking time out of your already busy schedules to explain the results of my study!

My parents Alan and Mary have always encourage me to follow my dreams and pushed the importance of education. Without your love and support through all of the college changes, thesis topic changes, and tears, I would not have my Master's Degree.

My fiancée has provided many roles throughout this process. He began as a phone consultant in Minnesota and then found himself immersed in the study! Thank you for assisting with data collection, data entry, photography, and proofreading! Whether you admit it or not, I know you learned a lot about the shoulder and volleyball. Thank you for providing the emotional support needed to succeed in graduate school.

Last but certainly not least I need to thank the Michigan State Club Volleyball teams. 31 of these athletes were willing to give up their time in order to help me graduate. I am graduating because of all of you!

TABLE OF CONTENTS

Electromyographic Analysis of Shoulder Muscle Activity During Two Volleyball Spike Mechanics

Chapter 1

INTRODUCTION

Overview of the Problem

Volleyball has become an extremely popular participation sport worldwide, and it is estimated to involve 800 million participants (Briner & Kacmar, 1997). Volleyball ranks eighth in the number of injured athletes between the ages of 14- and 20-year-olds with an injury rate of 3.0 per 100 hours (Verhagen, Van der Beek, Bouter, Bahr, & Van Mechelen, 2004). Although the incidence of acute injuries in volleyball is low, overuse injuries involving the shoulder is high, potentially contributing to impaired performance (Bahr & Reeser, 2003). It is estimated that shoulder injuries comprise up to 23% of total injuries incurred by volleyball players (Rokito, Jobe, Pink, Perry, & Brault, 1998).

Over the past decade, researchers have concluded that overhead activities create a mechanism of injury due to the repetitive high velocity stress placed on the glenohumeral joint (Witvrouw, Cools, Lysens, Cambier, Vanderstraeten, Victor, Sneyers, & Walravens, 2000). Due to the lack of boney stability, the shoulder relies on surrounding musculature to maintain dynamic joint control. Specifically, rotator cuff muscles (supraspinatus, infraspinatus, teres minor, subscapularis) play an active role in maintaining stability at the glenohumeral joint. One particular injury that previous researchers have studied is infraspinatus atrophy which contributes to shoulder pain in volleyball attackers (Witvrouw et al., 2000; Montagna & Colonna, 1993; Feretti, De Carli, & Fontana, 1998). While Witvrouw et al. (2000) suggests this muscle atrophy appears only isolated to the infraspinatus muscle, the cause of this hypotrophy is unclear to researchers.

With the growing number of volleyball athletes and the early specialization within the sport, understanding the cause of shoulder pain is crucial for all athletic trainers, physicians, and coaches. By comparing and contrasting the muscle activation patterns in two biomechanical methods to attacking, it may be possible to determine the most effective and safest method. As a result, coaches will be allowed to select the most appropriate biomechanical method. Thus, certified athletic trainers and strength and conditioning specialists will be able to develop the correct musculature in volleyball attackers.

To date, no researchers have compared shoulder muscle activation patterns in two separate volleyball attack methods. The majority of men finish their attack motion with their dominant arm on the contralateral aspect of the body similar to the motion of a baseball pitch. However, female volleyball players are coached at a young age to complete their follow-through on the same side as the dominant arm potentially causing the rotator cuff muscles to have an increase in eccentric load. This increase in eccentric load may potentially lead to an increase in infraspinatus injury. This study will examine muscle activation patterns at the shoulder during two different attack methods.

Significance of the Problem

The glenohumeral joint is characterized by its mobility and large range of motion. The rotator cuff is a group of muscles consisting of the supraspinatus, infraspinatus, teres minor, and subscapularis, which act as dynamic stabilizers for the humeral head on the glenoid fossa. If any of the static or dynamic stabilizers are injured by trauma or overuse, the shoulder is at increased risk for injury.

Although numerous researchers have examined atrophy of the rotator cuff muscles (Antoniadis et al., 1996; Bayramoglu et al., 2003; Cummins et al., 2004; Feretti et al., 1998; Kugler et al., 1996; Sandow & Ilic, 1998; Wang & Cochrane, 2001b; Witvrouw et al., 2000), considerable debate still remains as to the exact cause. Researchers have conducted studies using a variety of tools including isokinetic testing in order to establish profiles of strength and mobility (Wang, Macfarlane, & Cochrane, 2000), visual inspection, and electromyography (EMG). Isokinetic testing does not allow for precise movements of the entire shoulder complex and visual inspection will not indicate the exact nature of a problem. To date, no studies have examined two separate mechanics for attacking the volleyball. Therefore, the aim of this study is to examine muscle activation patterns of the shoulder complex in two biomechanical methods used to attack a volleyball.

Statement of the Purpose

The focus of this study was to examine the muscle activation patterns in the shoulder complex during two methods of a volleyball attack. The primary purpose was to determine if the rotator cuff muscles produced an increase in shoulder muscle activation when comparing two volleyball attack methods. For this research, method 1 was characterized with a follow-through on the ipsilateral side as the dominant arm. Method 2 had a follow-through ending on the contralateral side as the dominant arm; this method is similar to an overhand baseball pitch technique. A secondary purpose was to determine if there were gender differences between the two methods. The third purpose was to identify an interaction between attack method and gender. The final purpose was to determine preferred attack method for each subject. The following hypotheses were tested:

H1: The traditional method [method 1] of attacking a volleyball will produce a higher motor unit activation in the rotator cuff compared to the non-traditional method [method 2].

H2: Muscle activation of the shoulder girdle will not differ between men and women, regardless of which method is used.

Definitions

<u>Attack Method 1</u>- the dominant arm will start horizontally adducted so that the fingers are near the opposite Anterior-Superior Iliac Spine (ASIS). The subject will then begin the wind-up phase by horizontally abducting and flexing the glenohumeral joint until the glenohumeral joint comes to 90 degrees of abduction and external rotation and

the elbow at 90 degrees of flexion. The cock phase maintains glenohumeral abduction and elbow flexion and adds glenohumeral horizontal abduction and continued external rotation. The attack phase will start with glenohumeral abduction and internal rotation, elbow extension, and wrist flexion. The follow-through begins with eccentric external rotation along with eccentric glenohumeral flexion while resuming 90 degrees of abduction and flexion of the elbow finally resting at glenohumeral internal rotation of the glenohumeral joint and extension of the elbow.

Attack Method 2- the start, wind-up, cock, and attack phases of method 2 are the exact same as attack method 1. However, for attack method 2, eccentric glenohumeral flexion is combined with eccentric horizontal adduction and minimal internal rotation. The dominant arm finishes at the contralateral ASIS.

Electromyography (EMG)- uses a recording device that measures the electrical impulse of the muscle in order to quantify and qualify contraction or motor unit recruitment. EMG may be performed with electrode contact on the surface of the skin or with fine needles placed into the muscle belly.

Polymeric- the process of muscular activity, which involves the eccentric loading of a muscle, followed by an immediate concentric unloading

Rotator Cuff Muscles- a musculotendonous structure about the capsule of the glenohumeral joint, including the 1) supraspinatus, 2) infraspinatus, 3) teres minor, and 4) subscapularis

Limitations

1) Due to research laboratory space available, participants were not able to provide an attack on an actual volleyball.
2) Research participants performed the upper-body portion of the attack with limited lower-body involvement.
3) Small population size between genders.

CHAPTER 2

REVIEW OF LITERATURE

Overview of Volleyball

With 800 million participants in the world of volleyball today (Briner and Kacmar, 1997), researchers continue to study both the acute and chronic injuries associated with this sport. Overall injury incidence in the sport of volleyball has been estimated to range from as low as 2.6 per 1000 hours to as high as 4.2 per 1000 hours. (Verhagen, Van der Beek, Bahr, & Mechelen, 2004; Aagaard, Scavenius, Jorgensen, 1997). Aagaard et al. (1997) even went so far as to discuss the injury rate in volleyball to be comparable to sports such as European handball and ice hockey. Most researchers agree that acute injuries such as ankle sprains and finger injuries represent the vast majority of injuries associated with the sport of volleyball. However, chronic injuries to the shoulders, knees, and back are also associated with this sport. It has been reported that overuse shoulder injuries comprise 23% of all injuries in volleyball players (Rokito, Jobe, Pink, Perry, & Brault, 1998).

The first reports of suprascapular nerve entrapment syndrome date back to 1959 (Thompson & Kopel, 1959). Since the original diagnosis, several researchers have studied the population in which this injury can occur. In a study by Antoniadis, Richter, Rath, Braun, and Moese (1996) involving 28 cases of documented suprascapular nerve entrapment and infraspinatus atrophy, the authors indicated that half of all patients whose injury was due to athletic competition were volleyball players. Furthermore, researchers have discovered that as many as 20% of elite volleyball players show clinical signs of isolated infraspinatus atrophy (Feretti, De Caril, & Fontana, 1998). Studies indicate that muscle atrophy seems to be isolated to the infraspinatus due to the anatomical position of the rotator cuff and nerve innervation in the shoulder complex (Montagna & Colonna, 1993; Witvrouw, Cools, Lysens, Cambier, Vanderstraeten, Victor, Sneyers, & Walravens, 2000). Therefore, an in depth analysis of injuries to the shoulder complex during a volleyball attack is warranted.

Anatomy

"The glenohumerual joint exhibits the greatest amount of motion of any articulation in the human body; consequently little inherent stability is provided by its osseous configuration" (Reinold, Wilk, Fleisig, Zheng, Barrentine, Chmielewski, Cody, Jameson, & Andrews, 2004, p. 385). The rotator cuff musculature acts as a stabilizer by keeping the humeral head into the concave shape of the glenoid fossa (Reinold et al., 2004). In order to elevate the humerus, forces from the supraspinatus and deltoid occur in one movement and subscapularis, infraspinatus, and teres minor in the next (David, Magarey, Jones, Dvir, Turker, & Sharpe, 2000). Work, leisure, and sporting activities that involve raising the arm increase the possibility of developing shoulder pain and injury to the shoulder complex (Brox, Roe, Saugen, Vollestad, 1997).

Branching off from the brachial plexus at the fifth and sixth cervical roots is the suprascapular nerve. As the nerve passes laterally through the posterior neck, it travels under the trapezius to arrive at the supraspinatus muscle. The suprascapular nerve then exits the supraspinatus and travels along the spinoglenoid notch to gain entrance into the infraspinatus musculature. This nerve is held against the scapula and muscle belly of the infraspinatus (Witvrouw, Cools, Lysens, Cambier, Vanderstraeten, Victor, Sneyers, & Walravens, 2000; Feretti, De Carli, & Fontana, 1998; Antoniadis, Richter, Rath, Braun, & Moese, 1996). It is injury to the spinoglenoid notch that causes a paralysis in the terminal branch and thus affects the infraspinatus muscle and not the supraspinatus muscle (Feretti et al.; Sandow & Ilic, 1998).

The infraspinatus has been studied at length due to the muscle atrophy observed by many researchers. This muscle originates on the medial aspect of the infraspinatus fossa just below the spine of the scapula and inserts posteriorly on the greater tubercle of the humerus (Thompson & Floyd, 2004). The infraspinatus muscle acts as an external rotator of the glenohumeral joint and also assists with horizontal abduction, extension, and stabilization (Thompson & Floyd, 2004; Worrell, Corey, York, & Santiestaban, 1992; Bradley & Tibone, 1991; Glousman, 1993; Illyes & Kiss, 2005). It is anticipated that the infraspinatus will be highly active during any type of volleyball attack due to its function as an external rotator.

Similar to the infraspinatus, the teres minor acts as an external rotator along with horizontal abduction, extension, and a stabilizer for the glenohumeral joint (Thompson & Floyd, 2004; Bradley & Tibone, 1991). The teres minor originates posteriorly on the upper and middle aspect of the lateral border of the scapula and inserts on the posterior aspect of the greater tubercle (Thompson & Floyd, 2004). Despite having the same muscle action as the infraspinatus, the teres minor has a different nerve innervation (axillary); therefore, it is theorized that the teres minor is not affected by suprascapular nerve entrapment (Montagna & Colonna, 1993).

Originating from the medial two-thirds of the supraspinatus fossa is the supraspinatus muscle. It inserts superiorly on the greater tubercle of the humerus. It functions as an abductor and stabilizer of the humerus in the glenoid fossa (Thompson & Floyd, 2004; Worrell et al., 1992). The supraspinatus junction is the most frequent location for rotator cuff injury (Worrell et al., 1992). Suprascapular neuropathy has been studied in volleyball and other activities that involve overhead action. It has been concluded that the neuropathy is restricted only to the infraspinatus and not the supraspinatus (Montagna & Colonna, 1993; Feretti et al., 1998; Wivrouw, Cools, Lysens, Cambier, Vanderstraeten, Victor, Sneyers, & Walravens, 2000; Cummins, Messer, & Schafer, 2004). Montagna and Colonna (1993) reported in their study that lesions occurred distal to the branches that innervate the supraspinatus. Therefore, atrophy of the rotator cuff appears to be isolated to the infraspinatus when injury to the suprascapular nerve occurs.

The subscapularis is the last of the rotator cuff muscles. It originates on the anterior surface of the subscapular fossa, and it inserts on the lesser tubercle of the humerus (Thompson & Floyd, 2004). The subscapularis is an internal rotator, adductor, extender, and stabilizer of the glenohumeral joint (Thompson & Floyd, 2004; Bradley & Tibone, 1991). Bradley and Tibone (1991) also indicate that the subscapularis acts to decelerate external rotation. Illyes and Kiss (2005) report that the subscapularis is crucial for anterior stability of the glenohumeral joint.

The anterior deltoid is often studied by EMG analysis because of its role in overhead activities. The anterior deltoid assists the shoulder joint in abduction, flexion, horizontal adduction, and internal rotation of the glenohumeral joint. The anterior deltoid originates along the anterior lateral third of the clavicle and inserts along with all fibers of the deltoid on the deltoid tuberosity of the lateral humerus (Thompson & Floyd, 2004).

The pectoralis major can be studied using surface electrodes because of its superficial placement in the body (Illyes & Kiss, 2005). The pectoralis major has two origins one arising from the clavicle and the second from the sternum. It inserts on the flat tendon to the lateral lip of the intertubercular groove of the humerus. It acts as an internal rotator, horizontal adductor, diagonal adductor, extender, and adductor (Thompson & Floyd, 2004). During a baseball pitch, the pectoralis major acts concentrically to start the acceleration phase; however, it eventually acts eccentrically in order to slow the glenohumeral joint during the follow-through phase (Bradley & Tibone, 1991).

The biceps brachii functions predominantly to flex the elbow; however, it also provides weak flexion at the shoulder joint. This muscle has two parts, long and short heads. The long head originates at the supraglenoid tubercle above the superior lip of the glenoid fossa while the short head originates at the coracoid process of the scapula and upper lip of the glenoid fossa. Both heads insert at the tuberosity of the radius and bicipital aponeurosis (Thompson & Floyd, 2004). While examining muscle activity during a baseball pitch, research has found through EMG analysis that the biceps brachii peaks during the follow-through as the elbow is decelerating (Bradley & Tibone, 1991).

Studies of Volleyball Attack

Unfortunately, the most current available coaching literature for volleyball is at least ten years old

(Coleman, Benham, & Northcott, 1993). Coleman et al. (1993) discussed the importance of continually researching methods in order to improve the sport of volleyball and decrease the rate of injury. These authors discussed two methods of preparation a volleyball player may use for the upper body in an attack. The first method is known as the drawn bow. The drawn bow method involves keeping the glenohumeral joint elevated while the elbow flexes and the glenohumeral joint extends much like an archery shooter shooting a bow. The second method discussed was the backswing style in which the glenohumeral joint depresses followed by elbow joint flexion and glenohumeral joint extension. Coleman et al.'s study (1993) revealed via cinematography that only two subjects had a true drawn bow style, while only one subject had a true backswing style. The remaining seven subjects completed intermediate styles in which the glenohumeral joint was in a neutral position rather than always elevated or always depressed.

One important finding from the above study is that neither of the methods changed during the follow-through. Therefore, it can be concluded that the same muscles will be active during each follow-through method described above. Coleman et al. (1993) concluded from their study that the volleyball athletes used a variety of pre-impact humerus settings. Therefore, the authors were not able to classify the athletes into either backswing or drawn bow; however, the follow-throughs for all athletes were similar.

Rokito, Jobe, Pink, Perry, and Brault (1998) compared EMG shoulder function during a volleyball serve and spike. Using dual-wire electrodes and a single-needle technique, the authors studied the muscle activities of the anterior deltoid, supraspinatus, infraspinatus, teres minor, subscapularis, teres major, latissimus dorsi, and pectoralis major. Subjects performed the entire service and spike motion with a volleyball. The following phases of the respective motions were analyzed: Windup, Cocking, Acceleration, Deceleration, and Follow-through. While this study was able to examine two different volleyball movements, the follow-through of the dominant arm remained on the ipsilateral side for the follow-through.

EMG Analysis of Shoulder Complex Musculature

Myers, Pasquale, Laudner, Sell, Bradley, and Lephart (2005) used EMG analysis to study shoulder activity during resistance-tubing exercises. The authors used a combination of fine-wire and surface electrodes during the analysis. They placed surface electrodes on the sternal portion of the pectoralis major, anterior deltoid, and biceps brachii. Single fine-wire electrodes were placed intramuscularly into the subscapularis, supraspinatus, teres minor, and the rhomboid major. The authors studied 13 different resistance-tubing exercises and found that 7 of the exercises resulted in moderate activation of all muscles tested. These exercises included shoulder extension, shoulder flexion, throwing acceleration, throwing deceleration, external rotation at 90 degrees of abduction, scapular punches, and either high or low scapular rows. Myers et al. (2005) concluded that there was moderate activation of the rotator cuff during these specific 7 exercises. They also stated, "The results of this descriptive study will assist clinicians, coaches, and athletes in deciding which exercises may be better suited to include in their rubber-resistance tubing warm-up programs before throwing" (p. 18). Rehabilitation protocols utilize many of the techniques listed above to advance the biomechanical approaches to overhead activities.

David, Magarey, Jones, Dvir, Turker, and Sharpe (2000) also used a combination of surface and fine-wire electrodes to examine the strength of selected shoulder muscles during rotations of the glenohumeral joint. They inserted needles into the supraspinatus and subscapularis. This was the only study that examined the infraspinatus and teres minor muscles using surface EMG analysis. Other studies indicate muscles such as the infraspinatus and teres minor need to be analyzed with intramuscular needle in order to fully analyze the activation of the muscle with the least amount of muscular noise (Rokito, Jobe, Pink, Perry, & Brault, 1998; Reinold et al., 2004; McCann, Wootten, Kadaba, & Bigliani, 1993). David et al. (2000) were able to conclude from their study that internal rotation and external rotation motions involve pre-setting the rotator cuff before executing a specific movement. They also stated that based on muscle activation patterns, "stability takes precedence over mobility" (p. 99). The authors stressed the importance of testing the entire rotator cuff complex rather than examining the external rotators and internal rotators separately.

In another study examining muscle activity of the shoulder complex during a baseball pitch, Bradley and Tibone (1991) inserted fine-wire needles into all three parts of the deltoid muscle, biceps brachii, all rotator cuff muscles, pectoralis major, latissimus dorsi, and scapular rotators. The authors were able to test these muscles with EMG analysis and cinematography. The authors noted peak activity of each muscle during a baseball pitch at each of the five phases: wind-up, early cocking, late cocking, acceleration, and follow-through.

The act of pitching a baseball revealed that the anterior, middle, and posterior deltoid reach peak activity in early cocking and when the glenohumeral joint is elevated to 90 degrees. However, these muscles decrease the amount of firing in the late cocking phase when the firing of the rotator cuff musculature becomes more prominent. The supraspinatus reached peak activity in the late cocking phase when the arm was already in an abducted position. In this position, the supraspinatus contributed to glenohumeral stability by bringing the humeral head toward the glenoid fossa. The infraspinatus and teres minor were noted to have a high firing pattern during the late cocking phase and follow-through. These muscles always followed the supraspinatus in firing pattern. The pectoralis major provided internal rotation of the glenohumeral joint. The actions of the pectoralis major were two-part. The pecotralis major muscle began an eccentric muscle action during the late cocking phase in order to stabilize the anterior glenohumeral joint. When the subject was in the late cocking phase with the pectoralis major at pre-stretched mode, this muscle was crucial for the initiation of the acceleration phase. This muscle was found to be actively contracted during the acceleration phase causing an increase in velocity of the ball (Bradley and Tibone, 1993).

Bradley and Tibone (1993) summarized their study by comparing these muscle activities between amateur and professional baseball pitchers. The authors noted that the biceps brachii and rotator cuff muscles were used during acceleration by amateur pitchers to a much greater extent than by experienced pitchers. The supraspinatus was shown to have a high firing pattern in amateurs. Bradley and Tibone (1993) stated that because less experienced pitchers use the supraspinatus to a greater extent, fatigue of the rotator cuff complex can cause overuse injuries, and therefore compromising the glenohumeral joint. The authors suggest that professional pitchers are more "selective, economical, and proficient" when it comes to the supraspinatus and rotator cuff activity (p. 794).

Much like the findings by Bradley and Tibone (1993), research completed by Glousman (1993) found that activity of the anterior deltoid is at its highest during the early cocking phase of throwing. Much like the early cocking phase in throwing, the wind up phase in the volleyball spike caused the anterior deltoid to activate at 58% of maximal capacity. The anterior deltoid only produces 27%

function during deceleration and fell further to 15% during follow-through (Rokito, Jobe, Pink, Perry, & Brault, 1998). Therefore, it is expected that the anterior deltoid will produce much of the activity in the wind-up phase of the volleyball spike.

Worrell, Corey, York, and Santiestaban (1992) analyzed supraspinatus EMG activity and isometric force development during two maximal voluntary contractions. They reported that the most intense activity for the rotator cuff muscles occurs during the deceleration/follow-through phases and places a large amount of stress on the posterior muscles such as the supraspinatus, infraspinatus, and teres minor. During their analysis, they found that the most accurate method of testing the supraspinatus was for the patient to lie in the prone position.

Possible Explanations for Injury

In a study conducted by Feretti et al. (1998), the authors discussed the possibility of injury to the infraspinatus due to the floater serve. A floater serve does not require maximum speed, but the serve attempts to confuse the opponents by using the same arm motion and speed but breaking the acceleration of the arm suddenly to create a "float" of the ball. The authors concluded based on EMG analysis that this type of serve creates greater muscle activation in the infraspinatus than other volleyball motions. Feretti et al. (1998) state, "The maximum eccentric contraction of the infraspinatus muscle, which is required to put a brake on the movement of the arm and to stabilize the shoulder, increases the distance between the points of origin and termination of the nerve, and stretching of the nerve can occur across the lateral edge of the spine of the scapula" (p. 761).

While the study by Feretti et al. (1998) addressed some implications of a specific movement in volleyball associated with injury to the infraspinatus, the authors failed to realize that volleyball players do not serve very often in the sport of volleyball. A volleyball player may only complete approximately 15 serves in a match. The number of serves an athlete completes is based on the match and the skills of the athlete. Some attackers may not play back row, so they may never serve. Also, not every service attempt will call for a floater serve. Thus, a volleyball player may only complete two or three floater serves in a match. However, a highly skilled attacker may spike approximately 40,000 times per year assuming practice time of 16-20 hours every week (Kugler, Kruger-Franke, Reininger, Trouilier, Rosemeyer, 1996). Therefore, attackers have more opportunity to involve their infraspinatus muscle during the attack rather than a serve. Researchers who have examined suprascapular entrapment and associated infraspinatus atrophy have concluded that injury to the suprascapular nerve is due to repetitive motion that can cause mechanical irritation to the nerve (Antoniadis et al., 1996; Cummins et al., 2004; Montagna & Colonna, 1993; Sandow & Ilic, 1998). Therefore, future research should concentrate on overhead activities that occur at a higher frequency than serving. Hence, there are significantly greater numbers of attack opportunities than there are serves for any individual player. Authors have also indicated through interviewing elite volleyball players that the majority of shoulder injuries were associated with spiking movements (Wang & Cochrane, 2001a).

Wang and Cochrane (2001b) performed an in depth analysis of mobility impairment, muscle imbalance, muscle weakness, and scapular asymmetry of volleyball players. Using EMG analysis, they found that "average eccentric external strength was weaker in the dominant arm compared to the concentric internal strength" (p. 408). They added that a decrease in external rotation strength may be caused by repetitive eccentric conditions which lead to suprascapular nerve injury. Although these authors never directly associated these problems with infraspinatus atrophy, other authors previously cited (Antoniadis et al., 1996; Bayramoglu et al., 2003; Briner & Kacmar, 1997; Cummins, Messer, & Schafer, 2004; Feretti et al., 1998; Mallon et al, 2006; Sandow & Ilic, 1998; Witvrouw et al., 2000) have proven that injury to the suprascapular nerve most often leads to injury of this muscle.

Sandow and Ilic (1998) studied five elite, male volleyball players who were all affected by infraspinatus atrophy. These authors operated on all five players hoping to reduce the compression on the suprascapular nerve by releasing the superior transverse ligament. They also deepened the spinoglenoid notch to further release compression on the nerve. These researchers concluded that the extreme arm position in volleyball players places the suprascapular nerve under compression by the medial aspect of the rotator cuff musculature. This compression leads to a compression neuropathy of the infraspinatus muscle, which ultimately leads to atrophy and loss of function.

It has been observed that many health care providers misdiagnose suprascapular neuropathy because it often mimics a rotator cuff tear (Mallon, Wilson, Basamania, & Durham, 2006). Although Mallon et al. (2006) had a very small sample size, their research provides further explanation as to the injury and treatment options of this type of shoulder injury. The authors report that many technicians are not experienced enough in studying the suprascapular nerve via EMG and rely on an MRI report to diagnose a patient with a rotator cuff tear. Mallon et al. (2006) explained that while a patient may suffer from a rotator cuff tear, the result of the tear may also compress the suprascapular nerve causing atrophy of the infraspinatus. The authors have hypothesized that the longer a rotator cuff tear goes untreated, the greater chance for compression of the suprascapular nerve. They also stated, "Partial repair of the rotator cuff tear may allow recovery of the suprascapular neuropraxia and improve function of the shoulder" (p. 397). While the study is limited due to its small sample size, it does provide insight as to why suprascapular neuropathy is still an anomaly.

Wang and Cochrane (2001b) suggested that in order to increase strength and potentially reduce injury to the shoulder complex, exercises need to be developed to strengthen the external rotators eccentric strength. Thus, rehabilitation and preventative methods need to be implemented for volleyball attackers to strengthen the infraspinatus. The authors ended their research by stating,

> Athletes with muscle strength imbalance, where the dominant arm average external rotation eccentric torque was less than that in concentric internal rotation, were more likely to have an injured or painful shoulder. If muscle imbalance about the shoulder joint is needed to preserve normal function and concentric internal rotation strength is important for the serving and spiking actions, the implication of this finding is that eccentric external rotator strength may need to be developed as an integral part of the training programme of these athletes (p. 410).

Wang and Cochrane's (2001b) recommendations may potentially strengthen the muscle, but can a muscle that is used to attack a volleyball up to 40,000 times a year be strengthened fully to prevent injury? Furthermore, Kugler, Kruger-Franke, Reininger, Trouillier, and Rosemeyer (1996) commented, "the technique of attacking should be optimized to use the shoulder muscles in an efficient manner" (p. 259).

Summary

Based on the review of literature, the current study is being conducted to examine muscle activation patterns of the shoulder complex in two separate volleyball attack methods: the traditional volleyball attack and an attack method which is very similar to the actions of a baseball pitch. All phases of motion will occur for this study: start, wind-up, cock, attack, and follow-through. Because of the injury to the infraspinatus being so prevalent in volleyball players, the aim of this study is to find more answers as to the mechanism which causes suprascapular nerve entrapment. Since no researchers have ever compared two volleyball attack methods, the results of the current study could potentially change the way the method of attacking is taught to amateur athletes.

CHAPTER 3

METHODS

The focus of this study was to examine the muscle activation patterns in the shoulder complex during two methods of a volleyball attack. The primary purpose was to determine if the rotator cuff muscles produced an increase in shoulder muscle activation when comparing two volleyball attack methods. For this research, method 1 was characterized with a follow-through on the ipsilateral side as the dominant arm. Method 2 had a follow-through ending on the contralateral side as the dominant arm; this method is similar to an overhand baseball pitch technique. A secondary purpose was to determine if there were gender differences between the two methods. The third purpose was to identify an interaction between attack method and gender. The final purpose was to determine preferred attack method for each subject. Hypotheses tested included:

H1: The traditional method [method 1] of attacking a volleyball will produce a higher motor unit activation in the rotator cuff compared to the non-traditional method [method 2].

H2: Muscle activation of the shoulder girdle will not differ between men and women, regardless of which method is used.

Research Design

A randomized, counterbalanced, within-subject experimental design was used to compare the two different volleyball attack motions. Dependent variables were EMG muscle recruitment for the infraspinatus (IF), supraspinatus (SS), teres minor (TM), pectoralis major (PM), anterior deltoid (AD), and the biceps brachii (BB). The independent variables were the two different volleyball attack motions.

Participants

Twenty-nine students (15 male, 14 female; age range= 18-30 years) attending a midwestern university volunteered for this study. All participants played for the university club volleyball teams and were familiar with the sport of volleyball and biomechanics of attacking the volleyball. Participants were excluded from the study if they had surgery on the dominant shoulder within the previous 12 months or previous injury to the dominant arm within the previous six months. Participants were instructed to restrict upper body maximal lifting activities for 48 hours prior to testing.

Electromyography

An eight-channel FM transmitter attached to the Myopac System (Run Technologies, Mission Viejo, CA) was used to detect EMG activity of the infraspinatus, supraspinatus, teres minor, pectoralis major, anterior deltoid, and biceps brachii. The Myopac System is equipped with eight channels, each with two leads. Each lead has an alligator clip that attaches to the surface electrodes. In order to use fine wire electrodes, each channel required an individual adapter. Adapters included a small rectangle base with two male connectors for the alligator clips and two coils for the fine wires to attach. Adapters were placed near the fine-wire after Mastisol had been placed on the subjects' skin. The adapters were further secured with tape so that the adapters would not move during testing. Once all electrode placements were verified through manual muscle tests, the subjects began their randomized trials.

Raw data was obtained by using electromyographic analysis through Datapac 2K2 (Run Technologies, Mission Viejo, CA). Manual muscles tests (MMT) were conducted pre- and post-testing which served as reference contractions for each of the six muscles. Each contraction lasted five seconds with at least three to five seconds of rest between the contractions. For each muscle, manual muscle tests were performed with a joint angle that maximized EMG activity under isometric conditions and within a normal range of motion (Kendall, McCreary, & Provance, 1993). The manual muscles test results were used as a baseline for EMG data collection during the specified volleyball attack methods.

During the EMG reading, signals from the leads were inserted or attached to the electrodes of each muscle and passed to a battery operated Myopac eight-channel FM transmitter (Run Technologies, Mission Viejo, CA). The signal was amplified by a gain of 1000 V with a single-ended amplifier with impedance greater than ten MOmega. Waveform processing was filtered with a notch Butterworth filter (60.0 Hz) and common mode rejection ratio of 130 dB at direct current with a minimum of 85 dB across the entire frequency of 10-500 Hz. A Datapac receiving unit with a sixth order filter (gain 2, total gain 2000) further amplified the signal. The analog signal was converted to a digital signal by an analog-to-digital converter card and was stored in the Datapac Software, version 3.00. The raw digital signal (reference contraction and trials) was sampled at a rate of 960 Hz and smoothed using a root mean square algorithm over a 50-ms moving window (Run Technologies, Mission Viejo, CA).

Procedures

Prior to data collection, this study was approved from the Biomedical & Health Institutional Review Board (BIRB) at Michigan State University. Each participant was asked to read and sign an informed consent, complete a health history questionnaire, and exclusion criteria form. These forms can be found in Appendix A. Data collection was conducted in the Athletic Training Research Laboratory at Michigan State University.

After the participant completed a health history, exclusion criteria questionnaire, and informed consent, his/her dominant arm was determined by each participant as the arm used most often for attacking a volleyball. Areas of surface electrode placement were cleansed with 70% isopropyl alcohol pads, shaved, abraded, and cleansed again with the alcohol preparation pads. All muscles with superficial orientation were assessed with surface electrodes (pectoralis major, anterior deltoid, and biceps brachii). Surface electrode placement was determined by finding the mid-point between the origin and insertion of the designated muscle. A forty millimeter-diameter self-adhesive silver/silver-chloride bipolar surface electrode (AMBU, Blue Sensor electrodes, Glen Burnie, Maryland) was placed just inferior to the participant's olecranon process to serve as the dispersion electrode. This electrode functions to complete the circuit, and is not used in EMG analysis.

After proper preparation, two forty-millimeter-diameter self-adhesive silver/silver-chloride bipolar surface electrodes (AMBU, Glen Burnie, Maryland) were placed parallel to the muscle fibers. Each pair of surface electrodes had a 2 cm separation (Kelly, Cooper, Kirkendall, & Speer, 1997). Correct electrode placement was confirmed by real-time visual inspection of the EMG signal during manual muscle testing that isolated activation of each muscle (Basmajian & Blumenstein, 1989). Under sterile conditions, a sports medicine physician inserted fine wire needles were into the infraspinatus, supraspinatus, and teres minor. All participants were given the option to receive Flori-Methane spray (Gebauer Company, Cleveland, OH) for an analgesic effect prior to insertion of the fine wire needles.

The fine wire electrodes consisted of a 0.002 x 8″ nickel alloy wire insulated with nylon (Chalgren Enterprise, Inc. Gilroy, CA). This type of fine wire was chosen according to published recommendations (Kelly et al., 1997). Fine wires were inserted intramuscularly into the respective muscle via a disposable paired fine wire EMG needle electrode 1.5-in (3.81-cm), 27-gauge needle (Chalgren Enterprise, Inc. Gilroy, CA).

Manual muscle tests (MMT) were performed for each muscle to ensure proper electrode placement. The manual muscles tests chosen isolated each muscle according to Kendall, McCreary, Provance, Rodgers, and Romani (2005). These manual muscle tests were performed before and after the participants performed the attack methods to serve.

Each subject was given a tutorial on attack method 1 (see Figure 3.1). The dominant arm started horizontally adducted so that the fingers were near the opposite Anterior-Superior Iliac Spine (ASIS). The subject will then begin the wind-up phase by horizontally abducting and flexing the glenohumeral joint until the glenohumeral joint comes to 90 degrees of abduction and external rotation and the elbow at 90 degrees of flexion. The cock phase maintains glenohumeral abduction and elbow flexion and adds glenohumeral lateral extension and continued external rotation. The attack phase will start with further glenohumeral abduction and internal rotation, glenohumeral flexion, elbow extension, and wrist flexion. The follow-through begins with eccentric external rotation along with eccentric glenohumeral flexion while resuming 90 degrees of glenohumeral abduction and flexion of the elbow finally resting at glenohumeral internal rotation and -20 degrees of extension and extension of the elbow. Each participant completed five swings of method 1.

Figure 3.1
Method 1: Windup Phase; Attack Phase; Follow-through Phase.

Participants were then instructed in attack method 2 in which the preparation phases are the exact same as attack method one, except the follow-through phase (see Figure 3.2). However, for attack method 2, eccentric glenohumeral flexion is combined with eccentric horizontal adduction and minimal internal rotation. The dominant arm finishes at the contralateral ASIS. Each participant completed 5 swings of method 2.

Figure 3.2
Method 2: Windup Phase; Attack Phase; Follow-through Phase.

Participants were asked to perform each swing as if they were actually attacking a volleyball. They were encouraged to swing as forcefully as during a game. Participants were allowed to take a step with their contralateral leg, since this is often done during game conditions. However, the subjects did not attempt the complete lower-body portion of the attack. Thus, no jumping was performed by any participant.

Statistical Analysis

Means and standard deviations were calculated for descriptive statistics. Manual muscles tests were completed according to *Muscles Testing Function* (Kendall et al., 1993) for the anterior deltoid, pectoralis major, biceps brachii, supraspinatus, infraspinatus, and teres minor. The raw data from the manual muscle testing was used as the denominator to determine muscle activity for each muscle in both methods.

A 2 technique (method 1, method 2) X 2 Gender X 6 muscles repeated measures analysis of variance (MANOVA) was conducted to determine if the differences among muscle firing patterns seen between the two techniques were statically significant. The level of significance was set at p = .05 and all analyses were conducted using SPSS version 15.0 for Windows (SPSS Inc., Chicago, IL). Follow-up ANOVAs were conducted once significance in the MANOVA was found. ANOVA testing was conducted to determine the specific muscles that showed significantly different firing patterns between the two techniques, or between genders.

In order for the first hypothesis to be supported, two out of three rotator cuff muscles (supraspinatus, infraspinatus, and teres minor) tested need to have more muscle activation in method 1 (traditional method) than method 2 (non-traditional method). The second hypothesis will be supported if four of the six muscles (anterior deltoid, supraspinatus, pectoralis major, infraspinatus, teres minor, biceps brachii) demonstrate more muscle activation in the same gender.

Chapter 4

RESULTS

The focus of this study was to examine the muscle activation patterns in the shoulder complex during two methods of a volleyball attack. The primary purpose was to determine if the rotator cuff muscles produced an increase in shoulder muscle activation when comparing two volleyball attack methods. For this research, method 1 was characterized with a follow-through on the ipsilateral side as the dominant arm. Method 2 had a follow-through ending on the contralateral side as the dominant arm; this method is similar to an overhand baseball pitch technique. A secondary purpose was to determine if there were gender differences between the two methods. The third purpose was to identify an interaction between attack method and gender. The final purpose was to determine preferred attack method for each subject. For clarity, this chapter is separated into subject demographics, average muscle contraction, muscle activation for methods 1 and 2, and gender differences.

Subject Demographics

A total of 31 Michigan State University club volleyball athletes volunteered to participate in this study (See Table 4-1). There were a total of 15 male subjects (age = 19.9 ± 1.8 years, 186.2 ± 8.1 cm, 78.4 ± 11.9 kg) and 14 female subjects (21.0 ± 2.3 years, 172.5 ± 6.6 cm, 68.6 ± 6.0 kg). Two subjects were excluded from statistical analysis because they were uncomfortable with the testing procedures. Therefore, a total of 29 subjects participated in this research. All subjects in this study were right hand dominant; therefore, they performed both methods with their right arm.

Table 4-1 Subject Demographic Information

Subjects	N	Age (years)	Height (cm)	Weight (kg)	Experience (years)
Male	15				
Mean		19.9	186.2	78.4	4.53
SD		±1.8	±8.1	±11.9	±2.29
Female	14				
Mean		20.9	172.5	68.6	9.79
SD		±2.3	±6.6	±6.0	±3.20
Total	29				
Mean		20.4	179.2	73.5	7.16
SD		±2.1	±10.1	±11.3	±3.81

Average Muscle Contraction Results

Average muscle contractions were calculated by averaging pre- and post- manual muscle tests for each of the six muscles (See Table 4-2). Females produced the greatest muscle activation for the supraspinatus (1.038 V) and had the lowest muscle activation for the teres minor (0.120 V). Males produced the greatest amplitude for the infraspinatus (1.102 V) and also had the lowest muscle activation for the teres minor (0.187 V).

Table 4-2 Average Muscle Contractions by Gender.

Muscle	Mean	SD	Max	Min
Anterior Deltoid				
Male	.818	±.447	1.729	.352
Female	.820	±.321	1.282	.371
Biceps Brachii				
Male	1.061	±.712	3.067	.326
Female	0.547	±.163	0.835	.236
Infraspinatus				
Male	1.102	±.609	2.308	.170
Female	0.908	±.367	1.447	.359
Pectoralis Major				
Male	.341	±.169	.705	.080
Female	.225	±.122	.432	.052
Supraspinatus				
Male	.980	±.345	1.734	.479
Female	1.038	±.440	1.890	.292
Teres Minor				
Male	.187	±.262	1.115	.034
Female	.120	±.109	0.327	.017

All units measured in Volts.

Muscle Activation for Volleyball Methods 1 and 2

A repeated measures multiple analysis of variance (MANOVA) was conducted to determine the effect of method 1 and 2 on the six dependent muscle group contraction variables. Gender was specified as a between-subject factor in the repeated measure MANOVA design. The two methods were a traditional follow-through swing (method 1) and a cross-body follow-through (method 2). The six dependent muscle groups examined for muscle activation were the anterior deltoid, supraspinatus, pectoralis major, infraspinatus, teres minor, and the biceps brachii.

Results revealed significant MANOVAs for technique (Wilks' Λ= .465, F[6,22]= 4.214, p= .006, η^2= .535) and gender (Wilks' Λ= .463, F[6,22]= 4.248, p= .005, η^2= .537). The interaction between technique and gender was not significant in the MANOVA (Wilks' Λ = .953, $F_{[6,22]}$ = 0.181, p = .979, η^2 = .047) nor was preferred swing technique (Wilks' Λ= .675, $F_{[6,22]}$ = 1.768, p= .152, η^2 = .352). Table 4-3 presents a summary of the MANOVA results.

Table 4-3 MANOVA Results

	Wilks' Λ	F	p	η^2
Technique	0.465	4.214	0.006	0.535
Gender	0.463	4.248	0.005	0.537
Interaction (Technique*Gender)	0.953	0.181	0.979	0.047
Attack Preference	0.675	1.768	0.152	0.352

Univariate ANOVAs were conducted as follow-up tests. By Bonferroni's adjustment, the pairwise comparisons are significant only at p-values less than 0.0083. ANOVA results supported the conclusion that technique significantly impacted the anterior deltoid ($F_{[1,27]}$ = 9.055, p = .006, η^2 = .251), pectoralis major ($F_{[1,27]}$ = 9.413, p =

.005, $\eta^2 = .259$), and teres minor ($F_{[1,27]} = 10.788$, $p = .003$, $\eta^2 = .285$).

For the anterior deltoid muscle, the average muscle contraction was significantly greater for method 2 ($M = .2481$, $SD = .096$) compared to method 1 ($M = .2157$, $SD = .068$). Similarly for the pectoralis major muscle, the average muscle contraction was significantly greater for method 2 ($M = .5606$, $SD = .402$) compared to method 1 ($M = .3933$, $SD = .528$). However, for the teres minor muscle, muscle contraction was significantly less for method 2 ($M = 2.903$, $SD = 2.95$) than method 1 ($M = 3.703$, $SD = 3.625$).

Technique did not significantly impact the supraspinatus ($F_{[1,27]} = 1.401$, $p = .247$, $\eta^2 = .049$), the infraspinatus ($F_{[1,27]} = .671$, $p = .420$, $\eta^2 = .024$), or the biceps brachii ($F_{[1,27]} = 5.197$, $p = .031$, $\eta^2 = .161$) muscles. Thus, for the supraspinatus muscle, muscle contraction was not significantly different between method 1 ($M = .3521$, $SD = .131$) and method 2 ($M = .3219$, $SD = .136$). Similarly, muscle contraction was not significantly different between method 1 ($M = .3131$, $SD = .370$) and method 2 ($M = .3390$, $SD = .511$) for the infraspinatus muscle. Finally, for the biceps brachii muscle, muscle contraction was not significantly different for method 1 ($M = .1802$, $SD = .104$) than method 2 ($M = .1991$, $SD = .117$). Table 4-4 contains the means and standard deviations for each muscle group for each method.

Table 4-4 Means and Standard Deviations for Each Muscle Group by Technique

	Technique			
	Method 1		Method 2	
Muscle Group	M	SD	M	SD
Anterior Deltoid*	.2157	.068	.2481	.096
Supraspinatus	.3521	.131	.3219	.136
Pectoralis Major*	.3933	.235	.5606	.402
Infraspinatus	.3131	.370	.3390	.511
Teres Minor*	3.703	3.625	2.903	2.948
Biceps Brachii	.1802	.104	.1991	.117

*significant at the .05 level with Bonferroni's correction to 0.0083

All units measured in Volts.

Gender Differences in Muscle Activation

Gender was examined by using a repeated measure MANOVA by specifying gender as a between-subject factor. Results reveal significant differences for gender (Wilks' Λ = .463, $F_{[6,22]} = 4.248$, $p = .005$, $\eta^2 = .537$). Follow up ANOVAs revealed that gender resulted in significant differences in muscle contraction only for the biceps brachii muscle ($F_{[1,27]} = 19.627$, $p < .000$, $\eta^2 = .421$). Women exerted significantly greater muscle contraction for the bicep brachii muscle (*M* = .261, *SD* = .023) compared to men (*M* = .123, *SD* = .022). None of the other muscle groups resulted in significant differences in muscle contraction between males and females. Additional descriptive information about muscle activation by males and females for each muscle group is reported in Table 4-5.

Table 4-5 Descriptive Statistics for Methods (1) and (2) by Muscle and Gender

		Gender			
		Male		Female	
		N = 15		n = 14	
Muscle group		Mean	SD	Mean	SD
Anterior Delt.	(1)	.208	.076	.224	.061
	(2)	.242	.083	.255	.111
Supraspinatus	(1)	.307	.090	.400	.153
	(2)	.292	.077	.354	.177
Pec. Major	(1)	.312	.154	.481	.279
	(2)	.477	.220	.650	.528
Infraspinatus	(1)	.332	.456	.293	.266
	(2)	.378	.667	.297	.282
Teres Minor	(1)	3.012	3.734	4.443	3.485
	(2)	2.276	2.523	3.574	3.304
Biceps Brachii*	(1)	.111	.064	.254	.088
	(2)	.134	.073	.269	.117

*significant at p= .001
All units measured in Volts.

CHAPTER 5

DISCUSSION

The focus of this study was to examine the muscle activation patterns in the shoulder complex during two methods of a volleyball attack. The primary purpose was to determine if the rotator cuff muscles produced an increase in shoulder muscle activation when comparing two volleyball attack methods. For this research, method 1 was characterized with a follow-through on the ipsilateral side as the dominant arm. Method 2 had a follow-through ending on the contralateral side as the dominant arm; this method is similar to an overhand baseball pitch technique. A secondary purpose was to determine if there were gender differences between the two methods. The third purpose was to identify an interaction between attack method and gender. The final purpose was to determine preferred attack method for each subject.

Research Findings

There were several major findings in this study. First, method 2 produced more muscle activation than method 1 in the anterior deltoid and the pectoralis major. Although these muscles are not often injured by volleyball players, the results do indicate that method 2 produces higher muscle activation than method 1 for two muscles.

While much of the research on shoulders of volleyball players has concentrated on infraspinatus atrophy, it is important to consider all muscles that act to stabilize the glenohumeral joint.

Several researchers have studied baseball pitchers and found that the anterior deltoid was most active during the early cocking phase (Bradley & Tibone, 1991; Glousman, 1993 Illyes & Kiss, 2004). In the current research, method 2 looks very similar to a baseball pitch. Although the methodology in the current research is not able to determine the exact timing of muscle activation, it is important to realize that method 2 did, in fact, produce more motor unit recruitment for the anterior deltoid. Therefore, it may be important to study the volleyball attack examining muscle activity in accordance with each phase of an attack rather than overall muscle contraction.

It is not surprising that the pectoralis major activated more during method 2 than method 1 considering the muscle functions as a horizontal adductor (Thompson & Floyd, 2004). When visually observing the two attack methods tested, attack method 2 should have produced more muscle activation because the follow-through ends with the arm on the contralateral aspect of the body. Again, this method looks similar to a baseball pitch or tennis serve.

The pectoralis major propels the glenohumeral joint at the start of the acceleration phase and provides horizontal adduction and internal rotation so that the follow-through will occur across the body of a baseball pitcher (Bradley & Tibone, 1991).

A second finding in the current research revealed that in contrast to the anterior deltoid and pectoralis major, the teres minor produced more muscle activation in method 1 than in method 2. The exact reasons for this difference are unclear; however, it can be speculated that subjects unfamiliar with one method versus the other would use a higher motor recruitment due to the unfamiliarity of a particular method. While the teres minor is not a muscle that is usually injured or studied, Rokito et al. (1998) concluded that the teres minor has high motor unit recruitment during active motion of a throw rather than a single-movement activity such as a manual muscle test. The teres minor functions in high-velocity activities to position the humeral head in the proper position of the glenoid fossa (Reinold et al., 2004). This finding is important for health care providers to remember so that the teres minor can be strengthened dynamically rather than in single-plane motions.

It should be noted that the teres minor had a very high activation in both methods when compared to the other muscles. It is possible that since the teres minor contracted very little during the manual muscle testing (MMT), comparing the MMT with the activity of the muscle during the two methods calculated a very high number. Research has indicated that the teres minor has more muscle activation when the patient is sidelying and performs external rotation than when the patient is standing or sitting (Reinold et al., 2004). Therefore, the current method of manual muscle testing the teres minor reported in Kendall et al. (2005) may need to be reconsidered if the clinician is trying to examine the strength of the teres minor muscle while the subject is completing dynamic activity.

A third result from the current research indicated that there was not a statistically significant difference for gender. There was no difference in either method 1 or 2 when compared across gender. The only muscle that showed significant difference between gender was the biceps brachii. Research on the overhead activity in baseball players has not included females because baseball pitching is not an activity commonly performed by females (Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005).

Therefore, since little research has been done comparing the biceps brachii between genders, the explanation for this difference is unclear.

The initial review of literature indicated that suprascapular nerve injury which resulted in infraspinatus hypotrophy is common in volleyball attackers. At present, only one author has offered a volleyball sport-related activity that could potentially cause the nerve injury (Feretti, 1998). Feretti, De Carli, and Fontana (1998) described a floater serve as possible explanation to the infraspinatus hypotrophy. When the serve is performed, the overhead motion of the glenohumeral joint is similar to that of a volleyball attack; however, the floater serve requires the glenohumeral joint to stop suddenly as soon as contact is made with the volleyball. This type of serve is used so that the ball moves erratically with the air flow rather than normal spin of the ball (Briner & Kacmar, 1997). However, as described in Chapter 2 of the current research, athletes rarely practice and perform this skill when compared to the number of times a volleyball athlete may attack the ball. For example, final statistics of the 2006 Michigan State University collegiate volleyball team revealed that a given player attempted 1,001 attacks in 104 games compared to only 101 serves in 104 games. While other athletes completed more serves than the above listed athlete, no MSU athlete attempted more attacks than this athlete. The most serves attempted in a possible 105 games was 487 (Michigan State University volleyball statistics). Researchers who have examined suprascapular nerve entrapment and associated infraspinatus atrophy have concluded that injury to the suprascapular nerve is due to repetitive motion that can cause mechanical irritation to the nerve (Antoniadis et al., 1996; Cummins et al., 2004; Montagna & Colonna, 1993; Sandow & Ilic, 1998). Therefore, future research should concentrate on overhead activities that occur at a higher frequency than serving.

Utilization for Health Care Professionals

While this particular study did not reveal significant differences for the infraspinatus during methods 1 and 2, the research is important for health care professionals to assist athletes in developing the shoulder musculature because of its role in overhead athletic activities. From the current research, muscles such as the anterior deltoid and pectoralis major should be emphasized along with the rotator cuff in pre-season shoulder preparation. While the rotator cuff is often focused in pre-season activity due to its inherent nature to be injured, it is musculature such as the anterior deltoid and pectoralis major that function to propel the glenohumeral joint through the entire range of motion.

Neither the supraspinatus nor the infraspinatus muscle activation differed significantly between attack methods; however, athletic trainers should continue to focus on strengthening both of these muscles. Appropriate strength of the infraspinatus is crucial in the overhead activity of a volleyball attack to develop the optimal amount of force to prevent joint distraction (Reinold et al., 2004). DiGiovine, Jobe, Pink, and Perry (1992) indicated that the eccentric strength of the external rotators is important for the deceleration of a limb following a forceful exertion of the agonists during a baseball pitch. Therefore, in order to prevent injury, researchers have proposed that eccentric external rotation strength should be equal to the agonisits' concentric strength (Forthomme, Croisier, Ciccarone, Crielaard, 2005; Wang & Cochrane, 2001b).

Positioning the glenohumeral joint into external rotation and abduction during the cocking phase of a volleyball attack occurs mostly because of the supraspinatus (Sandow & Ilic, 1998). Worrell et al. (1992) indicated that the supraspinatus junction was the most frequent location for injury when the rotator cuff has been stressed. The authors also recommended that strengthening of the supraspinatus muscle should be completed with the athlete or patient lying in a prone position. Several researchers have shown EMG results indicating higher muscle activation when lying prone compared to standing (Worrell et al., 1992; Malanga, Jenp, Growney, & An, 1996). This is important research for health care providers to remember when attempting to rehabilitate the supraspinatus following injury.

A point of emphasis from this research should be on the dramatic muscle activation of the teres minor. In the volleyball overhead attack, the teres minor acts as an external rotator in the preparation phase and then eccentrically contracts during the follow-through (Thompson & Floyd, 2004; Worrell, Corey, York, & Santiestaban, 1992; Bradley & Tibone, 1991; Glousman, 1993; Illyes & Kiss, 2005). Thus, health care providers should provide eccentric exercises of external rotators for all overhead activities such as baseball pitching and volleyball attacking (Perry, 1983). Reinold et al. (2004) recommend that an athlete should perform sidelying external rotation as the most effective exercise for the teres minor.

When interviewing the club volleyball athletes post-data collection, it was interesting to note that the athletes who had been coached from a young age tended to prefer attack method 1. However, those who had not been coached tended to use attack method 2. It seems as though attack method 2 is a more natural activity than attack method 1. More research should be conducted on this topic. Health care providers should understand the variations of a volleyball attack used by each athlete. Examining each volleyball athlete's attack biomechanics will allow athletic trainers, strength and conditioning professionals, and coaches to address the specific muscles that are used in excess during the particular volleyball attack method.

While the current volleyball attack study used only club volleyball athletes, they all had similar amount of experience. It may be difficult to generalize this study to NCAA collegiate volleyball athletes because they would be considered more skilled in their activity. Comparing the activation of muscles in the shoulder complex between different levels of volleyball athletes may be important to optimize strengthening techniques for particular muscles. Glousman (1993) examined the rotator cuff during a baseball pitch via EMG to compare shoulder activation in professional and amateur pitchers. Research indicates that professional baseball pitchers were able to demonstrate selective use of particular muscles when throwing rather than stressing the entire rotator cuff as a whole. Professional pitchers used more activation of the subscapularis compared to amateur pitchers who stressed the supraspinatus, infraspinatus, teres minor, and biceps brachii (Glousman, 1993; Illyes & Kiss, 2004). Illyes and Kiss (2004) commented that the "selective use of certain muscles to throw a ball determines the quality and experience of a thrower" (p. 286). Completing a similar study for the sport of volleyball may add insight for all athletes in the sport.

Limitations

Due to a lack of technology, cinematography was not able to be utilized. Also, the technology available did not allow the test subjects to actually attack a volleyball. We were not able to transport our EMG equipment out of the Michigan State University Athletic Training Laboratory. With mobile EMG equipment, future research could evaluate muscle activity during actual volleyball conditions.

Because all subjects had participated in the sport of volleyball for more than two years, each had a preferred method of attacking. Therefore, one method was foreign to the subject. Since one method is practiced repeatedly, the other method may have had less force production due to the unfamiliarity of the motion. There was no way to correct this discrepancy within the given time frame. Psychology researchers have documented that a skill does not become proficient until it has been practiced for 10,000 hours or 10 years (Ericsson, 1990). Therefore, one method will always be preferred over the other.

The small and restricted sample size limits generalizability of our findings. Only club volleyball athletes were studied; therefore, this research cannot be generalized to either the highly skilled collegiate athlete or recreational athlete. Club volleyball athletes were recruited because we wished to study experienced performers without interfering with the varsity team's schedule.

Future Research

Future researchers should continue to examine differences in muscle activation during overhead volleyball activities. Study limitations should be addressed in order to add to existing literature about the sport of volleyball. Many limitations present in this study can be changed with minimal alterations. Advanced technology should be utilized in order to examine shoulder muscle activation in which the subjects can complete a volleyball attack.

High school and NCAA collegiate athletes should be studied in order to examine the differences between inexperienced and experienced volleyball athletes. Whereas the current research can only generalize to populations with less and more experience respectively, similar research should be conducted to compare and contrast all levels of volleyball athletes. Bradley and Tibone (1991) noted several differences between professional and amateur baseball pitchers. For example, the biceps brachii and rotator cuff muscles were used in the act of acceleration much more in amateur pitchers compared to professionals (Bradley & Tibone, 1991). It would be interesting to study effects of the rotator cuff and biceps brachii in different levels of volleyball athletes. This information may help coaches and health care providers to strengthen the correct musculature for the level of the athlete.

The subscapularis should be included in the next study of overhead activities in volleyball players. Recent research suggests that hypertrophy of the subscapularis muscle may entrap the anterior surface of the suprascapular notch thus causing suprascapular nerve entrapment (Bayramoglu, Demiryurek, Tuccar, Erbil, Aldur, Tetik, & Doral, 2003). The current study did not include the subscapularis due to lack of technology. Including the subscapularis would have required another needle insertion due to the deep orientation of the muscle.

A study that examined pre- and post-pitching muscle activation revealed that internal rotation decreased after pitching and conversely external rotation significantly increased (Yanagisawa, Miyanaga, Shiraki, Shimojo, Mukai, Niitsu, Itai, 2003). Future research should use similar aspects of Yanagisawa et al.'s research and study the pre- and post-attacking muscle activation in volleyball players. Understanding the amount of fatigue in a muscle before and after workouts would allow health care providers the strengthen certain muscles at different times in a rehabilitation protocol. For example, if it is found in volleyball athletes that internal rotation strength dramatically decreased following a practice, encouraging the athlete to participate in internal rotation strengthening exercises at the end of a rehabilitation protocol may prevent injury to the internal rotators.

Conclusion

The current research did not support the original hypothesis that method 1 would cause more muscle activation than method 2 because the teres minor was the only muscle that showed statistical significance. However, continued research of the overhead attack in the sport of volleyball is needed. The technique of attacking a volleyball should be optimized in order to use the shoulder complex muscles in an efficient manner to potentially prevent injury (Kugler, Kruger-Franke, Reininger, Trouillier, & Rosemeyer, 1996).

The current research is an important addition to existing literature about the role of muscles in the shoulder complex and the overhead activities in the sport of volleyball. To date, no studies were found that are dedicated to volleyball players in the conditioning of the player (Forthomme, Croisier, Crielaard, Cloes, 2005). This study reported significance of the type of method that was used when compared as a whole. While the study did not report statistical significance of the infraspinatus and supraspinatus, it was able to report significant differences for the teres minor, anterior deltoid, and pectoralis major muscles for attack method. The interaction between gender and attack and preferred swing technique were not significant.

Gender was statistically significant as compared to attack method when examined as a whole. The hypothesis for gender, however, was not supported by this study because only one muscle revealed statistical significance for females. The research concluded that activation of the biceps brachii muscle was greater in women than in men. More research should be done for the biceps brachii in other overhead activities such as baseball pitching and tennis serves. While many researchers may not include women in a baseball pitching study because it is not a skill often used, the comparison would add to research literature about the differences in biceps brachii muscle activation between men and women.

Future research in the sport of volleyball should address the limitations discussed in the current research. It is clear that more research is needed in this area due to the rate and complexity of injuries associated with volleyball activities. Minimizing the limitations listed above may reveal different results when compared to the current research. It is recommended that health care providers strengthen the musculature about the shoulder complex in order to potentially prevent injury.

APPENDIX A: FORMS

Electromyographic Analysis of Shoulder Muscle Activity during Two Volleyball Spike Mechanics

Contact Information Form

Subject Name:______________________________________ **Age:**__________

Contact Phone Number:___________________________ **Height:**__________

E-mail Address:__________________________________ **Weight:**__________

Exclusion Criteria Questionnaire

Please answer the following questions regarding your health history.

Have you: (Circle your response)

Had an upper body extremity injury within the last six months?	Y N
Had an upper body extremity surgery within the last year?	Y N
Ever been diagnosed with peripheral vascular disease?	Y N
Ever been diagnosed with asthma?	Y N
Ever been diagnosed or hospitalized for a cardiovascular condition?	Y N
Ever been hospitalized for a respiratory illness?	Y N
Ever been diagnosed with hypertension?	Y N

Is there any reason that you can identify that you would not be able to complete the volleyball spike activity related to this research? Y N

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

Signature:__________________________________ **Date:**__________________

Michigan State University
38 IM Sports Circle
Exercise Program/Testing Readiness Questionnaire

Every participant must fill out this questionnaire and sign a release before he/she will be allowed to participate in physical activity and/or measuring shoulder muscle activity.

Name____________________________ Phone____________________ Date_______

Address____Date Of Birth________

E-mail_______________________ Height_________ Weight_________

___Yes ___No 1. Has your doctor ever said you have heart trouble?

___Yes ___No 2. Have you ever had chest pain or heavy pressure in your chest as a result of exercise, walking, or other physical activity, such as climbing a flight of stairs? (Note: This does not include the normal out-of-breath feeling that results from vigorous exercise).

___Yes ___No 3. Do you often feel faint or experience severe dizziness?

___Yes ___No 4. Has your doctor ever told you that you have high blood pressure or diabetes?

___Yes ___No 5. Have you ever had a real or suspected heart attack or stroke?

___Yes ___No 6. Do you have any physical condition, impairment or disability, including any joint or muscle problem that should be considered before you undertake an exercise program?

___Yes ___No 7. Have you ever taken medication to reduce your blood pressure or cholesterol levels?

___Yes ___No 8. Are you excessively overweight?

___Yes ___No 9. Is there any good physical reason not mentioned here why you should not follow an exercise program even if you wanted to?

___Yes ___No 10. Are you over age 40 or not accustomed to vigorous exercise?

REFERENCES

Aagaard, H., Scavenius, M., & Jorgensen, U. (1997). An epidemiological analysis of the injury pattern in indoor and in beach volleyball. *The International Journal of Sports Medicine,* 18, 217-221.

Alfredson, H., Nordstrom, P., Pietila, T., & Lorentzon, R. (1998). Long-term loading and regional bone mass of the arm in female volleyball players. *Calcified Tissue International,* 62(4), 303-308.

Antoniadis, G., Richter, H., Rath, S., Braun, V., & Moese, G. (1996). Suprascapular nerve entrapment: experience with 28 cases. *Journal of Neurosurgery,* 85(6), 1020-1025.

Bahr, R. & Reeser, J. (2003). Injuries among world-class professional beach volleyball players. *The American Journal of Sports Medicine,* 31(1), 119-125.

Basmajian, J.V. & Blumenstein R. (1989). Electrode placement in electromyographic biofeedback. *Biofeedback: Principles and Practice for Clinicians:* Baltimore, MD, Williams & Wilkins, 369-382.

Bayramoglu, A., Demiryurek, D., Tuccar, E., Erbil, M., Aldur M.M., Tetik, O., & Doral, M.N. (2003). Variations in anatomy at the suprascapular notch possibly causing suprascapular nerve entrapment: an anatomical study. *Knee Surgery, Sports Traumatology, and Arthroscopy,* 11, 393-398.

Bradley, J. & Tibone, J. (1991). Electromyographic analysis of muscle action about the shoulder. *Clinics in Sports Medicine,* 10(4), 789-805.

Briner, W. & Kacmar, L. (1997). Common injuries in volleyball: mechanisms of injury, prevention and rehabilitation. *Journal of Sports Medicine,* 24(1), 65-71.

Brox, J., Roe, C., Saugen, E., & Vollestad, N. (1997). Isometric abduction muscle activation in patients with rotator tendinosis of the shoulder. *Archives of Physical Medicine and Rehabilitation,* 78(11), 1260-1267.

Coleman, S.G.S., Benham, A.S., & Northcott, S.R. (1993). A three-dimensional cinematographical analysis of the volleyball spike. *Journal of Sports Sciences,* 11, 295-302.

Cummins, C., Messer, T., & Schafer, M. (2004). Infraspinatus muscle atrophy in professional baseball players. *The American Journal of Sports Medicine,* 32(1), 116-120.

David, G., Magarey, M.E., Jones, M.A., Dvir, Z., Turker, K.S., & Sharpe, M. (2000). EMG and strength correlates of selected shoulder muscles during rotations of the glenohumeral joint. *Clinical Biomechanics,* 15(2), 95-102.

DiGiovine, Jobe, Pink, & Perry. (1992). An electromyographic analysis of the upper extremity in pitching. *Journal of Shoulder and Elbow Surgery,* 1(1), 15-25.

Ericsson, K.A., Krampe, R.Th., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review,* 100, 363-406.

Feretti, A., De Carli, A., & Fontana, M. (1998). Injury of the suprascapular nerve at the spinoglenoid notch. *The American Journal of Sports Medicine,* 26(6), 759-763.

Forthomme, B., Croisier, J., Ciccarone, G., Crielaard, J., & Cloes, M. (2005). Factors correlated with volleyball spike velocity. *The American Journal of Sports Medicine,* 33(10), 1513-1519.

Glousman, R. (1993). Electromyographic analysis and its role in the athletic shoulder. *Clinical Orthopaedics and Related Research,* Mar(288), 27-34.

Illyes, A., & Kiss, R.M. (2004). Shoulder muscle activity during pushing, pulling, elevation, and overhead throw. *Journal of Electromyography and Kinesiology,* 15, 282-289.

Kelly, B.T., Cooper, W., Kirkendall, D.T., & Speer, K.P. (1997). Technical considerations for electromyography research on the shoulder. *Clinical Orthopaedic,* 335; 140-151.

Kendall,F.P., McCreary, E.K., Provance, P.G. (2003). *Muscle testing and function* (4^{th} ed.). Philadelphia: Lippincott, Williams, Wilkins.

Kugler, A., Kruger-Franke, M., Reininger, S., Trouillier, H-H., & Rosemeyer, B. (1996). Muscular imbalance and shoulder pain in volleyball attackers. *British Journal of Sports Medicine,* 30(3), 256-259.

Malanga, G.A., Jenp, Y., Growney, E., & An, K. (1996). EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. *Medicine and Science in Sports and Exercise,* 28(6), 661-664.

Mallon, W.J., Wilson, R.J., Basamania, C.J., & Durham. (2006). The association of suprascapular neuropathy with massive rotator cuff tears: a preliminary report. *Journal of Shoulder and Elbow Surgery,* 15, 395-398.

McCann, P.D., Wootten, M.E., Kadaba, M.P., & Bigliani, L.U. (1993). A kinematic and electromyographic study of shoulder rehabilitation exercises. *Clinical Orthopaedics and Related Research,* Mar(288), 179-188.

Montagna, P. & Colonna, S. (1993). Suprascapular neuropathy restricted to the infraspinatus muscle in volleyball players. *Acta Neurologica Scandinavica,* 87(3), 248-250.

Myers, J.B., Pasquale, M.R., Laudner, K.G., Sell, T.C., Bradley, J.P., & Lephart, S.M. (2005). On-the-field resistance-tubing exercises for throwers: an electromyographic analysis. *Journal of Athletic Training,* 40(1), 15-22.

Perry, J. (1983). Anatomy and biomechanics of the shoulder in throwing, swimming, gymnastics, and tennis. *Clinics and Sports Medicine,* 2(2), 247-270.

Reinold, M.M., Wilk, K.E., Fleisig, G.S., Zheng, N., Barrentine, S.W., Chmielewski, T., Cody, R.C., Jameson, G.G., & Andrews, J.R. (2004). Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. *The Journal of Orthopaedic and Sports Physical Therapy,* 34(7), 385-394.

Rokito, A.S., Jobe, F.W., Pink, M.M., Perry, J., & Brault, J. (1998). Electromyographic analysis of shoulder function during the volleyball serve and spike. *Journal of Shoulder and Elbow Surgery,* 7(3), 256-263.

Sandow, M.J. & Ilic, J. (1998). Suprascapular nerve rotator cuff compression syndrome in volleyball players. *Journal of Shoulder and Elbow Surgery,* 7, 516-521.

Thompson, C.W. & Floyd, R.T. (2004). Manual of structural kinesiology (15^{th} ed.). New York, NY: McGraw-Hill.

Thompson, W. & Kopel H. (1959). Peripheral entrapment neuropathies of the upper extremity. *New England Journal of Medicine,* 260, 1261-1270.

Verhagen, E.A.L.M, Van der Beek, A.J., Bouter, L.M., Bahr, R.M., & Van Mechelen, W. (2004). A one season prospective cohort study of volleyball injuries. *British Journal of Sports Medicine,* 38, 477-481.

Wang, H.K. & Cochrane, T. (2001a). A descriptive epidemiological study of shoulder injury in top level English male volleyball players. *International Journal of Sports Medicine,* 22(2), 159-163.

Wang, H.K. & Cochrane, T. (2001b). Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *Journal of Sports Medicine and Physical Fitness,* 41, 403-410.

Wang, H.K., Macfarlane, A., & Cochrane, T. (2000). Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *British Journal of Sports Medicine,* 34, 39-43.

Witvrouw, E., Cools, A., Lysens, R., Cambier, D., Vanderstraeten, G., Victor, J., Sneyers, C., & Walravens, M. (2000). Suprascapular neuropathy in volleyball players. *British Journal of Sports Medicine,* 34, 174-180.

Worrell, T.W., Corey, B.J., York, S.L., & Santiestaban, J. (1992). An analysis of supraspinatus EMG activity and shoulder isometric force development. *Medicine and Science in Sports and Exercise,* 24(7), 744-748.

Yanagisawa, O., Miuanaga, Y., Shiraki, H., Shimojo, H., Mukai, N., Niitsu, M, & Itai, Y. (2003). The effects of various therapeutic measures on shoulder range of motion and cross-sectional areas of rotator cuff muscles after baseball pitching. *The Journal of Sports Medicine and Physical Fitness,* 43(3), 356-366.