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A comparison of isotonic and elastic resistance exercise on trapezius muscle balance in overhead athletes

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A COMPARISON OF ISOTONIC AND ELASTIC RESISTANCE EXERCISE ON TRAPEZIUS MUSCLE BALANCE IN OVERHEAD ATHLETES

A Dissertation
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
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requirements for the degree of
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in

The Department of Kinesiology

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Table of Contents

ABSTRACT……………………………………………………………………….………..………iii

GENERAL INTRODUCTION……….…………………………………….……………….....1

STUDY

1. EMG CHARACTERISTICS OF THE TRAPEZIUS MUSCLE DURING THE SCAPTION EXERCISE ……………………….…….……………………...12
2. A COMPARISON OF TRAPEZIUS MUSCLE ACTIVATION BETWEEN OVERHEAD ATHLETES AND HEALTHY SUBJECTS DURING A SCAPTION EXERCISE……………………………………………….………….26
3. A COMPARISON OF ELASTIC AND ISOTONIC RESISTANCE ON TRAPEZIUS MUSCLE BALANCE IN OVERHEAD ATHLETES….…..…..……37

DISCUSSION AND CONCLUSION…….……………………………....……………..49

REFERENCES…………………………………………………………………………..52

APPENDIX A: RAW DATA………………………………………………………………56

APPENDIX B: ANOVA ANALYSIS TABLES………………………………………..64

APPENDIX C: GENERAL EXAM..………………………………………………………69

APPENDIX D: IRB APPROVAL.…………………………………………………..116

VITA……………………………………………………………………………...….118

Abstract

The scaption exercise (elevation of the arm in the scapular plane) is often performed in shoulder rehabilitation and preventive exercise programs. Three studies were performed to better understand the activation characteristics of the upper trapezius (UT) and lower trapezius (LT) muscles during scaption. The purpose of these studies was to 1) quantify and compare trapezius muscle activation ratios and onset of activation in normal subjects, 2) compare the findings from normal subjects with overhead athletes, and 3) compare the activation ratios and onset of the trapezius with 2 modes of resistance (elastic and isotonic) in overhead athletes.

Methods. Healthy college-aged subjects performed scaption to 90° with (W) and without (UW) standardized resistance. The average activation of the UT and LT was determined with surface electromyography (EMG) over 30° increments in concentric and eccentric directions. The UT:LT ratio was then determined for each interval and condition, as well as the average onset of activation. Statistical analysis using repeated measures and t-tests were used to determine significant differences.

Results. The UT:LT ratios of both (W) and (UW) conditions demonstrated a u-shaped curve over 90°. The UW condition consistently demonstrated significantly higher UT:LT ratios ranging from 1.5 to 4.5, while the W ranged from 0.9 to 2.4. There was no significant difference in activation ratios between athletes and non-athletes, or between elastic and isotonic resistance. The UT demonstrated earlier activation than the LT in the UW condition. The LT reduced its latency with the addition of resistance, reversing the firing order in overhead athletes. Isotonic resistance provided slightly faster activation of the LT compared to elastic resistance.

Conclusion. These 3 studies suggest that overhead athletes demonstrate the same UT:LT ratios as non-athletes over 90° during scaption with and without resistance. Adding resistance to the scaption exercise significantly reduces the UT:LT ratio and reverses the firing order, activating the LT significantly earlier than the UT. Both elastic and isotonic resistances demonstrate similar activation ratios in overhead athletes, although isotonic resistance activates the LT faster than elastic resistance. Using these results, clinicians may improve their clinical decision-making in prescribing scaption exercises.

General Introduction

Shoulder impingement is a common condition affecting overhead athletes due to the mechanics of the throwing motion. The combination of internal rotation with elevation of the shoulder to 90°, inherent in the overhead motion, can create subacromial impingement due to a decrease in the subacromial space (SAS). Shoulder impingement, first described by Neer (Neer, 1972), can be classified into two main categories: structural and functional. Subacromial impingement can be caused by narrowing of the SAS either by a reduction in the space due to bony growth ("structural" impingement) or superior migration of the humeral head caused by weakness and/or muscle imbalance ("functional" impingement) (Brossmann, et al., 1996; Hallstrom & Karrholm, 2006; Jerosch, Castro, Sons, & Moersler, 1989; Ludewig & Cook, 2002). Functional impingement is related to glenohumeral instability (Jobe, Kvitne, & Giangarra, 1989), which is sometimes described as "Functional Instability," occurring mostly in overhead athletes less than 35 years old (Belling Sorensen & Jorgensen, 2000). Tissues below the coracoacromial arch may sustain microtrauma in overhead athletes, leading to inflammation and tendinitis (Bigliani, Ticker, Flatow, Soslowsky, & Mow, 1991; Hawkins & Kennedy, 1980).

The shoulder relies on muscles to provide dynamic stability during its large range of mobility. Freely movable joints in the human body require proper muscle balance for normal function. Opposing muscle groups surrounding a joint must be balanced in both length and strength. Proper muscle balance surrounding the shoulder is also necessary for flexibility and strength; a deficit in flexibility or strength in an agonistic muscle must be compensated by the antagonist muscle, leading to dysfunction. These muscular imbalances lead to changes in arthrokinematics and movement impairments, which may ultimately cause structural damage.

Agonist and antagonist muscle groups surrounding joints typically provide opposing movements, such as flexion/extension or abduction/adduction. Proper muscle balance between agonists and antagonists in the shoulder is necessary for balanced muscle force production; any alteration in this balance can lead to dysfunction, including functional impingement. Muscular strength balance is particularly important for synergistic muscle activations known as “force couples.” One of the most important force couples in the shoulder involves the scapular muscles: the trapezius and serratus anterior.

Different parts of the trapezius (upper, middle and lower sections) have different fascicular orientations representing different functional demands for head, shoulder, and neck movements. For example, the middle and lower fibers maintain vertical and horizontal equilibrium, rather than generate torque (Johnson, Bogduk, Nowitzke, & House, 1994; Kibler, 1998; Lindman, Eriksson, & Thornell, 1990; Mottram, 1997; Wadsworth & Bullock-Saxton, 1997). The upper portions of the trapezius (UT) are coupled with the serratus anterior (SA) to produce upward rotation of the scapula. Contrary to popular opinion, the lower trapezius (LT) is not a scapular rotator, but acts as a stabilizer to counteract the lateral pull of the serratus anterior as it upwardly rotates the scapula (Johnson, et al., 1994). The lower trapezius is particularly important because it can dynamically modify forces on the scapula during mid-elevation (Bagg & Forrest, 1986).

The dynamic scapular stabilizers coordinate the position of the glenoid with the humerus (Belling Sorensen & Jorgensen, 2000; Kibler, 1998). Rotation of the scapula positions the glenoid during flexion and abduction, provides mechanical stability of the glenohumeral (GH) joint, and maintains the length-tension relationship of the rotator cuff and deltoid (Doody, Freedman, & Waterland, 1970; Lucas, 1973; Mottram, 1997; van der Helm, 1994). Upward scapular rotation helps maintain the SAS by lifting the acromion (Ludewig & Cook, 2000). Altered muscle activation patterns of the trapezius may change the scapulohumeral rhythm, leading to narrowing of the SAS as scapular rotation lags behind humeral elevation (Wadsworth & Bullock-Saxton, 1997).

Electromyographic (EMG) analysis of the shoulder muscles is commonly used to assess muscle activation levels and patterns. Muscle activity during shoulder motion may vary among different loads and speeds of movement. During scaption with progressive normalized loads, the peak EMG of the rotator cuff and deltoid shifts to earlier in the motion, suggesting earlier recruitment of motor units (Alpert, Pink, Jobe, McMahon, & Mathiyakom, 2000). Increasing the speed also causes a rise in EMG activity earlier in the motion; however, Alpert et al. did not assess the trapezius muscle for its response to increased load or speed. In addition, the researchers did not assess the eccentric (lowering) phase of scaption.

Muscle activation patterns are important for normal shoulder biomechanics. As stated previously, different parts of the trapezius can perform differently during the same motion. Several researchers have investigated the activation patterns of the trapezius during elevation in normal subjects (Bagg & Forrest, 1986; Filho, Fulani, & De Freitas, 1991; Wiedenbauer & Mortensen, 1952); however, these studies leave several questions unanswered. For example, Wiedenbauer and Mortensen reported that the lower trapezius was especially active during abduction through 180° but they did not evaluate changes in activation with resistance or during the eccentric phase. Filho et al. found a gradual increase in all portions of the muscle during abduction and a decrease during the return eccentric phase, but their data was only descriptive and was not normalized.

Researchers refer to the muscle balance between the upper and lower portions as the UT:LT ratio. There remains little information on normative EMG values for UT:LT ratios. Recently, researchers have started to report the ratios of upper and lower trapezius activation, rather than isolated muscle values alone (Cools, Declercq, Cambier, Mahieu, & Witvrouw, 2007). This change in reporting may demonstrate recognition that the UT:LT ratio represents the true function of the trapezius. By reporting on UT:LT ratios rather than individual activation levels of each muscle, researchers can provide information on the function of the trapezius as a whole. In addition, some patients demonstrate high UT:LT ratios which may be indicative of muscle imbalance contributing to pathology. An overactive UT or underactive LT can provide valuable clinical clues, but both values must be known in order to determine the relative increase or decrease in activation. Cools and colleagues reported a1.2 to 1.4 UT:LT ratio during maximal isokinetic-resisted scaption. Using EMG ratios, clinicians may make better clinical decisions on choosing appropriate exercises that restore muscle balance.

The change in trapezius muscle activation characteristics with the addition of external resistance remains unknown. This information would be important to clinicians for several reasons. First, understanding the normal activation pattern in healthy individuals may provide a clinical baseline to examine pathological conditions. Scaption performed with and without resistance may serve as a standard clinical EMG examination to assess pathological trapezius activation patterns. Secondly, understanding changes in muscle activation timing may provide better clinical decision making in choosing the appropriate exercise. For example, if shoulder patients demonstrate altered trapezius activation patterns, it would be critical to know if a particular exercise replicates the appropriate pattern or facilitates a dysfunctional pattern. Other external factors of trapezius activation to investigate include the influence of speed of movement, different planes of movement, and different degrees of shoulder rotation during scaption. This information may improve better clinical decision making for therapeutic exercise prescription.

There is a need for more clinically-oriented research on changes in trapezius muscle activation patterns under different internal and external conditions. This might include investigation of the effects of resistance, speed, and plane of motion, as well as the influence of pain and fatigue on trapezius activation patterns. Such information may improve diagnosis of shoulder dysfunction and help determine appropriate exercise prescription.

Electromyographic analysis is also used to determine onset of activation (“latency”) and coordination with other muscles. The shoulder EMG literature is dominated by studies evaluating muscle activation *levels*, rather than activation *patterns*, as well as changes to those patterns with different exercises, loads, or other conditions. There is little agreement among researchers on what constitutes the onset of muscle activation; for example, some report onset as 5% of the MVIC (Wadsworth & Bullock-Saxton, 1997), while others report 10% of MVIC above resting potential as the onset (Cools, et al., 2002). Still others (Santos, Belangero, & Almeida, 2007) have used a computer algorithm to define onset of activation as the point when the EMG signal first rises to three standard deviations above the resting level.

Timing of scapular muscle recruitment is critical in positioning the glenoid during shoulder rotation (Kibler, 1998). The actual pattern of trapezius muscle activation during shoulder elevation is not well established in the literature, primarily because individual motor patterns are quite varied and difficult to standardize. In addition, the variety of EMG measurement techniques (surface vs. intramuscular needle EMG), different muscles tested, and different distinctions of muscle onset provide the disparate results found in the literature. During shoulder elevation in the scapular plane for example, some researchers report the upper trapezius is activated 217 ms before movement starts and the lower trapezius is activated 349 ms after movement starts (at approximately 15°) (Wadsworth & Bullock-Saxton, 1997), while others (Santos, et al., 2007) find the same pattern but shorter latencies (40 ms prior and 20-40 ms after, respectively).

Few researchers have evaluated the activation of the trapezius during weighted exercises (Moseley, Jobe, Pink, Perry, & Tibone, 1992). Moseley et al. assessed the EMG of exercises using light-weight dumbbells in normal subjects. During the scaption exercise, the UT:LT ratio reached 0.9 during 120-150° in the motion. Their study has several shortcomings, however.

There was no report on a comparison of the increase in activation from non-weighted movement patterns. This would help quantify any changes in muscle activation levels after adding resistance to establish normative levels; such levels may then be used to compare with pathological populations. In addition, the weights used by subjects were not standardized; they were self-selected by the subjects. Using self-selected weights rather than standardized weights between subjects does not allow for comparison between subjects, since these values are individualized, rather than normalized between all subjects.

Imbalances or deficits in muscular strength and activation levels can lead to functional impingement. Both glenohumeral and scapulothoracic muscle imbalance can cause dysfunction. The pathomechanics of functional impingement may involve one or both of the shoulder force couples: deltoid/rotator cuff and scapular rotators. Because of the lack of prospective studies, few if any researchers have determined if muscle imbalance is a cause or effect of impingement.

Scapular muscle imbalances can also affect rotator cuff function. The rotator cuff originates on the scapula. Weakness of scapular stabilizers may lead to “pseudo-weakness” of the rotator cuff because of a lack of proximal stabilization for the rotator cuff to provide a stable origin. The effect of scapular muscle imbalance on rotator cuff strength has not been evaluated; however, fatigue of scapular retractors does reduce rotator cuff strength (Cuoco, Tyler, & McHugh, 2004).

Scapular rotator force couple imbalance leads to weakness and altered activation patterns. Most researchers have demonstrated an increase in upper trapezius activation and decrease of the middle and lower trapezius, as well as the serratus anterior in impingement subjects (Cools, Declercq, et al., 2007; Cools, et al., 2002; Cools, Witvrouw, Declercq, Danneels, & Cambier, 2003; Cools, Witvrouw, Declercq, Vanderstraeten, & Cambier, 2004; Ludewig & Cook, 2000; Moraes, Faria, & Teixeira-Salmela, 2008; Wadsworth & Bullock-Saxton, 1997). In contrast, some have reported increased activation in both the upper and lower trapezius in patients with impingement, compared to normal subjects (Ludewig & Cook, 2000). Ludewig and Cook hypothesized that the increased lower trapezius activation compensated for decreased serratus anterior activation. Interestingly, one study found similar decreased serratus anterior activity and increased upper trapezius activity with no change in lower trapezius activity in a group of subjects with various shoulder dysfunctions compared to normals (Lin, et al., 2005).

The specific reason for these conflicting results remains unclear, but may be related to the testing techniques and different subject populations. Ludewig & Cook assessed EMG during weighted scaption in construction workers; Lin et al. evaluated EMG during 4 different functional tasks without added resistance; and Cools, Declercq et al. used maximal isokinetic resistance during abduction in overhead athletes. Different movements and resistance levels may influence activation levels, and various populations may demonstrate different activation patterns. Future studies should evaluate the influences of different movement patterns and resistance levels in various populations.

The lower trapezius perhaps plays the most important role in scapular rotation because it acts as a stabilizer (Bagg & Forrest, 1986; Johnson, et al., 1994). Decreased activation of lower trapezius or increased activation of the upper trapezius may lead to upward migration of the axis of rotation of the glenohumeral joint, thus causing impingement. It is assumed that the lower trapezius will be more active than normal if the humeral head migrates upward during shoulder elevation (Bagg & Forrest, 1986); however, research has not verified this notion. Researchers have measured simultaneous trapezius EMG and 3-dimensional kinematics in patients with shoulder dysfunction (Lin, et al., 2005; Ludewig & Cook, 2000). These studies found no significant change in humeral elevation, and either no change (Lin, et al., 2005) or an increase (Ludewig & Cook, 2000) in lower trapezius activation; however, Ludewig and Cook reported small but significant increases in anterior-posterior translation of the humerus, possibly leading to decreased SAS.

In general, most studies on strength imbalances use static muscle tests or standardized isokinetic dynamic strength tests; however, these types of measurement are very limited in their relation to function. Maximal strength testing may not be appropriate, particularly in a patient population. Instead, a submaximal effort throughout the range of motion may provide additional neuromuscular clues on muscle activation and timing, rather than isolated muscle strength, which only gives a partial picture of muscle function. For example, testing the serratus anterior on an isokinetic dynamometer at 90° of elevation in a swimmer gives little information about muscle performance during the actual swimming motion. Other measurement techniques such as EMG can provide more valuable information on muscle function.

Delays or imbalances in activation can lead to shoulder dysfunction. EMG analysis is useful in quantifying muscle activation and onset during movement. As stated previously, muscle latency and activation patterns are generally considered important factors in shoulder dysfunction, although few studies have investigated this. While changes in scapular latencies in subjects with impingement have been described by some (Cools, et al., 2003; Moraes, et al., 2008; Wadsworth & Bullock-Saxton, 1997), others report no difference in muscle latency between patients with shoulder instability and normal subjects during elevation in the scapular plane (Santos, et al., 2007).

Several researchers have evaluated the effect of submaximal external resistance on glenohumeral and scapular muscle activation patterns during elevation in impingement patients, simulating light loads used during rehabilitation (Ludewig & Cook, 2000; Machner, et al., 2003; Myers, et al., 2003; Reddy, Mohr, Pink, & Jobe, 2000). Impingement patients exhibit altered co-activation of the rotator cuff both with and without loads, compared to normals (Myers, et al., 2003). Similarly, Reddy et al. found rotator cuff and deltoid EMG was decreased in impingement patients. While these researchers did not assess scapular muscle EMG, the authors noted that periscapular muscles may compensate for deficiency in rotator cuff and deltoid activation. This conclusion is partially supported by the finding of altered scapular muscle activation patterns in impingement patients, including increased upper trapezius activity at higher loads, and reduced serratus anterior activity at all loads (Ludewig & Cook, 2000). The major limitation of these studies is their lack of simultaneous glenohumeral and scapulothoracic EMG, limiting the ability to establish any compensatory relationships between the two muscle groups. The effects of adding resistance during scaption on scapular muscle activation and balance remain unknown.

Several studies on athletes with shoulder pain indicate altered EMG patterns and muscle imbalance (Pink, et al., 1993; Ruwe, Pink, Jobe, Perry, & Scovazzo, 1994; Scovazzo, Browne, Pink, Jobe, & Kerrigan, 1991; Wadsworth & Bullock-Saxton, 1997). Overhead athletes with shoulder dysfunction typically have increased upper trapezius activation (Cools, Declercq, et al., 2007), as well as decreased activation levels of the serratus anterior (Cools, et al., 2004), and decreased lower trapezius (Cools, Declercq, et al., 2007; Cools, et al., 2004), supporting the belief that the lower trapezius and serratus are most prone to weakness (Janda, 1993).

Researchers have compared the EMG activity of the trapezius in normal individuals, overhead athletes, and those with impingement (Cools, Declercq, et al., 2007; Cools, et al., 2002; Cools, et al., 2003). Cools, Declercq, et al. reported that athletes with impingement have a significantly higher upper trapezius activation compared to normal subjects, a significant decrease in lower and middle trapezius activation, and altered trapezius muscle balance. That study, however, was limited to maximal isokinetic concentric contraction during scaption, which does not represent more functional activities with submaximal resistances. Using isokinetic testing equipment, the eccentric activity of muscles could not be assessed since subjects had to perform maximal concentric adduction to return to the starting position.

Overhead athletes with impingement have delayed onset of middle and lower trapezius fibers in response to a sudden downward movement (Cools, et al., 2003). If the lower trapezius reacts too slowly compared to the upper trapezius, the upper trapezius may become overactive, leading to scapular elevation rather than upward rotation (Cools, et al., 2003). Freestyle swimmers with impingement are reported to have increased variability in timing of the onset of scapular rotators compared to healthy swimmers (Wadsworth & Bullock-Saxton, 1997).

In summary, strength imbalances have been identified in subjects with impingement. Scaption to 90° with resistance is common exercise performed both to prevent impingement in athletes, and for rehabilitation patients with shoulder pathology. EMG and kinematic data are useful in quantifying these imbalances; however, many questions remain unanswered, including changes in the trapezius muscle balance and activation during different load conditions. Since muscle activation and timing are critical to normal shoulder function, it is important to understand the specific changes to these patterns in different conditions, as well as different populations.

Based on the literature, the following research question was proposed: How does external resistance (with a handheld weight or elastic resistance) change the upper and lower trapezius activation ratio (ie, muscle balance) during shoulder scaption to 90° in shoulders of overhead athletes? The answers to this question may have implications in both prevention and rehabilitation as clinicians try to maximize SAS and improve muscular ratios during shoulder exercises with resistance.

The purpose of this dissertation was to identify the characteristics of trapezius activation during the scaption exercise in normal subjects and overhead athletes. Three distinct studies were performed to better understand the activation levels and patterns of the trapezius. The first study was performed to quantify and compare trapezius muscle activation ratios and onset of activation in normal subjects. The second study compared the findings from first study on normal subjects with overhead athletes, while the third and final study compared the activation ratios and onset of the trapezius with 2 modes of resistance (elastic and isotonic) during scaption in overhead athletes.

Study 1

EMG Characteristics of the Trapezius Muscle during the Scaption Exercise

Therapeutic exercise for the shoulder is important for rehabilitation and injury prevention. One of the most common shoulder pathologies is subacromial impingement. There are generally 2 types of impingement: structural and functional. In structural impingement, the soft tissue is actually pinched between the acromion and humerus. On the other hand, functional impingement is often caused by muscle imbalance. Typically, functional impingement patients demonstrate an increase in upper trapezius activation and decrease of the middle and lower trapezius, as well as the serratus anterior (Cools, Declercq, et al., 2007; Cools, et al., 2002; Cools, et al., 2003; Cools, et al., 2004; Ludewig & Cook, 2000; Moraes, et al., 2008; Wadsworth & Bullock-Saxton, 1997). Decreased activation of lower trapezius or increased activation of the upper trapezius may lead to upward migration of the axis of rotation of the glenohumeral joint, thus causing impingement.

Research shows that shoulder exercises are effective at treating impingement (Desmeules, Cote, & Fremont, 2003; Michener, Walsworth, & Burnet, 2004). The goal of therapeutic exercise for functional impingement is to restore muscle balance, particularly of the trapezius. A popular rehabilitation exercise for shoulder dysfunction is “scaption,” or elevation of the arm in the scapular plane. Scaption is preferred because elevation in the scapular plane is thought to provide the best alignment of the glenohumeral joint. This exercise is often prescribed for impingement patients. Because the pathomechanics of impingement often involve imbalance of the upper trapezius (UT) and lower trapezius (LT), it’s important to understand the effects of this exercise on trapezius muscle balance. The UT:LT ratio is often used to describe the relative activation of each muscle. For example, a ratio of 1.0 indicates that both the UT and LT have the same level of activation.

The existing literature contains little information regarding the electromyography (EMG) of shoulder exercise on trapezius muscle balance. Using UT:LT activation ratios, clinicians may make better clinical decisions on choosing appropriate exercises that restore muscle balance. Recently, researchers have reported the ratios of upper and lower trapezius activation, rather than isolated muscle values alone (Cools, Declercq, et al., 2007). This change in reporting may demonstrate recognition that the UT:LT represents the true function of the trapezius. By reporting on UT:LT ratios rather than individual activation levels of each muscle, researchers can provide information on the function of the trapezius as a whole.

Timing of scapular muscle recruitment is critical in positioning the glenoid during shoulder rotation (Kibler, 1998). The actual pattern of trapezius muscle activation during shoulder elevation is not well established in the literature, primarily because individual motor patterns are quite varied and difficult to standardize. During shoulder elevation in the scapular plane for example, some researchers report the upper trapezius is activated 217 ms before movement starts and the lower trapezius is activated 349 ms after movement starts (at approximately 15°) (Wadsworth & Bullock-Saxton, 1997), while others (Santos, et al., 2007) find the same pattern but shorter latencies (40 ms prior and 20-40 ms after, respectively). The change in trapezius muscle activation patterns with the addition of external resistance remains unknown.

Clinicians should choose therapeutic exercises that optimize the UT:LT balance, although few EMG studies report this ratio. Furthermore, no studies have compared the timing of upper and lower trapezius activation with and without resistance during scaption exercise. The purpose of this study was to determine the characteristics of trapezius muscle activation during scaption during unweighted (UW) and weighted (W) conditions, including activation levels, muscle balance ratios and timing of onset.

Methods

Healthy male and female subjects (n=17) without shoulder pain were recruited to participate in the study. Dual AgCl electrodes were placed on the upper and lower trapezius of the dominant arm (Cram & Kassman 1998). An inclinometer was affixed to the lateral upper arm. EMG and shoulder angle data was collected using a MyoSystem 1400 and MyoResearch XP 1.3 software (Noraxon, Scottsdale, AZ). Electrode placement was verified with active contraction of the tested muscles. EMG data was sampled at 1000 Hz.

Subjects were seated and a Plexiglas screen was placed in the scapular plane, approximately 30° anterior to the frontal plane; the stopping point of 90 degrees was verified with a goniometer and a marker was placed on the Plexiglas. Subjects performed 3 repetitions of scaption to 90° with the palm on the Plexiglas to maintain neutral humeral rotation. For both conditions, subjects completed each repetition in approximately 6 seconds (3 seconds for concentric and 3 seconds for eccentric phases) at a rate of 30°/s. For the W condition, subjects were given a dumbbell resistance that was standardized to each individual using an anthropometric formula (Li, Landin, Grodesky, & Myers, 2002) and then repeated the 3 repetitions with the dumbbell. The order of the testing was always UW before the W condition to minimize the effects of fatigue with the resistance condition.

Data Analysis

MyoResearch XP 1.3 software was used to rectify, filter, and smooth EMG data with a 2nd order low-pass Butterworth filter at 500 Hz and RMS smoothing with a 100ms window. The average EMG level over 30 degree increments (30-60°, 60-90°, 90°, 90-60°, and 60-30°) was determined over the 3 repetitions for both UW and W conditions in each subject and then averaged. The UT:LT ratio was then determined for each interval and condition. Next, the average onsets of activation of the UT and LT were determined for each condition using the

MyoResearch software as the time when activation exceeded 3 standard deviations of resting levels. Using SPSS 17.0 (Chicago, IL), t-tests were used to determine if the W and UW conditions were significantly different in activation, ratio, and onset of activation. Statistical significance was set at p<.05.

Results

Activation Levels. The percent increase in UT and LT activation levels from the UW and W conditions is presented in Table 1.1. The UT activation increased between 118 and 164%, while the LT increased between 248 and 325% after adding a standardized weight. The largest increases in activation in both muscles occurred at 90°. All W conditions were significantly greater than UW conditions for both muscles and all intervals (p=.000).

Table 1.1: Percent increase in UT & LT activation levels after adding weight to scaption for each interval. (* indicates significant difference, p=.000)

	30-60°	60-90°	90°	90-60°	60-30°
Upper Trap	118%	149.8%	163.9%	137.9%	158.2%
Lower Trap	285%*	289.8%*	325.2%*	285.8%*	248%*

Activation Ratios. The average UT:LT ratios in both UW and W conditions is presented in Table 1.2 and Figure 1.1. The UT:LT ratio was maximal during the concentric phase, less during the eccentric phase, and minimal at the mid-range of motion. Subjects demonstrated a “u-shaped” profile of the ratio in both conditions, but the UT:LT ratio consistently was lower in the W condition. Statistically significant lower activation ratios were noted in the 30-60° concentric, 90°, and 90-60° eccentric intervals.

Timing. The average onset of muscle activation in both UW and W conditions is presented in Table 1.3. During the UW condition, the UT was activated first in 12 of 13 subjects, with average latency of 589 ms. In the W condition, the LT was activated first in 11 out of 13

Table 1.2: Average UT:LT ratios (± SD), percent difference between UW and W conditions, and p-values (*statistically significant)

	Concentric			**Eccentric**	
	30-60°	**60-90°**	**90°**	**90-60°**	**60-30°**
Unweighted	3.2 ± 3.4	1.8 ±1.75	1.5 ± 1.24	1.6 ±1.6	2.2 ±2.2
Weighted	1.6 ± 1.47	1.2 ±1.28	0.9 ± .84	1 ± .65	1.6 ± .97
Difference	-100%	-50%	-66.60%	-60%	-37.50%
p-value	.010*	.105	.035*	.022*	.208

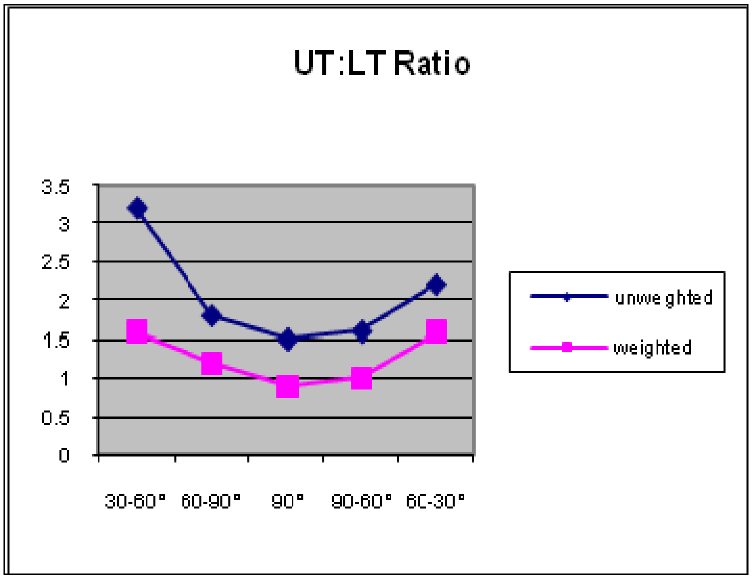

Figure 1.1: UT:LT ratio of UW and W conditions

Table 1.3: Average onset of muscle activation (in seconds)

	Unweighted	Weighted	p-value
Upper Trapezius	.589 ± .46	.942 ± .46	.008
Lower Trapezius	1.147 ± .70	.646 ± .27	.062

subjects. Comparing the UW and W conditions, the UT was 63% slower in the W condition, while the LT was 56% faster. Onset of activation was significantly longer in the UT in the weighted condition, while the LT was earlier, but only approaching statistical significance. Figure 1.2 demonstrates the reversal in firing order of the UT and LT between UW and W conditions.

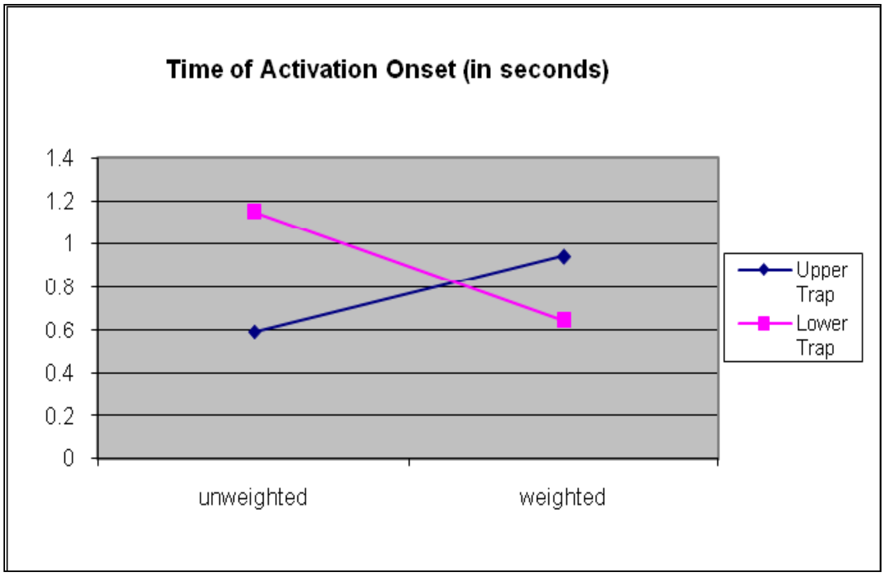

Figure 1.2: Average onset of muscle activation (in seconds)

Discussion

The scaption exercise is commonly used in rehabilitation of shoulder impingement patients. This study has quantified the changes in upper and lower trapezius activation levels, ratio, and timing during scaption exercise to 90° with and without resistance in healthy normal subjects. Adding weight to the scaption exercise improves each variable through increased activation of the LT. Findings related to activation levels are discussed first, then the results of the UT:LT ratio will be discussed, followed by the results of onset timing.

Activation Levels. As one would expect, both muscles significantly increased in activation with the addition of a standardized weight. Interestingly, the UT increased in activation between 118-164%, while the LT increased in activation nearly twice as much, between 248 and 325%. It may be possible that the larger increase in LT is due to an increased need for scapular stabilization, since it functions more as a stabilizer than mover (Bagg & Forrest, 1986; Johnson, et al., 1994). The disproportionate increase in LT compared to UT may also be related to changes in activation of other muscles, such as the serratus anterior (Ludewig & Cook, 2000) or strategies to maintain the subacromial space (SAS) with added resistance. The serratus anterior is synergistic with the UT as a primary upward rotator of the scapula; adding resistance during the exercise likely increases activation of the SA to assist the UT in rotating the scapula.

It is assumed that the LT will be more active than normal if the humeral head migrates upward during shoulder elevation (Bagg & Forrest, 1986), however research has not verified this notion. In addition, the LT may posteriorly tilt the scapula, or oppose anterior tilt. Anterior scapular tilt reduces the SAS; it's possible that the LT is activated more during weighted scaption to maintain the SAS during shoulder elevation. This hypothesis is countered by the findings of Graichen and colleagues (Graichen, et al., 2005), who noted a decrease in SAS during weighted abduction, although those patients were in a supine position. The supine position may have reduced the activation of the UT because of the lack of gravity on the shoulder girdle.

In the current study, the greatest increase in activation level was seen at 90° in both muscles. This may be due to the fact that subjects changed direction from concentric scaption to eccentric scaption; this change in direction may have also required increased muscle activation to stabilize the scapula to change muscle activation as the direction of motion was reversed.

While this study evaluated scapular activation patterns in healthy shoulders, other researchers have evaluated the effect of external resistance on scapular muscle EMG in patients with impingement. Using submaximal loads, Ludewig and Cook (Ludewig & Cook, 2000) found increased UT activity at higher loads, and reduced SA activities at all loads. In comparison, Cools et al. (Cools, Declercq, et al., 2007) found significantly higher UT activation and reduced LT activation in athletes with impingement compared to control subjects during maximal isokinetic scaption.

Muscle activity during shoulder motion may also vary among different load and speed conditions. During 180 degrees of scaption with progressive normalized loads, the peak EMG of the rotator cuff and deltoid shifts to earlier in the motion, suggesting earlier recruitment of motor units (Alpert, et al., 2000). The current study did not demonstrate such a shift in the trapezius, instead finding the greatest activation levels at 90°. In comparison to Alpert et al., this study only used one resistance load through 90 degrees.

Subjects performed 90 degrees of motion because this is the typical limit on the scaption exercise performed in patients with impingement. Raising the arm above 90° is thought to further decrease the SAS, possibly aggravating impingement symptoms. Because this study may be replicated in impingement patients, only 90° of scaption was used; such limited ROM may not give full representation of the trapezius activation, since Moseley et al. (Moseley, et al., 1992) reported peak activation of the upper and lower trapezius at 120-150° during resisted scaption.

The activation levels reported here are not normalized for several reasons. First, the purpose was to evaluate changes in activation of the same muscle in 2 conditions; therefore, the muscle was compared to itself, and did not need to be normalized for comparison between subjects. Using a percentage of EMG during a submaximal movement to compare between subjects has been suggested (Palmerud, et al., 1995). In addition, this study did not normalize EMG levels to maximum voluntary isometric contraction (MVIC) because this study should be replicated in subjects with shoulder impingement. It would be difficult to attain true MVIC of patients experiencing painful impingement. In addition, the reproducibility and stability of MVIC testing is questionable (Aaras, Veierod, Larsen, Ortengren, & Ro, 1996; Jensen, Vasseljen, & Westgaard, 1993).

Ratio. It is important to compare relative activation between the UT and LT, rather than assessing their activation independently. These regions of the trapezius can be synergistic in frontal-plane rotation or antagonistic in elevation/depression. This relationship is a primary factor in the development of muscle imbalances and subsequent dysfunction. For example, the

LT is often found clinically to be weak, while the UT is often found to be tight and overactive (Janda, 1993). If a weak LT cannot counteract the upward pull of a tight UT, the subacromial space may become reduced, leading to impingement.

Both UW and W conditions demonstrate a “u-shaped” profile. The UW ratio ranged from 3.2 to 1.5, while the W ratio ranged from 0.9 to 1.6. There remains little information on normative values for UT:LT ratios, although Cram & Kassman (Cram & Kasman, 1998) suggest a 1:1 ratio during shoulder abduction in their textbook. This suggestion has not been validated in any published study, and seems oversimplified considering the results of this study. Recently, Cools et al. (Cools, Declercq, et al., 2007) reported on the UT:LT ratios of overhead athletes with and without impingement during maximal isokinetic scaption. They noted a 2.19 ratio in the painful shoulder and 1.56 in the uninvolved shoulder. In comparison, they found overhead athletes without impingement exhibited ratios between 1.23 and 1.36. These findings are somewhat consistent with the current study, noting ratios between .9 and 1.6 in the W condition; however, Cools et al. did not evaluate an UW condition.

In the UW condition, the highest ratio was in the 30-60° interval, indicating higher UT activation in the initial phases of the UW condition. During the W condition, this ratio significantly decreased by 100% due to the increase in LT activation early in the range of motion. Consequently, the UW condition produced an asymmetrical curve during the start of the concentric phase. The ratios were significantly different between the UW and W conditions during the 30-60° concentric, 90°, and 90-60° eccentric phases, while the 60-90° concentric and 60-30° intervals were not significantly different. The final interval of the eccentric phase (60-30°) provided the least amount of difference between conditions (37.5% lower ratio in the W condition).

Knowing the UT:LT ratio will help in choosing appropriate exercises during rehabilitation. In patients with classic trapezius muscle imbalance (tight UT and weak LT), clinicians should choose exercises that have lower UT:LT ratios in order to restore “normal” muscle balance. Exercises with high UT:LT ratios, such as a shoulder shrug, may not be an appropriate choice for rehabilitation. Ideally, an exercise to restore muscle balance should have a ratio less than 1.0. Cools et al. (Cools, Dewitte, et al., 2007) found 4 shoulder exercises with favorable UT:LT ratios less than 1.0: sidelying external rotation (.16), sidelying forward flexion (.32), prone horizontal abduction with external rotation (.46) and prone extension (.59). The authors reported that scaption with light weights produced a ratio of 1.9 between 0 and 90°, which is greater than reported in the current study.

Timing. As described earlier, some researchers report the upper trapezius is activated 217 ms before movement and the lower trapezius is activated 349 ms after movement starts (Wadsworth & Bullock-Saxton, 1997), while others (Santos, et al., 2007) find the same pattern but shorter latencies (40ms prior and 20-40 ms after, respectively). Unfortunately, neither Santos et al. or Wadsworth and Bullock-Saxton evaluated changes in muscle activation pattern with the addition of hand-held weights. The current study found the same temporal pattern in the UW condition, but longer latencies, noting upper trapezius latency averaging 589 ms, followed by lower trapezius at 1147 ms. The large difference in latencies between these studies may be due to different definitions of ‘onset of activation.’ Unfortunately, there is little agreement among researchers on what constitutes the onset of muscle activation. The current study used the pre-defined routine within the MyoResearch XP software to calculate latency as the time when activation exceeded 3 standard deviations of resting levels from the onset of motion.

Adding a standardized weight to scaption reversed the temporal pattern, noting LT activation (646 ms) before UT activation (942 ms). As postulated previously, the lower trapezius may undertake more of a stabilization role in weighted conditions, causing it to fire earlier and at higher levels. While there was a statistically significant increase in UT latency (p=0.008), the decrease in LT latency only approached significance (p=0.062) with the addition of a hand-held weight.

The change in trapezius muscle activation patterns with the addition of hand-held weights provides valuable information. Understanding the normal activation pattern in healthy individuals may provide a clinical baseline to examine pathological conditions. Scaption performed with and without hand-held weights may serve as a standard clinical EMG examination to assess pathological trapezius activation patterns. Secondly, understanding changes in muscle activation timing may provide better clinical decision making in choosing an appropriate exercise. Based on this study, it would appear that scaption to 90° with weights would be an appropriate exercise to facilitate early activation of the lower trapezius. This information may improve clinical decision making for therapeutic exercise prescription.

This study has several limitations. First, only healthy subjects were tested. As suggested previously, these results should be compared to patients with impingement. By understanding the normal changes in activation in healthy shoulders, clinicians may be able to use these values as a diagnostic in patient populations. The number of subjects is relatively small, and should be continued with more subjects to establish normative values in healthy shoulder.

This study did not examine actual changes in the SAS or scapular kinematics during the scaption exercise. It would be interesting to see if the SAS was decreased during the exercise as reported by Graichen et al. (Graichen, et al., 2005) in both healthy subjects and impingement patients. Scapular kinematic data may provide some insight into the changes noted with muscle activation levels, comparing the UW and W conditions.

Another limitation was the examination of only the upper and lower trapezius. The purpose of this study was to report only on the relative changes in the trapezius. Future studies may include other scapular muscles such as the serratus anterior or the glenohumeral muscles.

Finally, only 1 standardized resistance was used in this study. More research using progressive weights, different modes of resistance (elastic tubing, isokinetics, etc), and different speeds of motion may provide more information to support clinical decision making.

Conclusion

In healthy subjects, adding resistance to the scaption exercise increases lower trapezius activation significantly more than upper trapezius, thus improving the UT:LT ratio during the exercise. This suggests the weighted scaption exercise may be beneficial during rehabilitation of impingement patients with scapular muscle imbalance, although further research is needed. In addition, adding resistance shortens the latency of the lower trapezius, and reverses the temporal activation pattern in healthy subjects. This study provides evidence to support better clinical decision making in shoulder rehabilitation, but more research is needed on patient populations.

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Study 2

A Comparison of Trapezius Muscle Activation between Overhead Athletes and Healthy Subjects during a Scaption Exercise

Shoulder impingement is a common condition affecting both athletes and non-athletes and is particularly troublesome to overhead throwers due to the mechanics of the motion. A frequently performed exercise in rehabilitation and prevention is “scaption,” which is arm elevation performed in the scapular plane. Elevating the shoulder in this fashion provides the most stability and mobility of the shoulder joint (Borsa, Timmons, & Sauers, 2003; Comtet, Herzberg, & Naasan, 1989; Johnston, 1937).

One of the goals of shoulder rehabilitation is to improve muscle balance, particularly balance of the upper trapezius (UT) and lower trapezius (LT). The ratio of UT to LT activation (UT:LT) helps identify imbalances: ratios greater than 1.0 indicate more UT activity than LT, while ratios less than 1.0 indicate more LT activity. In general, higher ratios are not favorable in shoulder rehabilitation; therefore it’s important to find exercises with UT:LT ratios near or below 1.0 (Cools, Dewitte, et al., 2007).

The first study presented in this dissertation using normal, healthy individuals performing the scaption exercise found that adding resistance to the exercise increases lower trapezius activation significantly more than upper trapezius, thus improving the UT:LT ratio during the exercise. This finding suggests that the weighted scaption exercise may be beneficial during rehabilitation of impingement patients with scapular muscle imbalance. In addition, adding resistance shortened the latency of the lower trapezius, and reversed the temporal activation pattern. Without weight, the upper trapezius fired first, while adding a weight caused the lower trapezius to fire first.

Because the first study of this dissertation was limited to non-athletes, further research was needed to determine if overhead athletes exhibit similar responses to the exercise. Overhead athletes commonly perform this exercise as part of a preventive exercise program and for rehabilitation after injury. Trained overhead athletes may exhibit different muscle activation characteristics from untrained individuals. It would be important to know if athletes have different trapezius activation ratios or timing of onset to identify any competitive advantage over non-athletes. In addition, such information may provide possible parameters for injury prevention and return to sport after shoulder rehabilitation. The purpose of this study was to compare trapezius muscle activation during scaption in baseball position players with healthy non-athletes during unweighted (UW) and weighted (W) conditions, including activation levels, muscle balance ratios and timing of onset.

Methods

Healthy normal subjects (n=17) and baseball position players (n=12) without shoulder pain were recruited to participate in the study. Dual AgCl electrodes were placed on the upper and lower trapezius of the dominant arm (Cram & Kasman, 1998). An inclinometer was affixed to the lateral upper arm. EMG and shoulder angle data was collected using a MyoSystem 1400 and MyoResearch XP 1.3 software (Noraxon, Scottsdale, AZ). Electrode placement was verified with active contraction of the tested muscles. EMG data was sampled at 1000 Hz.

Subjects were seated and a Plexiglas screen was placed in the scapular plane, approximately 30° anterior to the frontal plane; the stopping point of 90 degrees was verified with a goniometer and a marker was placed on the Plexiglas. Subjects performed 3 repetitions of scaption to 90° with the palm on the Plexiglas to maintain neutral humeral rotation. For both conditions, subjects completed each repetition in approximately 6 seconds (3 seconds for concentric and 3 seconds for eccentric phases) at a rate of 30°/s. For the W condition, subjects were given a dumbbell resistance that was standardized to each individual using an anthropometric formula (Li, et al., 2002) and then repeated the 3 repetitions with the dumbbell.

The order of the testing was always UW before the W condition in order to prevent the potential effects of fatigue or changes in neuromuscular activation by using a weight first.

Data Analysis

MyoResearch XP 1.3 software was used to rectify, filter with a 2nd order low-pass Butterworth filter at 500 Hz and smooth data using RMS with a 100ms window. The average EMG level over 30 degree increments (30-60°, 60-90°, 90°, 90-60°, and 60-30°) was determined over the 3 repetitions for both UW and W conditions for each subject and then averaged. The UT:LT ratio was then determined for each interval and condition. Next, the average onset of activation of the UT and LT were determined for each condition using the MyoResearch software as the time when activation exceeded 3 standard deviations of resting levels. Using SPSS 17.0 (Chicago, IL), repeated measures ANOVA used to determine if the W and UW conditions were significantly different between groups in activation levels and UT:LT ratio, while a simple t-test was used to analyze the difference in onset of activation between the W and UW conditions. Statistical significance was set at $p<.05$.

Results

Activation Levels. The increase in activation of the upper trapezius after adding resistance ranged from 147% to 187% in baseball players, compared to a range of 118-164% in normal subjects (Figure 2.1). The lower trapezius increased from 257% to 323% in baseball players, compared to 248-325% in normals (Figure 2.2); therefore increases in both populations were similar. There was no statistically significant difference between changes in activation levels between normal subjects and baseball players ($p>.05$).

Ratios. The weighted condition resulted in lower UT:LT ratios in both groups (Table 2.1), indicating a larger increase in LT activation when using a weight. In baseball players, the UT:LT ratio demonstrated similar trends to normal subjects with a “u-shaped” profile, although

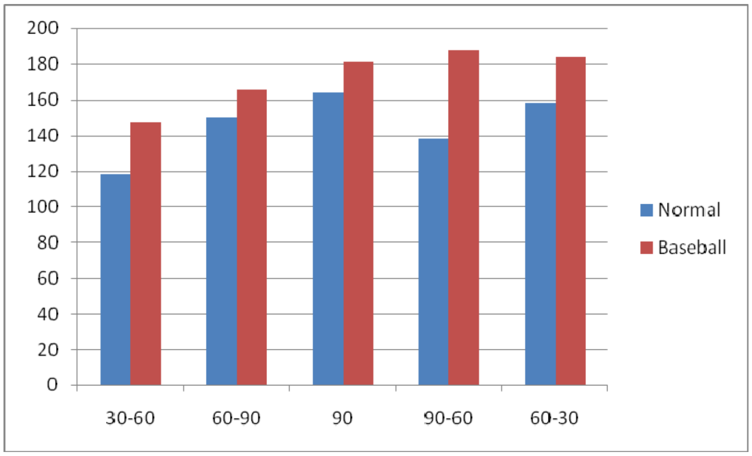

Figure 2.1: Percent increase in UT activation after adding hand held weight

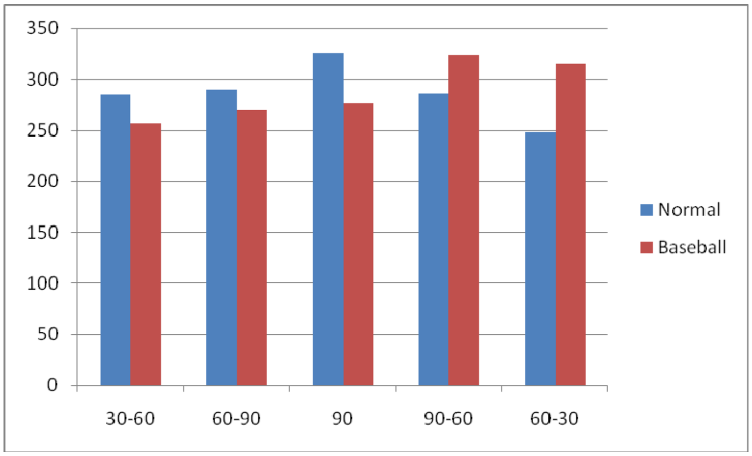

Figure 2.2: Percent increase in LT activation after adding hand held weight

Table 2.1: UT:LT ratios of UW and W conditions in baseball players and normal subjects

	30-60°	60-90°	90°	90-60°	60-30°
UW Baseball	1.82 ± 1.45	1.67 ± 1.45	1.59 ± 1.27	1.96 ± 2.11	3.1 ± 3.5
UW Normal	3.2 ± 3.4	1.8 ± 1.75	1.5 ± 1.24	1.6 ± 1.6	2.2 ± 2.2
W Baseball	1.26 ± .83	1.09 ± .71	1.07 ± .61	1.21 ± .68	2.42 ± 3.25
W Normal	1.6 ± 1.47	1.2 ± 1.28	0.9 ± .84	1.0 ± .65	1.6 ± .97

less shallow and symmetrical (Figure 2.3). The average UW UT:LT ratio in baseball players ranged from 1.6 to 3.1, while the average ratio ranged from 1.5 to 3.2 in normal subjects; the average W ratio ranged from 1.1 to 2.4 and 0.9 to 1.6 in baseball players and normal subjects, respectively. There was no significant statistical difference between the groups for the UT:LT ratio at any ROM interval in the UW (p = .935) or W (p=.727) conditions.

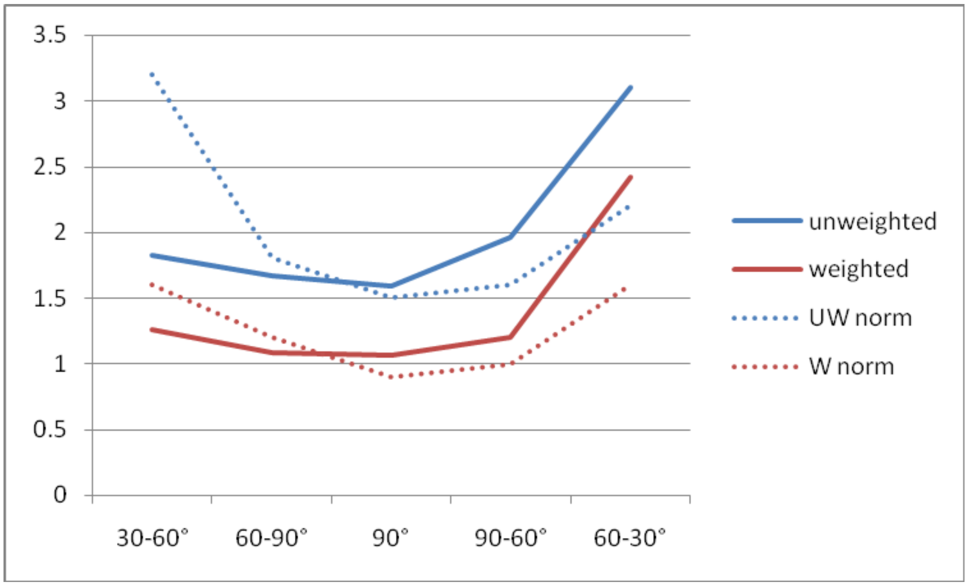

Figure 2.3: UT:LT ratios of W and UW conditions in baseball players and normal subjects

Timing. In regards to the onset of activation, the difference scores were calculated in the UW and W conditions by subtracting the LT onset time in seconds from the UT onset (difference=UT-LT). A negative value indicates that the UT fired first (Table 2.2). A simple t-test was performed to determine differences between baseball players and normal individuals for their change in onset of activation between conditions. In the UW condition, the difference scores were not significantly different (p=.127). Both groups activated the UT first, averaging 0.559 seconds earlier than LT in the normal group, and 0.156 seconds earlier in the baseball group. During the W condition, however, there was a significant difference between groups, as

Table 2.2: Difference in onset of activation between UT and LT in baseball players and normal subjects (*indicates significant difference)

Condition	Group	Average Difference (seconds)
Unweighted	Normal	-.559 ± .555
	Baseball	-.156 ± .709
Weighted	Normal	-.057 ± .444
	Baseball	.362 ± .397*

the baseball players activated their LT significantly faster than the normal individuals (p=.021). Baseball players averaged activation of their LT 0.362 seconds prior to the UT, compared to normal individuals who still fired upper trapezius first 0.057 seconds before LT, but faster than the UW condition.

Discussion

This study compared the changes in upper and lower trapezius activation levels, ratio, and timing during scaption exercise to 90° with and without resistance in healthy normal subjects and overhead athletes. Scapular muscles such as the UT, LT and serratus anterior must work together in a balanced and efficient manner for normal scapular kinematics. Abnormal scapular motion may cause further dysfunction, causing more harm than good. In particular, the balance of the upper and lower portions of the trapezius is important to ensure normal upward rotation of the scapula. This allows the glenoid to be properly positioned with the humerus during shoulder elevation. A decrease in scapular upward rotation may lead to subacromial impingmenet as the humerus elevates.

The lower trapeizus must counteract the upward movement caused by contraction of the UT (Bagg & Forrest, 1986); therefore, both the UT and LT must be balanced as a “force couple” to ensure normal scapular rotation, both concentrically as the arm is raised, and eccentrically as the arm is lowered. Clinicians prescribing both rehabilitation and preventive exercise programs should consider exercises that facilitate the appropraite UT:LT ratio (Cools, Dewitte, et al., 2007).

The scaption exercise consists of elevation of the arm in the scapular plane, which is approximately 30° anterior to the frontal plane. Its popularity as an exercise is likely due to research showing that scaption provides the most balanced relationship of the glenohumeral ligaments and congruity of the humerus on the glenoid (Borsa, et al., 2003; Comtet, et al., 1989; Johnston, 1937). While biomechanically efficient, few researchers have evaluated the EMG activation levels or timing of activation of the trapeizus during resisted scaption. This study demonstrated that both baseball position players and normal subjects exhibit similar activation levels and UT:LT ratios during a resisted scaption exercise. In this discussion, findings related to activation levels are presented first, then the results of the UT:LT ratio are discussed, followed by the results of onset timing.

Activation Levels. Both groups increased in activation levels of each muscle with the addition of a hand-held weight. While the UT increased 118 to 187% in both groups, the LT experienced much more activation with the addition of a weight, ranging from 248 to 325%. This is likely explained by the need for the lower trapezius to counteract the increased activation of the UT and serratus anterior against resistance to balance scapular elevation and protraction caused by those muscles, respectively.

Ratios. Few researchers have assessed the ratios of UT:LT in healthy overhead athletes, instead focusing on athletes with impingement (Cools, Declercq, et al., 2007; Cools, et al., 2003; Cools, et al., 2004), reporting resisted UT:LT ratios of 1.23 in healthy subjects to 2.19 in athletes with impingement. This supports an increase in UT and/or decrease in LT activation in athletes with impingement, consistent with Janda's findings in muscle imbalance syndromes (Janda, 1993). The current study found similar ratios of UT:LT activation during scaption, finding a range of 1.1 to 2.4, and 0.9 to 1.6 for baseball position players and normal subjects respectively during W scaption (See Table 2.1).

Both normal subjects and baseball players decrease their UT:LT ratios with the addition of a handheld weight, reducing the ratios to 1.1 to 2.4, and 0.9 to 1.6 for baseball players and normal subjects, respectively. The differences were greater in magnitude for the normal individuals (27 to 100% decrease) compared to baseball position players (22 to 38%), although not statistically different between groups. This characteristic may demonstrate a ‘training effect’ of overhead athletes as a better ability to activate their LT with the addition of resistance, or minimization of UT activation compared to untrained subjects.

The u-shaped representation of the UT:LT ratio through 90° of concentric and eccentric scaption is similar in both normal subjects and baseball players. Interestingly, baseball players demonstrated higher UT:LT ratios during the late eccentric portion (60-30°), while normal subjects demonstrate higher ratios at the beginning of the concentric motion between 30-60°. It is possible that baseball players initiate abduction with more LT activation and use more UT during the eccentric lowering phase, possibly due to a training effect since these athletes regularly perform the resisted scaption exercise. The lowest ratios consistently occurred at 90° in both conditions and both populations. The 90° UT:LT ratio was higher in the unweighted condition, though not statistically different between baseball players and normal subjects.

While the ratio of UT:LT is an important consideration in terms of muscle activation levels, the timing of activation is also an important consideration when prescribing appropriate exercises for normal scapular function. The order of firing is critical to synergistic muscle function: a muscle firing out of sequence (early or late) may change kinematics, leading to or contributing to dysfunction.

Timing. This study defined onset of activation as other researchers have (Santos, et al., 2007), using a computer algorithm to define onset of activation as the point when the EMG signal first rises to three standard deviations above the resting level. Both groups activated their UT first during the UW condition, with the difference between UT and LT averaging 0.599s for normal subjects and 0.156s for baseball players. This indicates that baseball players had shorter latency than normal subjects in activating their LT. Interestingly, the addition of a hand-held weight resulted in a reversal of the firing order for the baseball players who activated their LT significantly faster than the UW condition, averaging 0.362 s prior to the UT. Normal subjects also reduced the difference in onset between the UT and LT (indicating faster onset of LT), but continued to activate the UT first. The difference between the groups may be attributed to a training effect since baseball players regularly perform weighted scaption, and may more readily activate LT to counteract an increase in scapular elevation and protraction caused by other scapular muscles during resisted scaption.

There are several limitations in this study. First, it was limited to healthy individuals without shoulder pathology. While information on healthy athletes might be beneficial in guiding decision-making for preventive exercise programs, the response of individuals with shoulder impingement and/or instability remains unknown. Therefore, this study should be replicated in subjects with impingement.

The EMG data was not normalized to maximal voluntary isometric contraction (MVIC), which is considered the standard in interpreting muscle activation. However, since this study was only concerned with the percent increase between UW and W conditions, and the ratio of UT to LT, it was not necessary to normalize the muscle activation to itself. Converting subjects' EMG activation to UT:LT ratio served as normalization for between-subject comparisons. Furthermore, testing MVIC on subjects with impingement may hamper attempts to replicate the methods of this study in patient populations.

This study only evaluated 2 muscles: the UT and LT. While the serratus anterior is involved in scapular rotation, the focus of this study was to evaluate the UT:LT ratio. Future studies should evaluate the effect of resistance on other muscles including the serratus anterior and rotator cuff. In addition, other modes (isokinetic, etc) and intensity levels should be evaulated.

Conclusion

These results are the first to quantify differences in trapezius EMG activation between W and UW conditions in both normal subjects and overhead athletes. This study indicates that normal subjects and baseball players demonstrate similar trapezius activation patterns and ratios. Addition of a standardized weight to the scaption exercise decreases the latency of LT firing in both groups; however, normal subjects continue to activate their UT first while baseball players reverse the order of activation, firing their LT first. These findings may have implications for both prevention and rehabilitation exercises in overhead athletes.

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Study 3

A Comparison of Elastic and Isotonic Resistance on Trapezius Muscle Balance in Overhead Athletes

Overhead athletes regularly perform shoulder strengthening exercises for prevention and performance enhancement, as well as for rehabilitation after injury. One common exercise is “scaption,” or elevation of the arm in the scapular plane. The scaption exercise is often performed with either isotonic resistance (cuff weight or dumbbells) or elastic resistance. Both modes of resistance demonstrate similar electromyographic (EMG) patterns (LeBlanc, et al., 2003; Matheson, Kernozek, Fater, & Davies, 2001); however, no studies have specifically investigated the difference in scapular muscle activation patterns between these 2 modes of resistance.

Elastic resistance can be quantified into pounds of resistance to calibrate it to isotonic weights. In a small pilot study, 3 samples of Thera-Band® resistance tubing were assessed for pounds of force produced when stretched. Each 12” sample of tubing was pre-stretched to 200% to set the initial length of material, and the resting length was verified. One end was securely attached to a force transducer (Noraxon USA, Scottsdale AZ), while the examiner pulled the other end to 150% elongation. The force produced at 50, 100, and 150% elongation was recorded both concentrically and eccentrically using Noraxon MyoResearch 1.3 software. There was a consistent increase and decrease of the tubing resistance with concentric and eccentric directions, respectively: yellow ranged from 2.2 to 4.8 lb; red from 2.8 to 5.6 lb; green 4 to 7.9 lb, and blue was 4.7 to 9.2 lb (Table 3.1).

The results of Study 2 in this dissertation revealed that healthy baseball players and non-athlete subjects exhibit similar upper trapezius (UT) and lower trapezius (LT) EMG activation patterns using isotonic resistance. Both groups demonstrated a reduction in the UT:LT ratio with the addition of resistance during the scaption exercise. Overhead athletes perform the scaption exercise with either hand-held isotonic weights or elastic bands or tubing. The question remains as to which mode (elastic or isotonic) provides more favorable trapezius activation levels and patterns. The effect of these different modes of exercise on the ratio of UT to LT activation (UT:LT) is not known.

Table 3.1: Force of Thera-Band tubing in pounds

	50%	100%	150%	100% eccentric	50% eccentric
Yellow	2.2	3.6	4.8	3.6	2.2
Red	2.8	4.4	5.6	4.3	2.7
Green	4	6.2	7.9	6.1	3.9
Blue	4.7	7	9.2	6.9	4.5

The purpose of this study was to compare the UT:LT ratio between elastic and isotonic resistance in overhead athletes, as well as to determine the order of activation of each muscle between the modes of resistance. The null hypotheses were (1) there will be no significant difference in the UT:LT ratio between the elastic and isotonic resistance, and (2) there will be no significant difference in the order of activation of the UT and LT between elastic and isotonic resistance.

Methods

Twenty-three collegiate male baseball (n=10, mean age 19.5) and female softball (n=13, mean age 19.5) performed scaption to 90° of abduction in a sitting position without resistance, then with elastic and isotonic resistance in a random order. Dual AgCl electrodes were placed on the upper trapezius (half way between C7 and the posterior lateral acromion) and lower trapezius (at a 55° angle at medial inferior border of scapula) of the dominant shoulder. The reference electrode was placed on the C-7 spinous process. EMG data was captured with the MyoSystem 1400 (Noraxon USA, Scottsdale AZ). Electrode location was verified by active scapular elevation and retraction/depression. A digital inclinometer (Noraxon) was attached to the lateral forearm, and in-line force transducer (Noraxon) was integrated for data collection. Subjects first performed scaption to 90° without resistance to establish a baseline of muscle activation. Subjects then grasped either a standardized isotonic dumbbell based on anthropometric measurements (Li, et al., 2002) or elastic tubing of an equivalent force. The color level of tubing provided for the exercise was chosen based on the results of the forces determined in the pilot study discussed previously (Table 3.2). The order of testing was randomized by drawing a number 1 (Weight) or 2 (Tubing). Subjects were seated on an adjustable-height stool and elevated so that there was no slack in the tubing. Subjects then performed 3 repetitions at a pace of 30°/s for each condition to replicate the pace of clinical application.

Table 3.2: Thera-Band tubing color prescribed based on standardized dumbbell resistance

Standardized weight	Thera-Band Tubing Color
5 #	yellow
6 -7#	red
8-9 #	green
10#	blue

Data collection included the level of EMG activation in each condition through 30° intervals both concentrically and eccentrically, as well as timing of onset of activation. MyoResearch XP 1.3 software (Noraxon) was used to rectify, filter with a 2nd order low-pass Butterworth filter at 500 Hz, and smooth using RMS with a 100ms window. The average EMG level over 30° increments was determined over the 3 repetitions for all 3 conditions in each subject and then averaged. The UT:LT ratio was then determined for each interval and condition. Next, the average onset of activation of the UT and LT was determined for each condition using the MyoResearch software as the time when activation exceeded 3 standard deviations of resting levels.

To analyze the order of activation, the difference in activation onset time was obtained by subtracting the onset of the LT from the UT, and recorded in seconds. A negative score indicated the UT fired first, while a positive score indicated the LT fired first. Statistical analysis with SPSS 17.0 (Chicago, IL) was performed to assess differences in activation pattern with a two-way repeated measures ANOVA, using the within-subjects factor of 5 ROM increments (30-60°, 60-90°, 90°, 90-60° and 60-30°), and three between-subject factors of type of resistance conditions (unweighted (UW), isotonic, and elastic). The difference in seconds between the onset of the UT and LT was analyzed using a repeated measure ANOVA with type of resistance as the independent factor. A repeated measure ANOVA was also performed to detect any effects of gender. The significance value was set at p<.05. A post-hoc analysis using Tukey's Least Significant Differences (LSD) was also performed for pairwise comparison.

Results

The UT:LT ratio during the UW condition demonstrated a u-shaped curve through the ROM, ranging from 2.9 to 4.5 (Figure 3.1). These ratios indicated the UT fired at a higher level than the LT in the UW condition. The UW condition demonstrated a main effect with

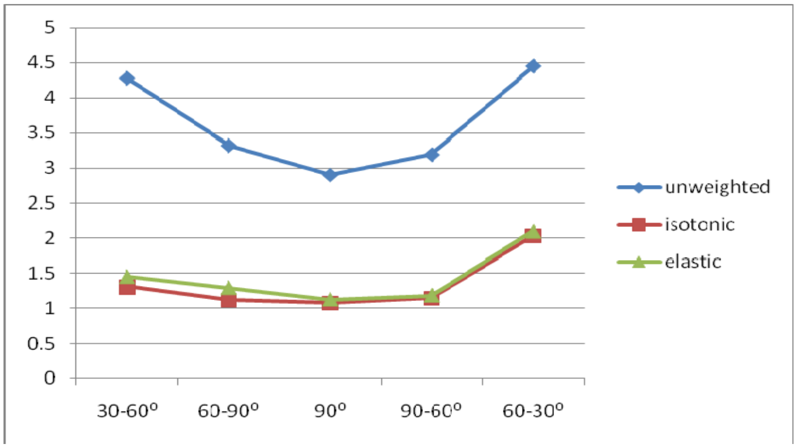

Figure 3.1. UT:LT ratio at different increments of ROM between UW, isotonic, and elastic conditions

Table 3.3: UT:LT ratios at different ROM across 3 conditions
*Indicates the UW condition is significantly greater than the isotonic and elastic conditions at each ROM interval.

degrees	Unweighted	Isotonic	Elastic
30-60°	4.28 ± 4.1*	1.3 ± 1.1	1.45 ± 1.3
60-90°	3.32 ± 3.4*	1.11 ± 1.1	1.29 ± 1.1
90°	2.90 ± 2.9*	1.07 ± 0.9	1.12 ± 0.9
90-60°	3.19 ± 3.4*	1.14 ± 0.9	1.18 ± 0.9
60-30°	4.45 ± 4.6*	2.03 ± 2.3	2.1 ± 2.3

significantly higher UT:LT ratios when compared to the isotonic and elastic conditions (p=0.000) (Table 3.3). Post-hoc analysis with Tukey's LSD found the UT:LT ratios of the elastic and isotonic conditions did not differ from one another at any of the ROM increments (p=0.000), but were significantly different than the UW condition (p=0.826). While there no significant difference in UT:LT ratio at any interval within the 2 resisted conditions, there were significant differences in UT:LT ratios in the UW condition between all intervals except between 90° and 90-60°. There was no significant difference in the ratios between concentric and eccentric phases in the UW condition between 30° and 60° (p=.196), and between 60° and 90° (p=.679). In addition, there was no effect of gender on activation ratio (p=.857).

In regards to order of activation, the UT fired first in the UW condition an average of 0.325 ± 0.135 seconds before the LT. Adding resistance, either isotonic or elastic, reversed the conditions (p=.001) (Table 3.4), with the LT firing before the UT under both the isotonic and elastic condition when compared to the UW condition. There was no effect of gender on onset timing (p=.653).

Table 3.4: Average difference in onset of activation between UT and LT in seconds (negative value indicates UT fired first) *Significant difference between each condition p<.01

	Difference in onset in sec
Unweighted	-0.325 ± .135*
Isotonic	0.515 ±.1*
Elastic	0.22 ± .06*

Discussion

The scaption exercise is commonly prescribed during shoulder rehabilitation and injury prevention exercise programs. One of the goals of a shoulder exercise program is to restore normal muscle balance of the glenohumeral and scapulothoracic musculature. Muscle imbalance of the scapular rotators is often implicated in shoulder dysfunction such as impingement. Most commonly, an over-activated UT is often opposed by a weaker and under-activated LT. Normal shoulder abduction is facilitated by a balanced force couple of the scapulo-thoracic rotators (UT, LT, and serratus anterior), rotating the scapula and glenoid upward to match the elevation of the humerus created by the glenohumeral muscle force couple (rotator cuff and deltoid). Scapular muscle imbalance usually results in excessive elevation of the scapula, rather than upward rotation. In this situation, excessive activation of the UT relative to the LT creates dysfunctional motion; therefore, representing activation ratios of the UT and LT is helpful in identifying situations of muscle imbalance. A ratio of less than 1.0 indicates that the LT is firing at a higher level than the UT. Recently, researchers have reported on the UT:LT ratio during shoulder exercises to identify the most appropriate exercises that activate the LT while minimizing activation of the UT (Cools, Dewitte, et al., 2007).

Few researchers have reported on the UT:LT ratio during resisted scaption exercise, and only in athletes (Cools, Declercq, et al., 2007; Cools, et al., 2003; Moseley, et al., 1992). Our previous research using the same methods as in this study found that both overhead athletes and non-athletes have similar UT:LT ratios during the scaption exercise with satndardized isotonic weights. The ratios, measured at 30° intervals between 0 and 90° ranged from 1.1 to 2.4 during both concentric and eccentric phases, demonstrating a ‘u-shaped’ curve. The current study on overhead athletes found a similar u-shaped curve and similar range in the ratio, between 1.1 and 2.1 with a standardized resistance. The lowest ratios occurred at 90°, while the highest ratios occurred while the resistance was eccentrically lowered between 60 and 30° of eccentric abduction. Lower ratios during the concentric portion of the exercise indicate higher levels of LT and/or lower levels of UT activation. An increase in activation of the LT during the concentric phase is likely necessary to counteract activation of the UT and serratus anterior as they upwardly rotate the scapula against resistance, while less activation of LT is necessary during the eccentric lowering phase, thus reducing the UT:LT ratio in the eccentric phase.

Scaption is usually performed with either a hand-held isotonic weight, or with elastic tubing or bands. While some researchers have reported on UT:LT ratio against isotonic and isokinetic resistance, no studies have evaluated ratios during elastic-resisted scaption. Such information would be useful to determine if both isotonic and elastic resistance provide similar and sufficient UT:LT ratios for exercise prescription. One of the advantages of this study is that it quantified activation through dynamic motion, rather than isometric contractions at specific points through the ROM. This may help clinicians better understand and comapre the activation patterns in both concentric and ecentric contractions, which is not possible during isometric or isokinetic-resisted testing.

Elastic resistance has been shown to have similar biomechanical characteristics to isotonic weights, demonstrating similar strength curves. A recent study comparing elastic and isotonic-resisted exercises found similar improvements in strength and muscle mass in middle-aged females over 12 weeks (Colado & Triplett, 2008). The current study found that elastic resistance produces the same UT:LT ratios as isotonic resistance, ranging from 1.1 to 2.1. These results support the agrument that both elastic and isotonic resistances are effective and beneficial for shoulder exercise. Contrary to popular opinion, elastic resistance tubing does not ‘stretch’ out over time with normal use and care (Patterson, Stegink Jansen, Hogan, & Nassif, 2001).

One difficulty in this study was equating isotonic resistance to elastic resisacne to ensure similar intensities between conditions. The isotonic resistance, ranging from 5 to 10 pounds, was standardized using anthropometric measurements and a formula used in several previous studies (Li, et al., 2002). Subjects used a specific color of tubing that corresponded to a standardized isotonic hand-held weight (Table 3.2). Unfortunately, there were 6 isotonic resistance levels (5, 6, 7, 8, 9, and 10 pounds) and only 4 elastic resistance levels (yellow, red, green, and blue) across the resistance spectrum. Based on the force-elongation results of the elastic tubing (Table

3.1), 2 colors ‘overlapped’ in resistance: the red (6-7 pounds) and the green (8-9 pounds). These two ranges accounted for the majority of subjects in this study. Despite a potential issue with this overlap of resistances, the activation ratios for both elastic and isotonic resistance conditions were not significantly different. The ratios were slightly higher during the elastic resistance condition, indicating potentially higher UT or lower LT activation levels.

Both of the resisted conditions, isotonic and elastic, had significantly lower UT:LT ratios than the UW conditions. The UW ratio ranged from 2.9 to 4.5. This suggests higher activation of the UT and less activation of the LT compared to the weighted condition. It’s possible that during the UW condition, the UT is a primary upward rotator, requiring less stabilizing forces of the LT due to the light resistance provided by the weight of the limb alone. Once resistance is added, the LT apparently increases its activation to stabilize the scapula during upward rotation. With an increase in resistance, the scapular muscles must increase their activation; therefore, the LT activates to counteract the scapular elevation and protraction created by the UT and serratus anterior, respectively.

Interestingly, the subjects demonstrated higher UT:LT ratios during the late eccentric portion (60-30°) of resisted scaption, although not significantly different from other intervals. It is possible that overhead athletes initiate abduction with more LT activation and use more UT during the eccentric lowering phase. The increase in LT activation at the beginning of the motion is thought to occur in order to neutralize the lateral and upward movement of the scapula created by increased activation of the UT and serratus anterior to overcome resistance at the beginning of scaption. In contrast, non-athletes exhibit higher UT:LT ratios early in scaption, indicating less activation of the LT; this difference may be due to a training effect since these athletes regularly perform the resisted scaption exercise.

While activation levels and ratios are important in describing the ability of an exercise to facilitate muscular activity and balance between synergistic or antagonistic muscles, the firing pattern of an exercise may be more important. Dysfunction is sometimes characterized by a delayed onset in synergistic muscle. Little research has been done on the firing pattern of UT and LT during resisted scaption exercises. Most researchers have investigated the activation patterns in patients with impingement, often finding a delay in LT onset relative to the UT (Wadsworth & Bullock-Saxton, 1997).

Our previous research has demonstrated that the UT normally fires first compared to the LT during UW scaption exercise in both normal and overhead athletes; however, with the addition of resistance, the LT is activated prior to the UT in overhead athletes, reversing the order of activation. Similarly, the present study found that the UT was activated 0.325 s prior to the LT in the unweighted condition, while the addition of resistance reversed the firing order, consistent with our previous research. The LT activated 0.515 s prior to the UT with a hand-held weight, compared to 0.22 s earlier activation of the LT with elastic resistance. The current study found significant differences in timing between each condition.

It's not clear why the isotonic and elastic resistance conditions were significantly different in onset, but not in UT:LT activation ratios. It's likely that the LT activates earlier with the addition of resistance because of its role as a stabilizer discussed previously. The isotonic hand-held weight provides immediate resistance to the arm before and at the very beginning of motion, while the elastic resistance does not. At the beginning of elastic-resisted scaption, there is no resistance until the tubing is stretched after initiating scaption. Since the resistance is more immediate with isotonic hand-held weight, the LT may be activated faster than the elastic condition. The elastic resistance gradually increases in resistance to a similar force level to isotonic resistance at 90°. The faster onset of the LT with isotonic resistance may be beneficial if the goal of exercise is to improve speed of contraction.

One limitation of describing patterns of activation is the process of determining onset of activation. There is little agreement among researchers on what constitutes the onset of muscle activation; for example, some report onset as 5% of the MVIC (Wadsworth & Bullock-Saxton, 1997), while others report 10% of MVIC above resting potential as the onset (Cools, et al., 2002). Still others (Santos, et al., 2007) have used a computer algorithm to define onset of activation as the point when the EMG signal first rises to three standard deviations above the resting level, which was also used in the current study.

There are several other limitations in this study. First, it was performed only on healthy, overhead athletes in baseball and softball. Activation levels and timing may be different in other overhead sports such as swimming or tennis. This study should be replicated in patients with impingement or instability to evaluate their response to this commonly-prescribed therapeutic exercise. Subjects were also limited to 90° of scaption, which is a common stopping point for the exercise. Future research should evaluate the changes in activation ratios and timing throughout 180° of scaption, or other planes of motion.

This study was also limited to only UT and LT muscles in one exercise. Other muscles such as the serratus anterior, rotator cuff, and deltoid should be assessed with different types of resistance and different exercises. In addition, different levels of resistance should be assessed to investigate the effects of different intensities of resistance on muscle activation.

This study did not normalize EMG values to maximal voluntary isometric contraction (MVIC) for several reasons. First, this study was aimed at the ratio of UT and LT activation; thus, the UT:LT ratio normalizes itself across each condition. EMG normalization often requires MVIC; however, since this study should be replicated in patients with shoulder dysfunction, it was determined that a maximal contraction may be harmful to patients, particularly in the LT MVIC test that requires maximal resisted overhead shoulder flexion. The lack of MVIC normalization in this study limits its comparison to other studies reporting UT:LT ratios that were normalized to MVIC, and does not allow for comparison of individual UT or LT activation levels.

This research has quantified that resistance increases LT activation during scaption, improving the UT:LT ratio, and often reverses the firing order of the trapezius, causing the lower portion to activate first. Resisted scaption with elastic tubing or dumbbells is often performed by baseball players as part of a shoulder exercise program to prevent impingement. It appears that both elastic and isotonic resistance produce similar trapezius activation in overhead athletes.

Conclusion

These results indicate that both isotonic and elastic resistance produce similar UT:LT ratios across 90° of scaption that are significantly less than the ratios produced during UW scaption. There was no significant difference in the UT:LT activation ratio between elastic and isotonic resistance, and no significant difference in the ratios across ROM intervals. Clinicians can chose either isotonic or elastic resistance during the scaption exercise to improve UT:LT ratios and increase the speed of activation of the LT, although isotonic resistance may elicit faster onset of LT.

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Discussion and Conclusion

Three studies were completed in this dissertation to determine the effects of resistance on the trapezius during the scaption exercise in overhead athletes. Each study used the same methods in college-aged subjects, examining the surface EMG activation levels and ratio of the UT and LT, as well as their onset of activation.

In the first study on normal healthy subjects, the LT increased EMG activation significantly more than the UT during 90° of shoulder elevation in the scapular plane with the addition of a standardized hand held weight, ranging from 248 to 345%. This significant increase in LT is thought to balance an increase in UT and SA activation with the addition of resistance. The second study on baseball position players confirmed these findings, demonstrating similar increases in LT activation with the addition of a hand held weight. Overhead athletes commonly perform this exercise as part of a preventive exercise program and for rehabilitation after injury. Trained overhead athletes may exhibit different muscle activation characteristics from untrained individuals. Information on trapezius activation ratios or timing of onset may identify a competitive advantage over non-athletes. In addition, such information may provide possible parameters for injury prevention and return to sport after shoulder rehabilitation.

One limitation of this dissertation is that the EMG data in this study was not normalized to MVIC. EMG data is customarily reported as a percentage of a maximal isometric contraction in order to compare activation levels between subjects. Because these methods may be replicated in patients with impingement, MVICs were not used as they may be harmful in patient populations. This study was concerned with increases in activation level in a W condition, compared to an UW condition, as well as the ratio of UT to LT activation; therefore, EMG data was normalized as W:UW and UT:LT ratios.

The UT:LT ratio is likely a better representation of overall trapezius function since both the upper and lower portions function as a force couple to rotate the scapula. Trapezius muscle imbalances often result in dysfunction and pain. Patients with impingement have increased UT and decreased LT activation, creating UT:LT ratios greater than 1.0. The goal of therapeutic exercise is to restore normal trapezius muscle balance with exercises that promote UT:LT ratios less than 1.0.

In both normal subjects and overhead athletes in this dissertation, the UW scaption exercise produced UT:LT ratios between 1.5 and 4.5. Adding resistance to scaption reduced the ratio to between 0.9 and 2.4; therefore, resisted scaption may be a more appropriate exercise for restoring trapezius muscle balance than unweighted scaption. The scaption exercise is often performed with either elastic or isotonic resistance. Overhead athletes routinely perform this exercise as part of a preventive exercise program or during shoulder rehabilitation. The final study in this dissertation determined that both elastic and isotonic resistance produce similar UT:LT ratios.

This study should be replicated in impingement patients to determine their responses to resistance during the scaption exercise. Because impingement often results in neuromuscular changes, their response may be different. In addition to EMG assessment, kinematic data or evaluation of changes in the SAS during the exercise should help quantify both muscular and skeletal effects. For example, the effect of different modes of exercise on SAS remains unknown.

Each study also evaluated the onset of activation of the UT and LT, comparing UW and W conditions. In each study, the UT consistently fired before the LT in the UW condition. The addition of resistance reversed the firing order, with the LT firing first in overhead athletes. In the final study, isotonic resistance was found to produce the shortest latency in the LT, and was significantly faster than the elastic and UW conditions.

Future studies should investigate the effects of progressive sub-maximal levels of resistance. This dissertation used one standardized resistance; however, many patients progress through several levels as their strength and pain improve. Information on progressive levels of resistance may guide appropriate exercise prescription.

In summary, these 3 studies found that normal healthy subjects and overhead athletes demonstrate similar EMG characteristics during scaption exercise both with and without resistance. Adding resistance to the exercise, either elastic or isotonic, significantly reduces the UT:LT ratio and reverses the firing order, causing the LT to fire before the UT in overhead athletes. Isotonic resistance activates the LT faster than elastic resistance. The findings for these 3 studies should help practitioners make better clinical decisions on which scapular exercise to provide for overhead athletes.

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Appendix A

Raw Data

Study 1

UT:LT Ratios

UW						W				
	30-60	60-90	90	90-60	60-30	30-60	60-90	90	90-60	60-30
1	4.0	2.0	1.9	1.8	1.1	3.0	1.5	1.1	1.3	3.4
2	0.2	0.1	0.1	0.2	0.4	0.2	0.2	0.1	0.2	0.2
4	4.1	2.0	1.6	1.7	1.0	1.6	1.1	0.9	1.1	1.6
5	0.6	0.4	0.4	0.3	1.0	1.0	0.4	0.3	0.5	2.2
6	4.8	3.0	2.5	2.3	1.1	0.9	0.7	0.7	0.8	0.9
7	1.9	1.1	1.3	2.0	0.6	1.0	0.6	0.5	0.6	2.1
10	10.6	7.4	5.1	5.1	1.0	3.7	2.5	1.9	2.0	3.0
11	1.7	1.1	0.9	1.1	0.8	0.6	0.3	0.3	0.4	0.9
12	8.2	3.4	3.1	3.1	1.0	2.2	1.0	0.7	0.9	0.9
14	0.7	0.8	0.9	0.9	1.0	0.9	0.7	0.6	0.9	1.5
15	2.0	1.7	2.1	1.4	1.5	1.2	1.5	1.0	0.8	0.6
16	0.5	0.4	0.4	0.4	1.1	0.7	0.3	0.2	0.3	0.5
18	10.3	3.0	2.0	2.0	1.0	6.1	5.6	3.7	2.7	2.4
25	1.4	1.6	1.3	1.5	0.9	1.5	1.6	1.4	1.5	2.0
26	0.5	0.4	0.3	0.4	0.8	0.6	0.7	0.7	0.7	0.6
27	2.6	2.0	1.6	1.6	1.0	1.8	1.1	1.1	1.4	2.7
28	1.0	0.8	0.8	1.2	0.6	0.7	0.5	0.6	0.8	2.5

Onset Timing in seconds

Subject	UT un time	LT un time	UT wt time	LT wt time
1	1.15	1.81	0.989	0.406
2	0.104	0.397	0.705	0.572
4	0.907	1.34	1.19	1.09
5	1.04	0.474	1.76	1.03
6	0.126	1.06	1.07	0.689
10	0.963	2.04	1.16	0.921
11	1.19	2.31	0.769	0.435
12	0.237	1.94	0.437	0.589
14	0.119	0.49	1.21	0.413
15	0.131	0.478	0.258	0.244
16	0.456	0.635	0.563	0.412
18	0.174	0.523	0.48	0.816
25	1.06	1.42	1.66	0.78

Study 2

UT:LT Ratios

group	30-60	60-90	90	90-60	60-30	condition
n	4.0	2.0	1.9	1.8	2.0	1
n	0.2	0.1	0.1	0.2	0.1	1
n	4.1	2.0	1.6	1.7	2.2	1
n	0.6	0.4	0.4	0.3	0.5	1
n	4.8	3.0	2.5	2.3	4.4	1
n	1.9	1.1	1.3	2.0	4.2	1
n	10.6	7.4	5.1	5.1	7.7	1
n	1.7	1.1	0.9	1.1	1.0	1
n	8.2	3.4	3.1	3.1	3.6	1
n	0.7	0.8	0.9	0.9	1.2	1
n	2.0	1.7	2.1	1.4	0.6	1
n	0.5	0.4	0.4	0.4	0.5	1
n	10.3	3.0	2.0	2.0	1.2	1
n	1.4	1.6	1.3	1.5	2.3	1
n	0.5	0.4	0.3	0.4	0.6	1
n	2.6	2.0	1.6	1.6	1.5	1
n	1.0	0.8	0.8	1.2	4.1	1
n	3.0	1.5	1.1	1.3	3.4	2
n	0.2	0.2	0.1	0.2	0.2	2
n	1.6	1.1	0.9	1.1	1.6	2
n	1.0	0.4	0.3	0.5	2.2	2
n	0.9	0.7	0.7	0.8	0.9	2
n	1.0	0.6	0.5	0.6	2.1	2
n	3.7	2.5	1.9	2.0	3.0	2
n	0.6	0.3	0.3	0.4	0.9	2
n	2.2	1.0	0.7	0.9	0.9	2
n	0.9	0.7	0.6	0.9	1.5	2
n	1.2	1.5	1.0	0.8	0.6	2
n	0.7	0.3	0.2	0.3	0.5	2
n	6.1	5.6	3.7	2.7	2.4	2
n	1.5	1.6	1.4	1.5	2.0	2
n	0.6	0.7	0.7	0.7	0.6	2
n	1.8	1.1	1.1	1.4	2.7	2
n	0.7	0.5	0.6	0.8	2.5	2
b	0.6	0.5	0.5	0.5	0.6	1
b	2.3	1.8	2.3	1.7	1.5	1
b	2.9	2.7	2.0	2.5	3.0	1
b	1.0	0.8	0.8	0.8	0.8	1

b	1.5	1.2	1.2	1.4	3.5	1
b	0.4	0.3	0.3	0.3	0.4	1
b	1.4	1.3	1.1	1.4	1.7	1
b	2.1	1.9	2.1	3.1	9.5	1
b	0.6	0.5	0.4	0.3	0.1	1
b	1.5	1.3	1.2	1.5	2.9	1
b	5.8	5.7	4.9	8.1	10.9	1
b	1.8	2.0	2.3	1.9	2.3	1
b	1.5	1.3	1.1	1.1	1.6	2
b	1.2	0.9	0.7	0.8	0.8	2
b	3.7	3.2	2.8	2.6	2.9	2
b	0.9	1.0	1.0	1.1	1.5	2
b	1.2	0.9	1.0	1.5	4.0	2
b	0.5	0.4	0.4	0.5	0.7	2
b	1.0	0.8	0.9	1.1	1.4	2
b	1.5	1.2	1.3	2.5	12.2	2
b	0.6	0.5	0.6	0.5	0.4	2
b	0.6	0.6	0.7	0.8	1.1	2
b	1.2	1.2	1.0	0.9	1.1	2
b	1.1	1.2	1.3	1.1	1.4	2

N=normal subjects; B=baseball players / 1= unweighted; 2=weighted

Onset Timing

group	unweighted	weighted
n	-0.66	0.744
n	-0.293	-0.468
n	-0.433	-0.183
n	0.566	0.01
n	-0.934	-0.563
n	-1.077	0.042
n	-1.12	0.755
n	-1.703	-0.352
n	-0.371	-0.294
n	-0.347	-0.113
n	-0.179	0.044
n	-0.349	-0.642
n	-0.36	0.28
b	-0.637	0.179
b	-0.301	0.434
b	-1.008	0.056
b	1.36	0.096
b	-0.35	0.88
b	0.48	0.299
b	0.637	0.735
b	-0.909	-0.374
b	-0.584	0.317
b	-0.447	0.04
b	-0.469	0.76
b	0.352	0.925

N=normal subjects; B=baseball players. Difference score = (UT-LT)

Study 3

UT:LT Ratios

Subj	30-60	60-90	90	90-60	60-30	condition
m	13.3	11.9	9.8	12.1	1.7	1
m	1.6	0.8	0.6	1.9	3.7	1
m	8.1	5.3	4.1	5.4	5.7	1
m	2.1	1.1	0.8	1.5	6.5	1
m	2.5	1.1	1.1	2.7	16.8	1
m	7.8	8.4	6.6	9.6	14.9	1
m	12.9	7.4	6.5	1.1	8.3	1
m	11.8	11.4	8.5	6.7	7.5	1
m	1.0	1.4	1.4	1.4	1.6	1
m	4.5	2.2	1.6	2.4	4.9	1
m	2.4	1.7	1.2	1.3	1.5	1
f	1.3	1.5	1.4	1.1	1.2	1
f	2.8	3.3	3.3	2.8	3.9	1
f	2.0	1.0	1.0	0.9	1.7	1
f	8.8	5.8	7.0	4.9	1.9	1
f	2.1	1.8	1.9	2.7	1.8	1
f	4.8	1.8	1.3	1.2	2.5	1
f	1.1	0.5	0.3	0.5	0.8	1
f	3.0	3.9	5.1	10.0	11.7	1
f	0.7	0.9	0.9	1.1	1.7	1
f	1.2	1.3	1.0	0.7	0.4	1
f	2.2	1.5	1.0	1.0	1.5	1
f	0.4	0.5	0.5	0.4	0.5	1
m	0.6	0.4	0.3	0.3	0.6	2
m	1.3	1.0	1.0	1.0	1.5	2
m	1.1	1.2	0.9	0.9	1.0	2
m	0.3	0.4	0.3	0.4	0.7	2
m	2.8	0.3	3.1	2.5	0.5	2
m	0.3	0.3	0.3	0.3	0.2	2
m	0.9	0.7	0.6	0.5	0.6	2
m	0.4	0.4	0.5	0.4	0.3	2
m	0.4	0.4	0.4	0.5	0.9	2
m	1.1	0.8	0.7	0.7	1.2	2
m	1.2	1.0	1.0	1.7	2.9	2
f	2.4	2.1	1.9	2.0	3.2	2
f	1.3	2.0	1.8	1.5	1.7	2
f	1.8	1.9	1.7	1.8	3.5	2
f	1.0	1.0	1.0	1.0	1.3	2
f	1.5	1.6	1.1	1.6	2.2	2
f	1.9	1.6	1.4	2.2	5.7	2

f	0.3	0.3	0.2	0.2	0.3	2
f	0.6	0.3	0.3	0.3	0.9	2
f	1.5	1.0	0.8	1.2	9.7	2
f	0.6	0.5	0.5	0.5	0.4	2
f	1.5	1.3	1.1	1.1	1.1	2
f	5.1	5.1	3.7	3.4	6.3	2
m	0.9	0.7	0.5	0.5	1.1	3
m	1.0	1.3	1.2	1.0	0.7	3
m	1.1	1.0	0.9	0.8	0.8	3
m	0.5	0.5	0.4	0.4	0.8	3
m	2.0	1.5	1.5	1.7	1.9	3
m	0.3	0.2	0.2	0.2	0.2	3
m	1.1	0.8	0.7	0.7	0.8	3
m	0.4	0.7	0.8	0.5	0.5	3
m	0.4	0.3	0.3	0.4	0.6	3
m	1.5	1.1	1.0	1.2	1.6	3
m	2.6	2.0	1.7	2.3	3.2	3
f	2.9	3.0	2.1	2.0	2.4	3
f	1.4	1.9	1.6	1.3	1.6	3
f	1.9	1.8	1.9	2.0	3.5	3
f	1.0	1.4	1.3	1.2	1.5	3
f	1.3	1.1	1.0	1.4	1.9	3
f	1.8	1.8	1.9	2.0	3.9	3
f	0.4	0.3	0.2	0.2	0.4	3
f	0.6	0.3	0.3	0.3	0.7	3
f	1.5	1.1	0.9	1.4	7.8	3
f	0.5	0.4	0.3	0.3	0.5	3
f	1.8	1.3	1.0	1.2	2.6	3
f	6.5	5.0	4.2	4.0	9.3	3

Condition 1=unweighted 2=isotonic 3=elastic

Onset Timing

gender	UTun	LTun	UTwt	LTwt	UTtube	LTtube
m	1.5	1.3	1.7	0.57	0.58	0.57
m	0.17	1.39	1.55	0.12	0.92	0.18
m	0.55	0.97	0.82	0.67	0.72	0.48
m	1.09	1.28	1.05	0.35	0.36	0.486
m	0.73	1.64	1.27	0.78	0.322	0.67
m	1.6	0.83	1.13	0.38	0.71	0.21
m	1.32	1.97	0.95	0.59	0.58	0.36
m	1.36	3.07	1.08	0.65	0.82	0.71
m	1.62	0.63	0.46	0.86	0.58	0.18
m	0.65	1.42	0.79	0.49	0.38	0.27
f	1.18	0.99	0.42	0.76	0.57	0.59
f	1.9	2.3	1.44	0.626	0.905	0.81
f	0.92	1.68	0.8	0.74	0.82	0.76
f	0.89	1.69	1.89	0.55	0.75	0.35
f	0.93	1.32	1.6	0.61	0.76	0.23
f	0.730	1.400	1.040	0.350	0.610	0.240
f	0.73	1.09	0.85	0.57	1.32	0.4
f	0.63	0.69	0.57	0.24	0.2	0.24
f	0.200	0.840	1.030	0.270	0.450	0.370
f	1.21	0.44	0.43	0.38	0.53	0.29
f	0.6	0.96	1.79	0.81	0.75	0.4
f	0.73	1.11	0.98	0.48	0.66	0.32
f	1.41	1.11	0.84	0.78	0.54	0.65

Appendix B

ANOVA Analysis Tables

Study 2

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
group	.112	1	.112	.007	.935
Error	hh444.203	27	16.452		

ANOVA of Between Subjects Effects with population as the grouping variable and Unweighted UT:LT ratio as the dependent variable

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
group	.578	1	.578	.124	.727
Error	125.830	27	4.660		

ANOVA of Between Subjects Effects with population as the grouping variable and Weighted UT:LT ratio as the dependent variable

Study 3

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	388.522	2	194.261	9.850	.000
Error	1301.605	66	19.721		

ANOVA of Between Subjects Effects with condition (UW, Isotonic, Elastic) as the grouping variable and UT:LT ratio as the dependent variable

(I) Condition	(J) Condition	[a]			95% Confidence Interval for Difference[a]	
		Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1.0	2.0	2.300[*]	.586	.000	1.131	3.470
	3.0	2.198[*]	.586	.000	1.029	3.368
2.0	1.0	-2.300[*]	.586	.000	-3.470	-1.131
	3.0	-.102	.586	.862	-1.271	1.067
3.0	1.0	-2.198[*]	.586	.000	-3.368	-1.029
	2.0	.102	.586	.862	-1.067	1.271

Post Hoc Analysis using Tukey's LSD (1=unweighted, 2=weighted, 3=elastic)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	388.522	2	194.261	9.850	.000
Error	1301.605	66	19.721		

ANOVA of Between Subjects Effects with Interval Angle as the grouping variable and UT:LT ratio as the dependent variable

(I) degrees	(J) degrees	[a]			95% Confidence Interval for Difference[a]	
		Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	.438*	.115	.000	.209	.668
	3	.647*	.137	.000	.373	.921
	4	.505*	.233	.034	.040	.970
	5	-.518	.397	.196	-1.311	.274
2	1	-.438*	.115	.000	-.668	-.209
	3	.209*	.082	.013	.045	.372
	4	.067	.162	.679	-.256	.390
	5	-.957*	.378	.014	-1.711	-.203
3	1	-.647*	.137	.000	-.921	-.373
	2	-.209*	.082	.013	-.372	-.045
	4	-.141	.136	.304	-.414	.131
	5	-1.165*	.371	.003	-1.905	-.425
4	1	-.505*	.233	.034	-.970	-.040
	2	-.067	.162	.679	-.390	.256
	3	.141	.136	.304	-.131	.414
	5	-1.024*	.346	.004	-1.716	-.332
5	1	.518	.397	.196	-.274	1.311
	2	.957*	.378	.014	.203	1.711
	3	1.165*	.371	.003	.425	1.905
	4	1.024*	.346	.004	.332	1.716

Post Hoc Analysis using Tukey’s LSD (1=30-60, 2=6-90, 3=90, 4=90-60, 5=60-30)

Source	Sum of Squares	df	Mean Square	F	p<
condition	3.406	1	3.406	13.002	.002
condition * sex	.009	1	.009	.033	.857
Error	5.500	21	.262		

Repeated Measures ANOVA for effects of gender on UT:LT ratios

Source	Sum of Squares	df	Mean Square	F	p<
condition	3.419	1	3.419	13.654	.001
Error	5.509	22	.250		

ANOVA of Between Subjects Effects with resistance condition as the grouping variable and Difference in Onset Timing as the dependent variable

		[a]			95% Confidence Interval for Difference[a]	
(I) condition	(J) condition	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-.840[*]	.198	.000	-1.251	-.430
	3	-.545[*]	.148	.001	-.851	-.239
2	1	.840[*]	.198	.000	.430	1.251
	3	.295[*]	.102	.009	.083	.507
3	1	.545[*]	.148	.001	.239	.851
	2	-.295[*]	.102	.009	-.507	-.083

Post Hoc Analysis using Tukey’s LSD (1=unweighted, 2= isotonic, 3=elastic)

Source	Sum of Squares	df	Mean Square	F	Sig.
sex	.040	1	.040	.208	.653
Error	4.047	21	.193		

ANOVA for effects of gender on onset of activation

Appendix C

General Exam

SHOULDER MUSCLE IMBALANCE AND IMPINGEMENT IN OVERHEAD ATHLETES

A General Examination
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Kinesiology

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April 21, 2009

Introduction

Shoulder impingement is a common condition affecting overhead athletes due to the mechanics of the throwing motion. The combination of internal rotation with elevation of the shoulder to 90°, inherent in the overhead motion, can create subacromial impingement due to a decrease in the subacromial space (SAS).

Shoulder impingement, first described by Neer (Neer, 1972), can be classified into two main categories: structural and functional. Subacromial impingement can be caused by narrowing of the SAS either by a reduction in the space due to bony growth (“structural”) or superior migration of the humeral head caused by weakness and/or muscle imbalance (“functional”) (Brossmann, et al., 1996; Hallstrom & Karrholm, 2006; Jerosch, et al., 1989; Ludewig & Cook, 2002). Functional impingement is related to glenohumeral instability (Jobe, et al., 1989), which is sometimes described as “Functional Instability,” occurring mostly in overhead athletes less than 35 years old (Belling Sorensen & Jorgensen, 2000). Tissues below the coracoacromial arch may sustain microtrauma in overhead athletes, leading to inflammation and tendinitis (Bigliani, et al., 1991; Hawkins & Kennedy, 1980).

The shoulder relies on muscles to provide dynamic stability during its large range of mobility. Proper muscle balance surrounding the shoulder is also necessary for flexibility and strength; a deficit in flexibility or strength in an agonistic muscle must be compensated by the antagonist muscle, leading to dysfunction. These muscular imbalances lead to changes in arthrokinematics and movement impairments, which may ultimately cause structural damage.

While structural impingement sometimes requires surgery to alleviate pain, functional instability requires precise therapeutic exercises to restore normal neuromuscular function. It’s important for clinicians to understand the pathomechanics of functional impingement in order to guide appropriate assessment and treatment, as well as prevention. The purpose of this paper is to review the literature on the neuromuscular pathomechanics of functional impingement in overhead athletes, focusing on muscle balance.

This review will begin by discussing the biomechanics and muscular balance of normal shoulders in Section 1.0 which presents a review of normal range of motion and muscular strength, including a discussion on the subacromial space and electromyographic (EMG) analysis of normal shoulder function. The next section, 2.0, will review the pathomechanics of functional shoulder impingement. This section discusses shoulder dysfunction from the perspective of imbalances in range of motion and strength. Included in this section is a review of EMG analyses of shoulder dysfunction and postural abnormalities associated with impingement.

1.0 Shoulder Muscle Balance

Freely movable joints in the human body require proper muscle balance for normal function. Opposing muscle groups surrounding a joint must be balanced in both length and strength.

1.1 Shoulder Range of Motion Balance

The glenohumeral (GH) joint works together with the scapulothoracic (ST) joint providing a "scapulohumeral rhythm," noted as a ratio between glenohumeral and scapular ranges of motion. The classic "2:1" ratio was established by Inman and colleagues in 1944 (Inman , Saunders, & Abbott, 1944). During 180° of abduction, the GH joint moves approximately 120°, while the scapula rotates the glenoid fossa approximately 60°. This provides a ratio of 2° of GH movement for every one degree of scapulohumeral movement. The 2:1 ratio, however, presents a rather simplistic view of scapulohumeral rhythm and does not account for different phases of movement, planes of motion, speeds of motion, and external loads.

The exact ratio for scapulohumeral rhythm has been debated in the literature. Researchers have reported ratios such as 3:2 (Freedman & Munro, 1966), 1.7:1 (McClure, Michener, Sennett, & Karduna, 2001), or 5:4 (Poppen & Walker, 1976).   While some have noted the greatest contribution of scapular movement at 30 to 60° (Mandalidis, Mc Glone, Quigley, McInerney, & O'Brien, 1999), others have found the greatest amount of scapular movement occurs around mid range (80 to 140°), when the scapulohumeral ratio decreases to between 0.7:1 to 4:5 after 80° of elevation (Bagg & Forrest, 1986; Doody, et al., 1970). These discrepancies may be due to different measurement techniques such as 2-dimensional x-ray or fluoroscopy versus 3-dimensional electromagnetic tracking. (This issue is addressed later in this review.)

The effect of resistance on scapulohumeral ratio also remains unclear. Some researchers have reported no significant change in the ratio with resistance (Freedman & Munro, 1966), while others report the ratio varies with different loads (McQuade, Dawson, & Smidt, 1998; Pascoal, van der Helm, Pezarat Correia, & Carita, 2000). McQuade et al. report that scapulohumeral rhythm appears to vary based on the load and phase of elevation, suggesting the traditional 2:1 ratio of humeral and scapular motion may not adequately explain normal shoulder kinematics (McQuade, et al., 1998). However, there are several limitations to this study. First, submaximal loads, such as those used in rehabilitation, were not evaluated. Secondly, a patient population was not assessed, which limits the clinical application of the results. Thirdly, the eccentric (lowering) phase of scapular elevation was not evaluated, therefore not allowing examination of the differences between concentric and eccentric movements. Finally, the study did not include EMG analysis to correlate muscle activity with changes in the ratio. More research is needed on the change of this ratio with different types of resistance, such as isotonic versus elastic resistance during abduction.

Interestingly, scapular kinematics do not appear to affect scapulohumeral rhythm (McQuade, et al., 1998). Normal scapular motion (Figure 1) during humeral elevation includes upward rotation (average 50°), external rotation (average 24°), and posterior tilt of the scapula (average 30°) (Ludewig, Cook, & Nawoczenski, 1996; McClure, et al., 2001).

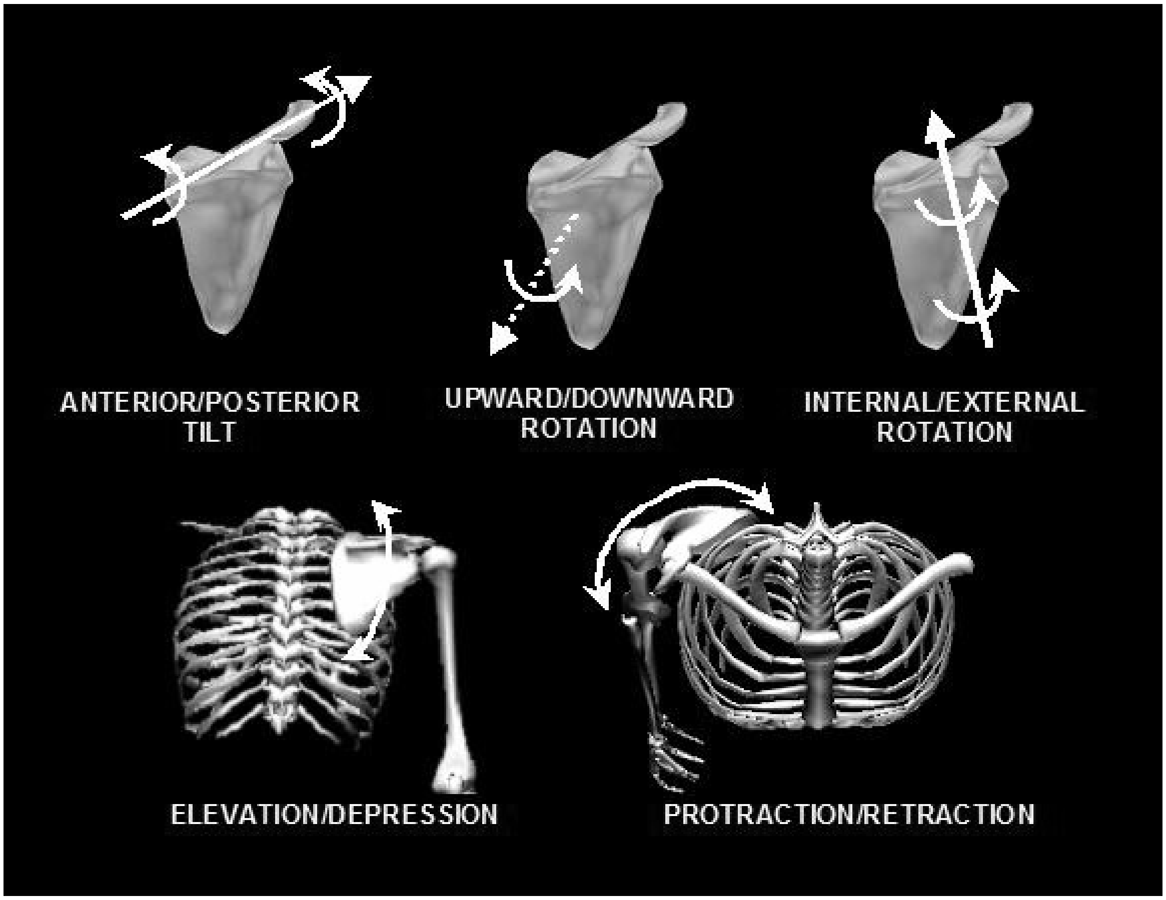

Figure 1: Scapular Motions (Laudner, Myers, Pasquale, Bradley, & Lephart, 2006)

During shoulder elevation, the scapula doesn't elevate; rather, it rotates upward (Hallaceli, Manisali, & Gunal, 2004). This scapular rotation is accompanied by rotation of the sternoclavicular and acromioclavicular joints (Bagg & Forrest, 1988). Rotation of the scapula positions the glenoid during flexion and abduction, providing mechanical stability of the GH joint and maintaining the length-tension relationship of the rotator cuff and deltoid (Lucas, 1973; Mottram, 1997). Despite the numerous scapular movements identified, little is known about the specific muscle actions responsible for internal/external rotation or anterior/posterior tilt of the scapula. This gap in the literature is likely due to a lack of simultaneous kinematic and EMG data that isolates these particular scapular movements, as well as the fact that the ranges of these movements are relatively small in comparison to upward and downward rotation.

The plane of humeral motion can affect scapular range of motion. Elevation of the shoulder in the scapular plane (also called “scaption”) provides the most stability and mobility of the shoulder joint (Borsa, et al., 2003; Comtet, et al., 1989; Johnston, 1937). Orientation of the humerus during scaption can affect scapular kinematics. Compared to scaption with neutral humeral rotation, scaption with humeral internal rotation increases scapular internal rotation and anterior tilt, which may also decrease the SAS. Scapular upward and downward rotation is greater in the scapular plane; upward rotation of the scapula decreases during elevation outside the scapular plane because of limited clearance for the humeral head in the SAS.

1.1.1 The Subacromial Space

The SAS is an area below the coraco-acromial arch, and averages 9 to 10 mm at rest in healthy shoulders (Petersson & Redlund-Johnell, 1984; Weiner & Macnab, 1970). Upward scapular rotation helps maintain the SAS by elevating the lateral acromion to prevent impingement (Ludewig & Cook, 2000). Posterior tilt of the scapula also elevates the anterior acromion to clear space for the rotator cuff in the SAS. Superior migration of the humeral head averaging 1 to 3 mm occurs during abduction between 30 and 60° (Chen, Simonian, Wickiewicz, Otis, & Warren, 1999; Ludewig & Cook, 2002; Poppen & Walker, 1976; Thompson, et al., 1996). In cadaver models, the SAS gradually decreases to 5 mm at 100 to 110° of shoulder elevation (Flatow, et al., 1994). Using 3-dimensional MRI, researchers have shown that the SAS decreases 3 mm, from 7 mm at 30° to 3.9 mm at 120° of abduction (Graichen, Bonel, Stammberger, Englmeier, et al., 1999). Even subtle changes (1-2 mm) can decrease the SAS and contribute to impingement.(Allmann, et al., 1997; Bigliani, et al., 1991; Graichen, Bonel, Stammberger, Haubner, et al., 1999; Hebert, Moffet, Dufour, & Moisan, 2003; Michener, McClure, & Karduna, 2003; Neer, 1972).

Early measurements of the SAS were performed using static x-ray techniques, limiting researchers to stationary, 2-dimensional measures at different points in the range of motion. Using static radiographs at various positions of scapular elevation, researchers compared normal and painful shoulders (of various diagnoses), finding that humeral head excursion greater than 1.5 mm was associated with shoulder pathology (Poppen & Walker, 1976). Impingement patients also demonstrate similar findings, noting 1 mm superior translation (Deutsch, Altchek, Schwartz, Otis, & Warren, 1996). Using the same radiographic technique, patients with rotator cuff tears, both with and without pain, demonstrated superior migration of the humeral head with increasing elevation (between 60 and 150°) compared to a normal control group (Yamaguchi, et al., 2000).

While these results are useful when examining possible humeral kinematic dysfunction in shoulder pathology, this static measurement technique has several limitations. First, static measures require isometric contraction at various points in the range of motion; an isometric contraction may cause different muscle activation patterns than a dynamic concentric movement. In addition, eccentric contractions cannot be assessed with static measures. Muscle activation was not assessed in these studies; thus, it is not possible to determine if changes in muscular activation are responsible for the changes in humeral position. These studies also did not examine the effect of an increase in load using external resistance during shoulder elevation. Furthermore, these studies did not examine changes to the SAS; they only noted superior migration of the humerus, which does not describe direct changes to the SAS.

New technology such as MRI and digital fluoroscopy has enabled researchers to evaluate dynamic changes to the SAS during movement rather than relying on selected isometrically held positions through the range of motion. Recent investigations with these new technologies have evaluated the dynamic migration of the SAS during scaption following a fatiguing exercise

(Teyhen, Miller, Middag, & Kane, 2008). Teyhen et al. found an average increase of .79 mm (range 0.15 – 1.18 mm) in superior migration of the humeral head, representing a 6 to 40% reduction in SAS. In contrast, researchers using static radiographs reported 2.5 mm migration after fatiguing shoulder exercise (Chen, et al., 1999). Unfortunately, Chen et al. did not directly assess changes in the SAS, instead reporting only changes in humeral position relative to the glenoid. For the fatiguing exercise, Teyhen et al. had subjects hold a 1.36 kg weight during scapular elevation, while Chen et al. had subjects perform a shoulder elevation exercise from a prone position, suggesting the different fatiguing exercise may have contributed to the different findings in the studies. Their conflicting results may also be due to the difference between static and dynamic imaging discussed previously. Unfortunately, neither of these studies evaluated EMG associated with the changes in SAS, or changes with the eccentric phase. Both studies were also limited to 2-dimensional views of the SAS, which limits evaluation of the SAS to superior-inferior translation only, rather than considering anterior-posterior translations as well.

Canadian researchers used MRI to measure the SAS in impingement patients in a sitting position, finding a progressive decrease in SAS during arm elevation particularly after 80° (Hebert, et al., 2003); however, they still used static holds to obtain images. German researchers have studied the effects of dynamic movement on the SAS using 3-dimensional MRI techniques (Graichen, Bonel, Stammberger, Englmeier, et al., 1999; Graichen, et al., 1998). Graichen and colleagues found that abductor muscle activity decreases the SAS from 6.7 mm to 4.9 mm at 90° of abduction, while an adductor moment increases the SAS 32-138%, creating an increase in the SAS from 2.8 mm to 5.8 mm (Graichen, et al., 2005; Hinterwimmer, et al., 2003). Unfortunately, their measurements were limited to subjects in a supine position; measuring SAS in a sitting position similar to Hebert and colleagues would be more functional and account for the effects of gravity.

While much research has been done on shoulder range of motion in cadaver models and normal human subjects, many questions remain regarding the specific kinematics and muscle activation during different conditions and patient populations. In addition, technological advances in measuring the SAS should help clinicians better-identify specific changes to the space during shoulder motion, particularly during functional movements such as throwing. This will increase the understanding of pathomechanics and lead to better therapeutic exercise prescription.

1.2 Shoulder Strength Balance: Force Couples

Agonist and antagonist muscle groups surrounding joints typically provide opposing movements, such as flexion/extension or abduction/adduction. Proper muscle balance between agonists and antagonists in the shoulder is necessary for balanced muscle force production; any alteration in this balance can lead to dysfunction, including functional impingement. Muscular strength balance is particularly important for synergistic muscle activations known as ‘force couples.’ There are 2 main force couples controlling dynamic motion of the shoulder: the rotator cuff/ deltoid and scapular rotator couples.

1.2.1 Rotator Cuff / Deltoid Force Couple

Contrary to the perception that the rotator cuff only performs humeral rotation, research demonstrates that its primary role is stabilization and elevation of the humerus in the scapular plane (Liu, Hughes, Smutz, Niebur, & Nan-An, 1997; Otis, et al., 1994; Sharkey, Marder, & Hanson, 1994). This stabilizing function of the rotator cuff draws the humeral head in toward the glenoid fossa. Researchers differ in the direction of this rotator cuff vector: some suggest a vector parallel to the axillary border (Inman , et al., 1944), while others (Poppen & Walker, 1978) report a vector perpendicular to the glenoid. While the literature is not clear on the specific direction of the rotator cuff stabilizing force, the net effect is a compressive force vector to counteract the elevation force of the deltoid.

This rotator cuff / deltoid force couple is essential to shoulder abduction (Lucas, 1973; Perry, 1978; Sarrafian, 1983). Contraction of the rotator cuff neutralizes the upward shear force of the contracting deltoid and supraspinatus during abduction (Payne, Deng, Craig, Torzilli, & Warren, 1997). Rotator cuff stabilization also reduces the workload of the deltoid during shoulder elevation by at least 17% by creating a compressive vector that provides a better mechanical advantage of the deltoid (Payne, et al., 1997; Sharkey, et al., 1994). Only a mild contraction of the rotator cuff is necessary for glenohumeral stabilization (McQuade & Murthi, 2004), suggesting that strength is not as important for rotator cuff function, contrary to popular opinion.

The dynamic stabilizing role of the rotator cuff has been demonstrated during radiographic studies of humeral head migration in cadaver models. Researchers have used fluoroscopy to compare active and passive scaption in cadaver shoulders (Xue & Huang, 1998). During active abduction, the researchers noted a more centered glenoid, compared to a 9 mm superior elevation of the humeral head during passive abduction, indicating that the dynamic stabilizers are vital for glenohumeral stability. As stated previously, rotator cuff fatigue causes increased superior migration of the humeral head (Chen, et al., 1999; Teyhen, et al., 2008); others have shown similar results in patients with rotator cuff tears (Yamaguchi, et al., 2000). These studies suggest the rotator cuff is vital in maintaining humeral head position within the glenoid during shoulder elevation.

Cadaveric studies have limited applicability to the true function of human subjects. It is obviously difficult to demonstrate specific forces of individual rotator cuff muscles in vivo. The clinical finding of humeral migration in rotator cuff patients supports the finding of cadaveric studies that suggest the importance of the rotator cuff for glenohumeral stability. When coupled with the deltoid, the rotator cuff forms a primary force couple for efficient shoulder motion.

1.2.2 Scapular Rotator Force couple

Different parts of the trapezius (upper, middle and lower sections) have different fascicular orientations representing different functional demands for head, shoulder, and neck movements (Figure 2). For example, the middle and lower fibers maintain vertical and horizontal equilibrium, rather than generate torque (Johnson, et al., 1994; Kibler, 1998; Lindman, et al., 1990; Mottram, 1997; Wadsworth & Bullock-Saxton, 1997).

The upper portions of the trapezius are coupled with the serratus anterior to produce upward rotation of the scapula. Contrary to popular opinion, the lower trapezius is not a scapular rotator, but acts as a stabilizer to counteract the lateral pull of the serratus anterior as it upwardly rotates the scapula (Johnson, et al., 1994). The lower trapezius is particularly important because it can dynamically modify forces on the scapula during mid-elevation (Bagg & Forrest, 1986). Rotation of the scapula positions the glenoid during flexion and abduction, provides mechanical stability

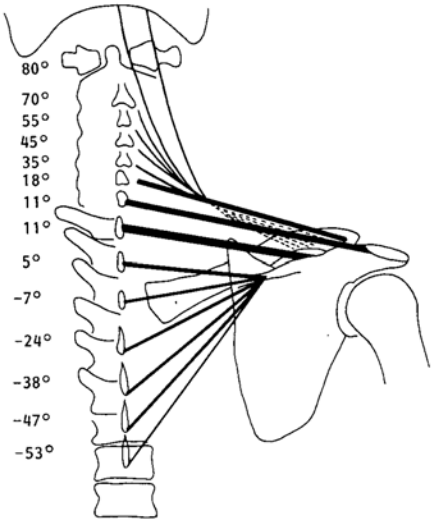

Figure 2: Fascicular orientation of the trapezius muscle (Johnson, et al., 1994)

of the GH joint, and maintains the length-tension relationship of the rotator cuff and deltoid (Doody, et al., 1970; Lucas, 1973; Mottram, 1997; van der Helm, 1994).

Upward scapular rotation will also help maintain the SAS by lifting the acromion (Ludewig & Cook, 2000). The dynamic scapular stabilizers coordinate the position of the glenoid with the humerus (Belling Sorensen & Jorgensen, 2000; Kibler, 1998). Altered muscle activation patterns may change the scapulohumeral rhythm. If scapular rotation lags behind humeral elevation, the SAS may narrow (Wadsworth & Bullock-Saxton, 1997).

Few studies have investigated the simultaneous movement of the scapula and the height of the SAS. When using radiographs, most studies only report 1-dimensional narrowing of the SAS if the humerus moves upward. Recent technological advances in measurement techniques using MRI and electromagnetic kinematics may allow researchers to correlate 3-dimensional changes in scapular movement with actual 3-dimensional changes in the SAS. Furthermore, the relationship of muscle activation patterns around the scapula should be considered. While few studies have evaluated SAS with simultaneous EMG of the glenohumeral muscles (Graichen, Bonel, Stammberger, Haubner, et al., 1999; Hinterwimmer, et al., 2003), no studies have compared simultaneous changes in the SAS with scapular muscle activation patterns. Because the scapular muscles are critical for positioning and moving the scapula, any changes in muscle activation or timing can alter normal scapular movement, resulting in changes in the SAS.

Understanding the relationship of scapular muscle activation and SAS may improve diagnosis and treatment of functional impingement syndromes. For example, an increase in scapular elevation or a decrease in scapular depression is thought to decrease the SAS. These changes may be caused by an overactive upper trapezius, or an underactive lower trapezius, respectively. Unfortunately, researchers have not correlated isolated EMG activation of scapular muscles with the motions of scapular tilt or internal/external rotation, instead relying on cadaveric studies of muscle tension. The limitations of using such cadaveric studies have been discussed previously.

1.3 EMG Analysis of the Shoulder

Electromyographic analysis of the shoulder muscles is commonly used to assess muscle activation levels and patterns. Muscle activation levels are typically reported as a percentage of a maximal voluntary isometric contraction (MVIC). By normalizing EMG levels to MVIC, EMG activation levels can be compared between subjects. Kelly and colleagues (Kelly, Backus, Warren, & Williams, 2002) described 3 progressive levels of EMG activation in the shoulder. They considered “minimal” activation as 0-39% MVIC, “moderate” as 40-74%, and “maximal” as 75-100% of MVIC.

There are several issues when using MVIC, the most important of which is the involvement of patient populations. Patients with pain and dysfunction should not perform maximal muscle contractions to avoid exacerbation of symptoms. In testing the MVIC for the lower trapezius, for example, the shoulder is placed in an overhead position, which might increase pain. Furthermore, the MVIC testing position (sitting vs. prone) should be similar to the actual EMG testing position, therefore possibly limiting the possibility of MVIC testing.

Maximal muscle testing has several other limitations. The reproducibility and stability of MVIC testing is questionable (Aaras, et al., 1996; Jensen, et al., 1993). In addition, MVIC testing is a static test, which is then used for a dynamic analysis of movement. To address this issue, some have suggested using a percentage of EMG during a submaximal movement to compare EMG activation between subjects (Palmerud, Sporrong, Herberts, & Kadefors, 1998).

A submaximal test allows normalization throughout the entire movement, rather than one static position which may not be representative of dynamic neuromuscular function. Using a submaximal movement as a basis for EMG normalization is not widely seen in the literature, since most studies use healthy subjects. Few EMG studies are performed on actual patient populations with pain and dysfunction. It is possible that submaximal normalization may be better suited for patient populations; however, this has not been validated in the literature.

Another limitation of EMG is the variability of individual motor patterns. Normalization of individuals to their maximum activation is used to help compare between individuals, but variability still exists. Regardless of the variability, trends in EMG activation such as plateaus can still be seen (Bagg & Forrest, 1986). Despite the limitations, EMG is a very useful tool to evaluate neuromuscular function when specific guidelines are followed for testing and interpretation.

Muscle activity during shoulder motion may also vary among different loads and speeds of movement. During scaption with progressive normalized loads, the peak EMG of the rotator cuff and deltoid shifts to earlier in the motion, suggesting earlier recruitment of motor units (Alpert, et al., 2000). Increasing the speed also causes a rise in EMG activity earlier in the motion; however, Alpert et al. did not assess the trapezius muscle for its response to increased load or speed. In addition, the researchers did not assess the eccentric (lowering) phase of scaption.

Electromyographical analysis is also used to determine onset of activation (“latency”) and coordination with other muscles. The shoulder EMG literature is dominated by studies evaluating muscle activation *levels*, rather than activation *patterns*, as well as changes to those patterns with different exercises, loads, or conditions. There is little agreement among researchers on what constitutes the onset of muscle activation; for example, some report onset as 5% of the MVIC (Wadsworth & Bullock-Saxton, 1997), while others report 10% of MVIC above resting potential as the onset (Cools, et al., 2002). Still others (Santos, et al., 2007) have used a computer algorithm to define onset of activation as the point when the EMG signal first rises to three standard deviations above the resting level.

Muscle activation patterns are important for normal shoulder biomechanics, as pre-movement dynamic stabilization must occur. For example, the rotator cuff and biceps are active as stabilizers before shoulder rotation initiates (David, et al., 2000). The glenohumeral muscles are activated before the scapular muscles in response to sudden arm movement (Cools, et al., 2002). These dynamic “feed-forward” mechanisms are critical because alterations in muscle activation patterns can lead to joint dysfunction.

Several other researchers have identified feed-forward mechanisms in the neck (Falla, Jull, & Hodges, 2004) and trunk (Hodges & Richardson, 1998) and their relationship to dysfunction. For example the transverse abdominus normally fires before the rectus abdominus and obliques prior to extremity movement in healthy subjects. In contrast, Hodges and Richardson found delayed activation of the transverse abdominus in patients with chronic low back pain. Similar studies on activation patterns in shoulder patients are few in number and are discussed in section 2.2.3. More research on shoulder feed-forward mechanisms is needed to quantify the activation patterns in order to better identify dysfunction and intervention.

1.3.1 EMG Activation and Timing of the Trapezius

As stated previously, different parts of the trapezius can perform differently during the same motion. Several researchers have investigated the activation patterns of the trapezius during elevation in normal subjects (Bagg & Forrest, 1986; Filho, et al., 1991; Wiedenbauer & Mortensen, 1952); however, these studies leave several questions unanswered. For example, Wiedenbauer and Mortensen reported that the lower trapezius was especially active during abduction through 180° but they did not evaluate changes in activation with resistance or during the eccentric phase. Filho et al. found a gradual increase in all portions of the muscle during abduction and a decrease during the return eccentric phase, but their data was only descriptive and was not normalized. Similarly, Bagg and Forrest did not statistically analyze the pattern of trapezius activation in their subjects.

Few researchers have evaluated the activation of the trapezius during weighted exercises (Moseley, et al., 1992). Moseley et al. assessed the EMG of exercises using light-weight dumbbells in normal subjects. During the scaption exercise, the upper trapezius peaked at 54% of MVIC between 120-150° in the motion, while the lower trapezius peaked at 60% during the same range of motion. Their study has several shortcomings, however. There was no report on a comparison of the increase in activation from non-weighted movement patterns. This would help quantify any changes in muscle activation levels after adding resistance to establish normative levels; such levels may then be used to compare pathological populations. In addition, the weights used by subjects were not standardized; they were self-selected by the subjects. Using self-selected weights rather than standardized weights between subjects does not allow for comparison between subjects, since these values are individualized, rather than normalized between all subjects.

Researchers typically report on the trapezius muscle balance between the upper and lower antagonistic portions as the upper trapezius to lower trapezius ratio (UT:LT). There remains little information on normative EMG values for UT:LT ratios. Recently, researchers have started to report the ratios of upper and lower trapezius activation, rather than isolated muscle values alone (Cools, Declercq, et al., 2007). This change in reporting may demonstrate recognition of true function of the trapezius being reported as a ratio of the upper and lower portions. By reporting on UT:LT ratios rather than individual activation levels of each muscle, researchers can provide information on the function of the trapezius as a whole. In addition, some patients demonstrate high UT:LT ratios which may be indicative of muscle imbalance contributing to pathology. An overactive UT or underactive LT can provide valuable clinical clues, but both values must be known in order to determine the relative increase or decrease in activation. Cools and colleagues reported maximal activation of the upper trapezius during scapular elevation in normal subjects was 74% MVIC, while lower trapezius was 62%, representing a 1.2 to 1.4 UT:LT ratio. Using activation ratios, clinicians may make better clinical decisions on choosing appropriate exercises that restore muscle balance.

Timing of scapular muscle recruitment is critical in positioning the glenoid during shoulder rotation (Kibler, 1998). The actual pattern of trapezius muscle activation during shoulder elevation is not well established in the literature, primarily because individual motor patterns are quite varied and difficult to standardize. In addition, the variety of EMG measurement techniques (surface vs. intramuscular needle EMG), different muscles tested, and different distinctions of muscle onset provide the disparate results found in the literature. During shoulder elevation in the scapular plane for example, some researchers report the upper trapezius is activated 217 ms before movement starts and the lower trapezius is activated 349 ms after movement starts (at approximately 15°) (Wadsworth & Bullock-Saxton, 1997), while others (Santos, et al., 2007) find the same pattern but shorter latencies (40 ms prior and 20-40 ms after, respectively).

The change in trapezius muscle activation patterns with the addition of external resistance remains unknown. This information would be important to clinicians for several reasons. First, understanding the normal activation pattern in healthy individuals may provide a clinical baseline to examine pathological conditions. Scaption performed with and without resistance may serve as a standard clinical EMG examination to assess pathological trapezius activation patterns. Secondly, understanding changes in muscle activation timing may provide better clinical decision making in choosing the appropriate exercise. For example, if shoulder patients demonstrate altered trapezius activation patterns, it would be critical to know if a particular exercise replicates the appropriate pattern or facilitates a dysfunctional pattern. Other external factors of trapezius activation to investigate include the influence of speed of movement, plane of movement, and different degrees of shoulder rotation during scaption. This information may improve better clinical decision making for therapeutic exercise prescription.

Different internal conditions such as pain and fatigue may also alter trapezius firing patterns, although these changes are not well-established in the literature. Experimental pain in the upper trapezius caused a reduction in upper trapezius EMG with an increase in lower trapezius activation during shoulder flexion (Falla, Farina, & Graven-Nielsen, 2007). Fatigue of shoulder muscles may also have an effect on trapezius muscle activation. Following fatiguing abduction/adduction isokinetic exercise, researchers reported significant increase in the latency of scapular muscle firing patterns in response to a sudden downward falling movement of the arm, but no change in the actual sequence of firing of different parts of the trapezius (Cools, et al., 2002).

In summary, there is a clinical need for more research on changes in trapezius muscle activation patterns under different internal and external conditions. This might include investigation of the effects of resistance, speed, and plane of motion, as well as the influence of pain and fatigue on trapezius activation patterns. Such information will improve diagnosis of shoulder dysfunction and determine appropriate exercise prescription.

2.0 Functional Impingement

This section will now discuss the pathomechanics associated with impingement. First, imbalances in shoulder range of motion and scapular dyskinesis are reviewed, followed by discussion of strength imbalances, including EMG in shoulder dysfunction. Finally, postural abnormalities in impingement are reviewed, including changes in scapular position.

Shoulder impingement accounts for 44 to 65% of shoulder complaints during physician visits (van der Windt, et al., 1996; Vecchio, Kavanagh, Hazleman, & King, 1995). As described previously, subacromial impingement occurs when the structures in the subacromial space (rotator cuff, biceps tendon long head, and bursa) become compressed and inflamed under the coracoacromial ligament (Bigliani & Levine, 1997). The suprasinatus tendon, in particular, comes in closest contact with the acromion at 90° of abduction combined with 45° of internal rotation (Graichen, Bonel, Stammberger, Englmeier, et al., 1999).

Patients with impingement have significantly less SAS space during shoulder elevation compared to the asymptomatic side (Graichen, Bonel, Stammberger, Haubner, et al., 1999), even though their SAS is not significantly different from healthy shoulders in the resting anatomical position (Hebert, et al., 2003). In addition, impingement patients demonstrate more proximal translation of the humeral head early in abduction (reducing the SAS) compared to normal shoulders (Deutsch, et al., 1996; Hallstrom & Karrholm, 2006).

Several factors have been identified in functional impingement and include imbalances in muscle strength and range of motion (ROM), scapular dyskinesis, and postural deviations. These factors are thought to lead to functional impingement by decreasing the SAS during active ROM.

2.1 Range of motion imbalance

Imbalances in range of motion (typically measured by shoulder internal and external rotation) will alter shoulder kinematics. Specifically, excessive external rotation leads to increased anterior and inferior translation of the humerus, leading to anterior instability (Mihata, Lee, McGarry, Abe, & Lee, 2004). In contrast, anterior tightness alters the scapulohumeral rhythm and decreases posterior scapular tilt (Lin, Lim, & Yang, 2006). Posterior capsular tightness, often demonstrated by a loss of internal rotation, may lead to more superior and anterior translation of the humeral head (Harryman, et al., 1990; Lin, et al., 2006; Tyler, Roy, Nicholas, & Gleim, 1999). This loss of internal rotation is known as glenohumeral internal rotation deficit, or "GIRD," and is defined as a loss of internal rotation greater than or equal to 20° compared to the contralateral side (Burkhart, Morgan, & Kibler, 2003).

GIRD is a relatively new concept in the literature and requires more research on its incidence and effects in normal, athletic, and injured populations; however, it's becoming apparent that overhead athletes with impingement often display signs and symptoms of GIRD (Kugler, Kruger-Franke, Reininger, Trouillier, & Rosemeyer, 1996; Myers, Laudner, Pasquale, Bradley, & Lephart, 2006; Tyler, Nicholas, Roy, & Gleim, 2000). Baseball players have significantly more external rotation ROM and less internal rotation ROM (Borsa, Dover, Wilk, & Reinold, 2006; Borsa, et al., 2005; Donatelli, et al., 2000; Tyler, et al., 1999); however, their total ROM is not significantly different from the non-dominant arm (Ellenbecker, Roetert, Bailie, Davies, & Brown, 2002). This suggests that ROM imbalances may be more functional than pathological in overhead athletes; however, it remains unclear if such imbalances are necessary for performance. Prospective studies examining the relationship between ROM imbalance and injury are lacking. Such studies would provide information which may prevent shoulder injuries in overhead athletes. In addition, the clinical question remains in treating these athletes with impingement: should rehabilitation strive to restore 'normal' flexibility and ROM balance, or will such attempts hinder performance?

Until more prospective studies can show a cause-and-effect relationship between shoulder ROM and pathology, clinicians must use their best judgment to determine the appropriate course of treatment. It is likely that some degree of ROM imbalance is necessary for function (ie, more ER than IR ROM), but there may be a yet undefined threshold ratio that correlates with pathology. For example, if studies show that a ratio of 75% IR:ER ROM is functional, while a ratio of 70% is pathological (indicating lower IR ROM), clinicians may be able to screen athletes for this ratio to prevent injury or establish the ratio as a criterion for rehabilitation progression.

2.1.1 Muscle Tightness in Impingement

Muscle tightness has also been implicated in subacromial impingement. In particular, muscle tension associated with arm elevation may tighten the leading edge of the coracoacromial ligament, leading to impingement (Bigliani, et al., 1991). Tightness of the pectoralis major creates an anterior force on the glenohumeral joint with a consequent decrease in stability (Labriola, Lee, Debski, & McMahon, 2005). A tight pectoralis minor limits scapular upward rotation, external rotation and posterior tilt, and reduces SAS (Borstad & Ludewig, 2005), altering scapular kinematics compared to those with normal muscle length (Borstad, 2006; Mottram, 1997). Measuring the direct influence of specific muscle tightness is difficult in human subjects. Much of the 'cause-and-effect' attributed to muscle tightness is based on logical biomechanics of origin and insertion, meaning a tight muscle will limit motion in a specific direction. In contrast to muscle activation studies with EMG, there are few direct measurements of individual muscle tightness to quantify imbalance.

Several muscles in the body have specific flexibility tests with "normal" values such as the hamstring. These tests may not be specific to individual muscle length, however. For example, shoulder joint ROM measurements such as shoulder external rotation cannot differentiate individual muscle tightness (pectoralis major versus subscapularis) or capsular restriction. Researchers have identified a method of measuring isolated pectoralis minor length using a tape measure (Borstad, 2006). However, such methods are few and, like many manual tests, subject to testing error. Perhaps technological advances in measurement will provide better methods of assessing individual muscle tightness.

2.1.2 Scapular Dyskinesis

Subacromial impingement is associated with altered kinematics (“dyskinesis”) of the scapula. Abnormal scapulothoracic motion was noted in 100% of impingement patients, compared to 18% of control subjects (Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1992); however, the researchers did not evaluate EMG or changes to the SAS. Orthopedic surgeon Ben Kibler (Kibler, 2006) described scapular dyskinesis in the pathomechanics of shoulder dysfunction: a loss in scapular external rotation and retraction leads to altered timing and magnitude of acromial upward rotation. This results in excessive anterior tilt of the glenoid and subsequent reduction in rotator cuff forces.

The current literature is conflicting as to the specific alterations in scapular motion in impingement patients. Some researchers report decreased posterior tilt in impingement patients (Borstad & Ludewig, 2002; Hebert, Moffet, McFadyen, & Dionne, 2002; Ludewig & Cook, 2000, 2002; Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999), while others report an increase in posterior tilt (Hebert, et al., 2002; Laudner, et al., 2006; McClure, Michener, & Karduna, 2006; McClure, et al., 2001). Similarly, some report decreased external rotation of the scapula during elevation (Endo, Ikata, Katoh, & Takeda, 2001), while others report decreased internal rotation (Ludewig & Cook, 2000). Researchers seem to agree that impingement patients have decreased upward rotation during elevation (Borstad & Ludewig, 2002; Endo, et al., 2001; Ludewig & Cook, 2000, 2002) with the exception of one study (McClure, et al., 2006). Interestingly, Karduna et al. reported that the SAS actually decreases as upward rotation increases (Karduna, Kerner, & Lazarus, 2005); however, they calculated displacement of the humeral head in cadaver models, rather than an actual measure of the SAS. The researchers postulated that a decrease in upward rotation in impingement may ‘open up’ the SAS as a compensatory movement.

This discrepancy reported in scapular motion in the literature is likely due to several reasons. Compared to scapular upward and downward rotation (50°), the measurements of scapular tilt and internal/external rotation are relatively smaller (25-30°). As stated previously, specific muscular mechanisms of anterior/ posterior tilt and internal/external rotation remain unclear, possibly due to a lack of valid measurement techniques, as compared to measures of upward and downward rotation.

It's also possible that the discrepancies in the literature associating scapular kinematics and impingement may be related to a specific type of shoulder impingement. Recently, shoulder impingement has been sub-classified into subacromial impingement and "internal impingement." Internal impingement in overhead throwers is characterized by pain in the late-cocking phase, where the supraspinatus and infraspinatus are impinged between the greater tuberosity and posterior-superior glenoid labrum (Walch, Boileau, Noewl, & Donnel, 1992). Recently, researchers assessed scapular dysfunction in overhead throwers with internal impingement (Laudner, et al., 2006). They used 3-D electromagnetic tracking to show an increase in posterior tilt in these athletes, in contrast to earlier findings of decreased posterior tilt in overhead workers with subacromial impingement (Ludewig & Cook, 2000).

Since internal impingement occurs on the posterior glenoid, it's possible that the pathomechanics of subacromial impingement differ from internal impingement. The specific scapular kinematics of posterior impingement remain unclear; therefore, if impingement subject populations include both subacromial and internal impingement, the results may vary between subjects. It is important to differentiate the two types of impingement; however, MRI and arthroscopy remain the most valid methods of differentiating this condition since clinical differentiation is sometimes difficult.

2.2 Strength imbalances

Imbalances or deficits in muscular strength and activation levels can lead to functional impingement. Both glenohumeral and scapulothoracic muscle imbalance can cause dysfunction. The pathomechanics of functional impingement may involve one or both of the shoulder force couples: deltoid/rotator cuff and scapular rotators. Because of the lack of prospective studies, few if any researchers have determined if muscle imbalance is a cause or effect of impingement.

2.2.1 Glenohumeral imbalances

Alterations in deltoid and rotator cuff co-activations and rotator cuff imbalances are evident in impingement patients (Burnham, May, Nelson, Steadward, & Reid, 1993; Leroux, et al., 1994; Myers, et al., 2003; Reddy, et al., 2000; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1990). The deltoid plays an important role in the pathomechanics of impingement. Muscle imbalances in the deltoid and rotator cuff force couple can cause compression within the SAS (Jerosch, et al., 1989; Payne, et al., 1997). The deltoid has been found atrophied and infiltrated with more connective tissue in patients with shoulder impingement (Kronberg, Larsson, & Brostrom, 1997; Leivseth & Reikeras, 1994); in addition, the deltoid exhibits lower levels of activation in impingement patients (Michaud, Arsenault, Gravel, Tremblay, & Simard, 1987; Reddy, et al., 2000). While it’s assumed that these effects on the deltoid are caused by impingement, it is unclear if the deltoid pathology precedes, or is a result of, impingement.

The rotator cuff is important in maintaining normal humeral head position during abduction. The compressive forces of the rotator cuff pulling the humerus toward the glenoid provide dynamic stabilization of the glenohumeral joint (Inman , et al., 1944; Poppen & Walker, 1978). Weakness of the infraspinatus reduces this compressive force, promoting instability (Labriola, et al., 2005). This instability may lead to functional impingement.

When the stabilizing forces are removed from the glenohumeral joint in a cadaver model, there is a significant increase in superior and anterior migration of the humeral head, possibly leading to impingement (Payne, et al., 1997; Sharkey, et al., 1994; Wuelker, Korell, & Thren, 1998). Downward compressive forces of the inferior rotator cuff are necessary to neutralize the upward shear of the deltoid (Payne, et al., 1997). Without rotator cuff stabilization, the humeral head migrates 1.7 mm vs. 0.7 mm with rotator cuff stabilization at 60°, and 2.1 mm vs. 1.4 mm at 90° of abduction (Sharkey, et al., 1994). Cadaver models do not accurately reflect the effect of dynamic neuromuscular activation (muscle activation and timing) of glenohumeral and scapulothoracic muscles in glenohumeral kinematics. Despite this limitation, cadaveric studies have been supported by human studies demonstrating decreased rotator cuff stabilization may in fact lead to impingement.

Decreased rotator cuff EMG levels may cause humeral head superior translation during early abduction, leading to impingement (Reddy, et al., 2000). Experimentally-induced fatigue of the rotator cuff also leads to superior migration of the humeral head at the initiation of abduction (Chen, et al., 1999; Teyhen, et al., 2008); however, the effects of fatigue experienced after actually participating in an activity (such as repeated throwing) has not been investigated. Since these studies only assessed scapular plane elevation, it is possible that other muscles may compensate for upward migration of the humeral head during functional activity. Few studies have assessed simultaneous rotator cuff EMG and glenohumeral kinematics in patients with impingement, leaving many questions on pathomechanics of impingement unanswered.

2.2.2 Scapulothoracic imbalances

Scapular muscle imbalances can also affect rotator cuff function. The rotator cuff originates on the scapula. Weakness of scapular stabilizers may lead to “pseudo-weakness” of the rotator cuff because of a lack of proximal stabilization for the rotator cuff to provide a stable origin. The effect of scapular muscle imbalance on rotator cuff strength has not been evaluated; however, fatigue of scapular retractors does reduce rotator cuff strength (Cuoco, et al., 2004).

Scapular rotator force couple imbalance leads to weakness and altered activation patterns. Most researchers have demonstrated an increase in upper trapezius activation and decrease of the middle and lower trapezius, as well as the serratus anterior in impingement subjects (Cools, Declercq, et al., 2007; Cools, et al., 2002; Cools, et al., 2003; Cools, et al., 2004; Ludewig & Cook, 2000; Moraes, et al., 2008; Wadsworth & Bullock-Saxton, 1997). In contrast, some have reported increased activation in both the upper and lower trapezius in patients with impingement, compared to normal subjects (Ludewig & Cook, 2000). Ludewig and Cook hypothesized that the increased lower trapezius activation compensated for decreased serratus anterior activation. Interestingly, a recent study found similar decreased serratus anterior activity and increased upper trapezius activity with no change in lower trapezius activity in a group of subjects with various shoulder dysfunctions compared to normals (Lin, et al., 2005).

The specific reason for these conflicting results remains unclear, but may be related to the testing techniques and different subject populations. Ludewig & Cook assessed EMG during weighted scaption in construction workers; Lin et al. evaluated EMG during 4 different functional tasks without added resistance; and Cools, Declercq et al. used maximal isokinetic resistance during abduction in overhead athletes. Different movements and resistance levels may influence activation levels, and various populations may demonstrate different activation patterns. Future studies should evaluate the influences of different movement patterns and resistance levels in various populations.

The lower trapezius perhaps plays the most important role in scapular rotation because it acts as a stabilizer (Bagg & Forrest, 1986; Johnson, et al., 1994). Decreased activation of lower trapezius or increased activation of the upper trapezius may lead to upward migration of the axis of rotation of the glenohumeral joint, thus causing impingement. It is assumed that the lower trapezius will be more active than normal if the humeral head migrates upward during shoulder elevation (Bagg & Forrest, 1986); however, research has not verified this notion. Researchers have measured simultaneous trapezius EMG and 3-dimensional kinematics in patients with shoulder dysfunction (Lin, et al., 2005; Ludewig & Cook, 2000). These studies found no significant change in humeral elevation, and either no change (Lin, et al., 2005) or an increase (Ludewig & Cook, 2000) in lower trapezius activation. However, Ludewig and Cook reported small but significant increases in anterior-posterior translation of the humerus, possibly leading to decreased SAS. Their findings reveal several measurement issues to consider related to glenohumeral kinematics when comparing 2-dimensional radiographs with 3-dimensionsal electromagnetic tracking in evaluating the SAS. First, 3-D analysis can determine both anterior and superior reductions in the SAS at the same time; Second, 2-D can only reveal superior OR anterior reductions in the SAS (not simultaneously). Third, although 3-D can provide information on changes in multiple planes, it is also limited because it uses surface markers to calculate kinematics based on changes in distance from a reference electrode. This technique requires an estimation of SAS based on the change in humeral and scapular kinematics, rather than a direct measure of the SAS used in 2-D radiographs.

2.2.3 EMG Analysis in Impingement

In general, most studies on strength imbalances use static muscle tests or standardized isokinetic dynamic strength tests; however, these types of measurement are very limited in their relation to function. Maximal strength testing may not be appropriate, particularly in a patient population. Instead, a submaximal effort throughout the range of motion may provide additional neuromuscular clues on muscle activation and timing, rather than isolated muscle strength, which only gives a partial picture of muscle function. For example, testing the serratus anterior on an isokinetic dynamometer at 90° of elevation in a swimmer gives little information about muscle performance during the actual swimming motion. Other measurement techniques such as EMG can provide more valuable information on muscle function.

When reviewing EMG data, it is important to remember that muscle activation measured by EMG should not be correlated with strength. A muscle that tests "strong" with manual muscle testing may have lower EMG levels than a muscle that tests "weak." This is likely due to differences in efficiency of neuromuscular coupling and contraction (Figure 3).

Figure 3: EMG activation and muscle force production related to efficiency of contraction. Atrophied muscle produces less force at the same EMG as trained muscle.

A muscle with relatively lower EMG levels may be considered "inhibited," while one with a higher EMG level would be "facilitated." Again, it is quite possible that a "weak" muscle has a higher EMG, as it has to recruit more motor units due to its intrinsic inefficiency in producing strength. In addition, EMG of one muscle during an isolated movement will have different activation patterns compared to a functional compound movement.

Delays or imbalances in activation can lead to shoulder dysfunction. EMG analysis is useful in quantifying muscle activation and onset during movement. As stated previously, muscle latency and activation patterns are generally considered important factors in shoulder dysfunction, although few studies have investigated this. While changes in scapular latencies in subjects with impingement have been described by some (Cools, et al., 2003; Moraes, et al., 2008; Wadsworth & Bullock-Saxton, 1997), others report no difference in muscle latency between patients with shoulder instability and normal subjects during elevation in the scapular plane (Santos, et al., 2007).

Several researchers have evaluated the effect of submaximal external resistance on glenohumeral and scapular muscle activation patterns during elevation in impingement patients, simulating light loads used during rehabilitation (Ludewig & Cook, 2000; Machner, et al., 2003; Myers, et al., 2003; Reddy, et al., 2000). Impingement patients exhibit altered co-activation of the rotator cuff both with and without loads, compared to normals (Myers, et al., 2003). Similarly, Reddy et al. found rotator cuff and deltoid EMG was decreased in impingement patients. While these researchers did not assess scapular muscle EMG, the authors noted that periscapular muscles may compensate for deficiency in rotator cuff and deltoid activation. This conclusion is partially supported by the finding of altered scapular muscle activation patterns in impingement patients, including increased upper trapezius activity at higher loads, and reduced serratus anterior activity at all loads (Ludewig & Cook, 2000). The major limitation of these studies is their lack of simultaneous glenohumeral and scapulothoracic EMG, limiting the ability to establish any compensatory relationships between the two muscle groups. In addition, clinical interpretation of these studies on the pathomechanics of impingement is limited because the authors did not directly assess changes to the subacromial space. The effects of adding resistance during scaption on scapular muscle activation and balance, as well as the effect on the SAS, remain unknown.

2.2.4 Imbalances in Athletes with Impingement

Several studies on athletes with shoulder pain indicate altered EMG patterns and muscle imbalance (Pink, et al., 1993; Ruwe, et al., 1994; Scovazzo, et al., 1991; Wadsworth & Bullock-

Saxton, 1997). Overhead athletes with shoulder dysfunction typically have increased upper trapezius activation (Cools, Declercq, et al., 2007), as well as decreased activation levels of the serratus anterior (Cools, et al., 2004), and decreased lower trapezius (Cools, Declercq, et al., 2007; Cools, et al., 2004), supporting the belief that the lower trapezius and serratus are most prone to weakness (Janda, 1993).

Researchers have compared the EMG activity of the trapezius in normal individuals, overhead athletes, and those with impingement (Cools, Dewitte, et al., 2007; Cools, et al., 2002; Cools, et al., 2003). Cools, Declercq, et al. (2007) reported that athletes with impingement have a significantly higher upper trapezius activation compared to normal subjects, a significant decrease in lower and middle trapezius activation, and altered trapezius muscle balance (See Table 1). This study, however, was limited to maximal isokinetic concentric contraction during scaption, which does not represent more functional activities with submaximal resistances. Using isokinetic testing equipment, the eccentric activity of muscles could not be assessed since subjects had to perform maximal concentric adduction to return to the starting position. In addition, changes to the SAS were not evaluated.

	Upper Trap Activation	Lower Trap Activation	UT:LT ratio
Involved (impingement)	95% MVIC	48% MVIC	2.19
Involved (control)	73% MVIC	62% MVIC	1.23
Uninvolved (impingement)	74% MVIC	56% MVIC	1.56
Involved (control)	74% MVIC	62% MVIC	1.36

Table 1: EMG activation of subjects with and without impingement during isokinetic abduction at 120°/s (Cools, Declercq, et al., 2007)

Overhead athletes with impingement have delayed onset of middle and lower trapezius fibers in response to a sudden downward movement (Cools, et al., 2003). If the lower trapezius reacts too slowly compared to the upper trapezius, the upper trapezius may become overactive, leading to scapular elevation rather than upward rotation (Cools, et al., 2003). Freestyle swimmers with impingement are reported to have increased variability in timing of the onset of scapular rotators compared to healthy swimmers (Wadsworth & Bullock-Saxton, 1997).

These alterations are often seen bilaterally (Cools, Dewitte, et al., 2007; Cools, et al., 2003; Leroux, et al., 1994; Roe, Brox, Saugen, & Vollestad, 2000; Wadsworth & Bullock-Saxton, 1997) supporting a central neurological mechanism of chronic tendinosis pain. Since both painful and non-painful shoulders exhibit altered activation patterns, it is possible that the dysfunction is related to a faulty motor program within the central nervous system (CNS). Some researchers have suggested a central control dysfunction in impingement based on findings of altered EMG in primarily unaffected muscle (Schulte, et al., 2006). Furthermore, researchers have noted decreased EMG levels in rotator cuff patients which subsequently increased upon pain reduction, suggesting that pain had an inhibitory effect on muscle activation that was restored after pain relief (Roe, Brox, Bohmer, & Vollestad, 2000). The influence of CNS processing on shoulder impingement remains unclear. The finding of bilateral neuromuscular deficits with unilateral impingement provides some initial clues, although a cause-and-effect relationship has not been established in the literature.

In summary, strength imbalances have been identified in subjects with impingement. EMG and kinematic data are useful in quantifying these imbalances; however, many questions remain unanswered, including changes in the trapezius muscle balance and activation during different load conditions. Since muscle activation and timing are critical to normal shoulder function, it is important to understand the specific changes to these patterns in different conditions, as well as different populations. Regrettably, however, few researchers have performed prospective studies to determine if such muscle imbalances are precursors to impingement. Such studies may establish cause-and-effect mechanisms of shoulder impingement to develop screening and prevention programs for overhead athletes. For example, pre-season EMG or kinematic assessments may identify differences in muscle balance that can be addressed with a preventive exercise program.

2.3. Postural abnormalities

In addition to muscle imbalance, poor posture is thought to be related to impingement. Forward head posture (protraction of the head and increased lordosis of the cervical spine) is often increased in patients with shoulder pain (Greenfield, et al., 1995). A forward head posture reduces the flexion range of motion of the shoulder (Bullock, Foster, & Wright, 2005). This forward head posture is often seen with an increase in thoracic kyphosis (an increased convexity of the thoracic spine). Forward head posture and protracted (rounded) shoulders change the normal orientation of the plane of the scapula from 30 to 45° anterior to the frontal plane (Doody, et al., 1970; Johnston, 1937; Poppen & Walker, 1976). This “slouched” posture (Figure 4) significantly alters the kinematics of the scapula during elevation and reduces shoulder ROM and strength (Finley & Lee, 2003; Kebaetse, McClure, & Pratt, 1999). Shoulder protraction also reduces the height of the SAS (Solem-Bertoft, Thuomas, & Westerberg, 1993), implicating protracted shoulders with impingement syndrome.

Figure 4: A “slouched” posture with forward head, increased thoracic kyphosis and protracted shoulders

Despite these suggestions that poor posture is related to impingement, no studies have established a cause-and-effect relationship. This may be due to the individuality of posture, and the inability to establish homogenous postural patterns between subjects. Interestingly, the actual posture in impingement does not follow the patterns suggested clinically: forward head posture, increased thoracic kyphosis, and shoulder protraction (Lewis, Green, & Wright, 2005; McClure, et al., 2006).

Postural assessment also includes the position of the scapula. A “normal” scapular position is not well established, but it is generally considered to be between the 2nd and 7th ribs (Culham & Peat, 1993). Altered position of the scapula changes the direction of the axis of the glenoid fossa, which may be accompanied by increased and constant activity of the rotator cuff, leading to rotator cuff tendonitis. A protracted and downward rotated scapula increases the risk of impingement (Kibler, 1998). Although a specific prospective study has not confirmed this suggestion, overhead athletes with impingement are known to have a more pronounced lateral position and depression of the scapula on the involved side (Kugler, et al., 1996). Others (Hebert, et al., 2002; McClure, et al., 2001) have reported no significant difference in scapular position between normal subjects and those with impingement. Obviously, more research is needed on any cause-and-effect relationship between scapular position and impingement.

“Scapular winging” refers to prominence of the medial border of the scapula (Figure 5). True winging of the scapula is caused by weakness or paralysis of the serratus anterior, often due to a long thoracic nerve palsy (Martin & Fish, 2008). Clinically, however, scapular winging is not always associated with serratus weakness. “Pseudowinging” of the scapula has been described as prominence of the inferior border (rather than medial border) due to tightness of the pectoralis minor (Mottram, 1997).

Figure 5: Scapular winging on the right, noted by prominence of the medial border

Three types of scapular position have been described based on the orientation of the medial scapular border (Lewis, et al., 2005). Type I is noted by prominence of the inferior medial border; Type II has prominence of the entire medial border, and Type III displays prominence of the superior medial border. While this classification is useful in describing scapular posture, the specific muscular involvement of these positions is unknown. It is well-established that a weak serratus anterior is related to prominence of the entire medial border; however, more research is needed to identify specific muscular weakness associated with Type I and III scapula positions.

Recently, the "SICK" scapula was described in the literature as: **S**capular malposition, **I**nferior medial border prominence, **C**oracoid pain, and dys**K**inesis of scapular movement (Burkhart, et al., 2003). The SICK scapula is most commonly seen in overhead athletes with impingement. Typically, the scapula is depressed, protracted, and downward rotated. It suggests underlying muscle imbalances that change scapular kinematics, such as tightness of the pectoralis minor.

Posture is thought to play an important role in shoulder dysfunction; however, clinical research does not substantiate these opinions. More studies on the specific causes of postural deviations, particularly on scapular position, are warranted.

Summary

The pathomechanics of functional shoulder impingement include muscle imbalances in the glenohumeral and scapulothoracic musculature. These imbalances may be due to muscle tightness or muscle weakness, leading to altered kinematics of the scapula and glenohumeral joint. These kinematic changes cause impingement by reducing the SAS. Little is known about the neuromuscular factors leading to muscle imbalance and functional impingement. While prospective studies establishing cause-and-effect relationships are lacking in the literature, functional impingement is often successfully managed through exercise prescription to restore muscle balance.

Research Questions

Based on the literature reviewed in this paper, the following research questions are proposed:

1. How does external resistance (with a handheld weight or elastic resistance) change the upper and lower trapezius activation ratio (ie, muscle balance) during shoulder scaption to 90° in shoulders of normal subjects and overhead athletes?
2. What is the relationship of the trapezius muscle ratio and subacromial space in normal shoulders and in overhead athletes during scaption to 90° with and without resistance?

Scaption to 90° with resistance is common exercise performed both to prevent impingement in athletes, and to rehabilitation patients with shoulder pathology. The answers to these questions may have implications in both prevention and rehabilitation as clinicians try to maximize SAS and improve muscular ratios during shoulder exercises with resistance.

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Appendix D

IRB Approval

LSU
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ACTION ON PROTOCOL APPROVAL REQUEST

TO: Dennis Landin
Kinesiology

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: November 16, 2008
RE: **IRB#** 2778

TITLE: "Shoulder joint kinematics, subacromial space variations and muscle activation patterns in overhead athletes: Comparing normal and pathologic shoulders"

New Protocol/Modification/Continuation: Continuation

Review type: Full X Expedited ___ **Review date:** 10/24/2008

Risk Factor: Minimal ______ Uncertain X Greater Than Minimal______

Approved X **Disapproved** _____

Approval Date: 10/24/2008 **Approval Expiration Date:** 10/23/2009

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 75

Protocol Matches Scope of Work in Grant proposal : (if applicable) N.A.

By: Robert C. Mathews, Chairman

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.fas.lsu.edu/osp/irb*

Vita

Phil Page is a licensed physical therapist, athletic trainer, and certified strength and conditioning specialist. He graduated from LSU in physical therapy and received his master’s degree in exercise physiology from Mississippi State University. He has been involved in rehabilitation and sports medicine for over 20 years. Since 1998, Phil has been the manager of clinical education and research for Thera-Band products. His duties include directing the international educational programs and managing product research around the world. His clinical and research interests include the role of muscle imbalance in musculoskeletal pain, and in promoting physical activity for health-related physical fitness, particularly for chronic disease management. Phil is a member of several national advisory boards and regularly reviews grants and journal article submissions. Phil lectures extensively and provides workshops on a variety of topics around the world, including the Janda Approach to Muscle Imbalance. He has presented over 100 international lectures and workshops on exercise and rehabilitation topics, and has over 50 publications including 2 books. He has worked with the athletic programs at LSU, Tulane, the New Orleans Saints and Seattle Seahawks, as well as the United States Olympic Track and Field Trials. He lives with his wife and 4 children in Baton Rouge, Louisiana.